INTRODUCTION

On the Origins of Our Ecological Crisis

"Hence the highest development of productive power together with the greatest expansion of existing wealth will… lead to explosions, cataclysms, [and] crises… These regularly repeated catastrophes will lead to their repetition on a higher scale, and finally to its violent overthrow"
– Karl Marx (1973: 750).

"*A hard rain's a-gonna fall*."
– Bob Dylan, 1963

Crisis is the watchword of our times. And underpinning it all is the crisis of Nature. Global warming. Catastrophic hurricanes. Mass extinctions. Falling water tables and disappearing glaciers. Dying oceans. Desiccated rivers. Superweeds and forest megafires. Toxic landfills. Cancer clusters and all manner of poisoned bodies. Dirty air and filthy water. New diseases and unpredictable disease vectors. And as if to move from the frying pan to the fires, these have fused with (and emerged from) the inner logic of "disaster capitalism," an increasingly militarized regime of global accumulation at the dawn of the third millennium[1] – resource wars, cluster bombs, depleted uranium, collective punishment, extraordinary renditions and black sites, mercenary cadres. It is as if we are standing on a great plain, watching the Four Horsemen approach.

Perhaps. But perhaps the Horsemen have *already* arrived. From the look of it, there is an important sense in which we are not waiting for the crisis to hit. The crisis *has* hit. We are, rather, waiting for the longstanding tension between a social system premised on infinite economic expansion and a biosphere with emphatically finite boundaries to reach some sort of really obvious tipping point. (And therefore the question of consciousness, not merely awareness, is what matters.) Given the chaos that inheres in any crisis – if the outcome could be determined in advance, we would be talking about development, not crisis – the precise form and timing of that tipping point is fundamentally unknowable.

A Chinese proverb tells us that a single spark can start a prairie fire. From which direction that spark will fly is anyone's guess. And yet the range of possibilities is not randomly distributed. Almost all are recent permutations of those *longue durée* movements that have propelled modernity (forward?) for the better part of six centuries. Just to name a few: conflicts between states and empires (regional and world wars); financial crises; strike waves; agrarian and urban revolts and revolutions (sprinkled with all manner of millenarian and fundamentalist outpourings, much as we saw in the late nineteenth century, although today on finding the entire globe as its theater);

[1] Among the signal contributions on this, see Klein (2007) and Retort (2005).

epidemiological wildfires; natural, and quite unnatural, disasters (increasingly driven, at wildly oscillating degrees of remove, by a relentless imperial order haunted by the more-than-spectral reality of creeping global stagnation) – tsunamis, Category 5 hurricanes, colonial occupations and the nightmarish punctuations of neoconservative "national-building"; movements for democracy that threaten the untrammeled freedoms of accumulation for accumulation's sake, revealing an energizing (or unsettling, depending on your perspective) diversity of "third ways" that ask for a new way, beyond twentieth century Developmentalisms.

And the beat goes on.

From whence did this state of affairs, at once and in successive turns hopeful, terrifying, and disorienting, originate? The danger of posing the big questions is always the temptation to explain everything, which quite naturally ends up explaining nothing. It is nevertheless a game well worth the candle. The answer to the question is I think straightforward and in plain sight. The origin of our ecological crisis finds its taproot in the transition to capitalism and Europe's overseas expansion during the "long" sixteenth century (c. 1450-1640).[2] The scale and speed of the environmental transformations that ensued was entirely without precedent – relative to medieval Europe in its heyday, and also relative to all previous "golden ages" enjoyed by the mighty civilizations fortunate to get face-time in our textbooks, the Greeks, Rome, Persia, China. It is a simple answer, and some say will say deceptively so. And surely there is much to the story of modernity's environmental history that must be left on the editing room floor. It is always a matter of one's priorities, of the argument one wishes to make, and the theoretical and methodological challenges inscribed in the nature of the problem itself.

In pursuing this story, my intent has been to organize a radical departure from conventional renderings of the ecological crisis narrative, based either in a misreading of history (for instance, industrialization and the industrial society as ecological bogeyman), or worse, in the erasure of history altogether (as the neo-Malthusians would have it). Mine is an argument about the point of departure, for the origins of a mode of production are also the origins of that historical system's decisive contradictions, the source (at once) of its dynamism and its ultimate demise. Therefore in arguing that the origins of our ecological crisis may be found in the long sixteenth century, my intention is to establish a distinctive world-historical frame through which to comprehend the environmental history of capitalist origins. It is a world-historical project with one overriding goal: to assess the degree to which the present accumulation regime (which is at the same time an ecological regime) is, *and is not*, today capable of adjusting within the established rules of the game, rules that first emerged, however tentatively and tenuously, some five centuries ago.

In what follows, I build out this argument in successive waves, corresponding roughly (and with considerable overlap) with the three meta-questions of historical social science: What is it? Why is it? How is it?[3] Thus we shall move from narrative sketch to

[2] The concept of the long sixteenth century originates with Braudel (1953). Recently, the notion of the long century as a fundamental temporal category of capitalist development has been offered by Arrighi (1994; also see Arrighi and Moore, 2001).

[3] These three questions I borrow from the implicit methodological framework of Arrighi (1994) and Arrighi, Silver, et al. (1999).

conceptual elaboration to methodological premises. And thence to the theory of ecological crisis.

Ten Years That Shook the World

In the transition from one historical period to the next, a single decade may reveal the contradictions of an entire epoch.[4] All narratives begin with a question about time (and therefore a question about space), and all narratives move forward with answers that say as much about the present as it does the past.

If one were compelled to give a precise date to the origins of the modern world, it would be more than a little tempting to say "1492." Other dates are surely candidates, but the landfall of the (aptly named) Colon on Hispaniola that year surely ranks at or near the top of epochal years in the making of modernity. I would suggest however a different point of reference in time, and therefore a different point of reference in space. 1492 rightly directs our focus to the conquest of the Americas. As parts go, it is huge. But it tells us little about the other side of the Atlantic. Was it mere happenstance that Colon hailed from Genoa, home to the greatest capitalists of the sixteenth century? That he was the son-in-law of a Portuguese nobleman whose lands included one of the Madeiras? That he spent three years on the island after 1478, the most dynamic years of the Madeira's sugar boom, when Colon sought (and failed) to buy sugar at the behest of two Genoese merchants (Birmingham, 2000: 14)?

1492 is big. But perhaps not big *enough*. It seems insufficient to communicate the breadth of transformation within the emergent European world-economy. It was a decade that records a list of events in which were inscribed the demise of the old order, and the birth of the new: 1) the end of the Anglo-French Hundred Years' War (1453); 2) the Ottoman seizure of Constantinople and the final eclipse of Roman power (1453); 3) the Guttenberg printing press (1453); 4) the refinement, in Saxony, of lead-smelting techniques to extract silver from relatively low-grade ores, the famous *saigerprozess* (c. 1451); 5) the commencement of sugar exports from Madeira (c. 1453); 6) the end of the Italians' hundred years' war at the Peace of Lodi (1454).[5] The 1450s marked the resumption of sustained economic growth after more than a century and a half of stagnation, contraction, and crisis. And for the all treaties and conquests that marked the end of medieval warfare, what followed was not peace but the reestablishment of permanent war on an increasingly capitalist rather than feudal footing – a footing whose foundation included the most prefigurative forms of industrial organization (mining, metallurgy, shipbuilding) and, more tentatively at first, precocious forms of finance. The "military revolution" and the transition to capitalism were inextricably bound (Parker, 1996; McNeill, 1982; Cipolla, 1966). A big part of this was the emergence, beginning right around 1450, of state machineries with borders approximating modern contours (to call them nation-states would put the cart some miles ahead of the horse in question). It was the accumulation of these forces and shifts that would lead Colon to the shores of Hispaniola in 1492, da Gama past the Cape in 1498, and Cabral to Brazil in 1500.

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[4] To borrow a phrase from Pontecorvo (1969).

[5] We should also note that Colon himself was born in 1451, probably in Genoa.

This is a study that began as an environmental history of European expansion, and subsequently became an environmental history of *capitalism's* geographical expansion. As the project developed, what became apparent was the fiction of European expansion as typically conceived. What became visible was the systemic nature of the relations between what I have been calling *commodity frontiers* (Moore, 2000a, 2003a, 2003b) within the Americas, and commodity frontiers within Europe. In what follows, I will highlight two aspects of this story: 1) the question of the parts, by illuminating the reciprocal linkages between regions; and 2) the question of the whole, by tracing the emergence and consolidation of world-historical patterns. Sugar and silver, the standard bearers of the New World's greatest commodity frontiers, were valorized only through their relation between the mining, forest products, fishing, and cereal frontiers within Europe, especially its northern zone, comprising Scandinavia and the Baltic. The expansion and development of capitalism in the Americas and the expansion of development of capitalism in Europe pivoted on a cascading and reinforcing series of colonizing movements. These aimed at enlarging the boundaries of the system in the interests of liberating cheap supplies of labor power and natural resources. The expansion of American silver mining made possible, for instance, the successive and dramatic waves of expansion in northern Europe, where cereal and forest-product commodity frontiers provided vital inputs of cereals and forest-products vital to the upward spiral of Dutch accumulation in the seventeenth century, which in turn provided the capital and shipping for sugar and other American products to move from New World to Old.

And our story is also partly one of the historical-geographical dynamic that commodity frontiers shared on both sides of the Atlantic. In the Americas and northern Europe, successive commodity frontiers, organized on agro-extractive bases seemingly as distinct from one another as silver extraction in the Andes, sugar cultivation in Brazil, and shipbuilding timber in Norway, followed a rhythm of ascent, expansion, and relative decline that was strikingly similar. Neither the local determinates of ecological transformation nor the various incarnations of long wave theory can explain it. The answer lies somewhere inbetween. Two things are, however, reasonably clear. First, the pace of geographical expansion from 1450 onwards was qualitatively faster than medieval Europe's. Second, the cyclical movement itself, operating as it did across the breadth and diversity of the Atlantic world, and paired as it was with cyclical extensions of the world-economy's division of labor, signified a distinctively modern crystallization of time and space.

It is from the perspective of the European world-economy as a whole, then, rather than the environmental history of the Americas or Europe, that I have written the story at hand. It is a story written in conversation with the New World History of Frank, Wong, Pomeranz, and others, who have argued so effectively against the assumed superiority of European civilization.[6] For all its successes, the New World History has tended to elide the distinctiveness of early modern Europe itself – above all, its dynamic and uneven syntheses of feudal and capitalist dynamics, manifested in population movements, proto-industrialization, financial innovations, military revolutions, and so forth. While colonial expansion is acknowledged as decisive in allowing western Europe to attain global economic primacy after 1800, the New World Historians remain scarcely interested in

[6] See Frank (1998), Pomeranz (2000), Wong (1997), also Manning (2003, 2006), Goldstone (2000, 2002), Marks (2002). For one of several important critiques, see Vries (2002).

specificities of that mode of expansion itself. And I think for this reason the decisive ecohistorical significance of early modern capitalism, with its simultaneous movements of enclosure within and expansion without, has remained obscured. This is unfortunate, because Europe's early modern expansion — while not the expression of technological or economic superiority once assumed — expressed a new and destabilizing crystallization of nature-society relations.[7] This study explores and explains this crystallization, highlighting relations between: 1) European expansion in the Americas; 2) the emergence of distinctively modern socio-ecological transformations in successive commodity frontiers, especially sugar and silver; 3) the geographies of commodity-led environmental transformation *within* Europe; and 4) the rise of capitalism as a whole, conceived as a system driven by the endless accumulation of capital and the ceaseless commodification of land and labor.

Imperial expansion was nothing new. For millennia, Afro-Eurasia's civilizations had practiced *resource* frontier expansionism as a means of attenuating regional ecological crises (Elvin, 1973; 2003; Hughes, 2001; Ponting, 1991). By 1450, however, Europe began to diverge sharply from this pattern. Commodity production and exchange, a longstanding aspect of civilizational expansion, was fast becoming an end unto itself. *Commodity frontiers* increasingly supplanted resource frontiers. Global expansion rather than regional accretion became the first, best response to socio-ecological problems. And where expansion once eased tensions engendered by demographic pressure, an ascendant capitalism turned this logic on its head. Population now *followed* expansion.

At the heart of this inversion lay a rupture with premodern dialectics of power.[8] As we shall see in Chapter One, the origins of this rupture may be found in Europe's long fourteenth century crisis (c.1290-1450). The centripetal (albeit still fragmented) tendencies of the feudal era had created the basis for peasant solidarities on a much broader geographical basis. The crisis mobilized these new solidarities in way that worked powerfully against feudal restoration after 1348 (Hilton, 1973). This contracted the surplus available to the states and seigneurs, who responded by trying to win in battle what they had lost in the class struggle (North and Thomas, 1973: 80-81; Strayer, 1970; Wallerstein, 1992). It was a struggle with epochal implications. For the geography of "parcellized sovereignty" overlaid the increasingly capital-intensive nature of warmaking to call forth rising demand for ready cash (Anderson, 1974b; McNeill, 1982; Parker, 1996; Arrighi, 1994). Thus were laid the conditions for a new and uneasy dialectic of territorial and capitalist power. In the process, urban capital was able to use its leverage it gained vis-à-vis the states to change the rules of the game. As a general rule, European expansion would thenceforth privilege commodity relations. On this basis emerged a new ecological regime predicated on the spatial fix of endless conquest. By-passing the empowered peasantries of the West, commodity-centered production in the Americas and in northern Europe satisfied capitalists, nobles, and Crowns, although never all equally. Moreover, feudalism's eco-demographic tendency[9] towards a declining rate of seigneurial

[7] This indeed may be key to understanding the *modern* and *capitalist* character of the era (*pace* Goldstone, 2002, *inter alia*).

[8] The decisive study of social power in world history is Mann (1986), which is most effective in its analysis before 1450, and less persuasive in centuries between 1450 and 1760 (when Mann stops the clock). This is largely because Mann does not see modernity's peculiar form of global conquest as all that decisive; while not entirely ignoring the latter, his focus remains trained on the state-machineries within European territory.

[9] And indeed the broad spectrum of civilizations organized around politically-enforced tribute.

levy[10] was at first greatly attenuated by commodity-centered expansion, and over time, largely displaced. Global expansion enabled a way out of premodern cycles of boom and bust whereby commercial efflorescence invariably gave way to demographic-ecological crises (Goldstone, 2002). These latter Europe's early modern imperialism would consistently export by extending its spatial hegemony through the endless commodification of nature.

Early capitalism's holiest trinity of endless accumulation, endless conquest, and endless commodification was driven forward, in hothouse fashion, by the concatenation of imperial power on a world-scale and the strategy of the commodity frontier within successive regions. Sugar planting and silver mining reveal most strikingly the socio-ecological contradictions of this commodity frontier strategy. No less important were those strategic commodity frontiers in forest products, metallurgy, and cereals within Europe. European wallflowers to the sweet and glittering drama queens of the Americas to be sure, but deserving of no less careful study. What we are in fact looking at in this account of the transition to capitalism is not the degree to which this or that zone corresponds with this that ideal type of capitalism. Rather we are looking at the ways in which systemwide commodification increased between 1450 and 1750 – between the first sugar exports from Madeira and the first *saigerhütten* disgorged its silver ingots in Central Europe during the 1450s, and the crisis of Europe's agro-extractive regime in the middle of the eighteenth century. The *durée* of this secular trend cannot be underemphasized as a cornerstone of the analysis. If Charles V (or less plausibly Philip II) had succeeded in converting the European world-economy into world imperium, we would today be talking about the commercial efflorescence of the fifteenth and sixteenth centuries as one of many such episodes in a world history of tributary modes of production, a period of commercial boom that invariably turned to bust, once manufacturing pressed against the agro-ecological structures of premodern societies (Brenner, 1985a). But Charles V did not succeed. And for all of capital's subsequent history of "jagged temporal rhythms and breaks, [its] uneven spatial distributions and displacements" (Anderson, 1980: 33-34), there would be no systemwide reversal of the trend towards the commodification of everything.

Commercialization is a big part of the story. But it is not everything. For a cornerstone of the commodity frontier strategy was its world-historical tendency to effect, in the same breath, the creative destruction *and* preservation of extant socio-ecological arrangements: "The colonial [and within Europe, semi-colonial] expansion of capitalism not only absorbed pre-capitalist economic systems; it created them" (Fox-Genovese and Genovese, 1983: 59).[11] This it seems to me is at the core of the problem of transition. By emphasizing this dialectic of creative destruction and preservation in the context of a longer-run (asymptotic) secular trend towards absolute commodification, I am trying to get some degree of separation from ideal type renderings of transition and above all the notion of "failed transition" (Krantz and Hohenberg, 1974; e.g. Byres, 1996). In its place, I would put a dialectical emphasis on the process of *becoming capitalist* and the

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[10] A phrase I have borrowed from Bois (1978).

[11] We may quarrel with the Genoveses' formulation of "pre-capitalist" here, which reflects an ideal type rather than dialectical understanding of capitalism's internally diverse relations of production. But we needn't make too much of this.

combined and uneven fashion in which regional transitions to capitalism shaped and were shaped by the emergence, consolidation, and expansion of world capitalism.

The Structure of the Argument, and the Argument about Structure

> Every process contains moments of before and after, encompassing both buildup... and what that leads to. Initially, movement within any process takes the form of quantitative change. One or more of its aspects – each process being also a relation composed of aspects – increases or decreases in size or number. Then, at a certain point... a qualitative transformation takes place, indicated by a change in its appearance and/or function. It has become something else while, in terms of its main constituting relationships, remaining essentially the same. This qualitative change is often, though not always, marked by the introduction of a new concept to designate what the process has become (Ollman 1993: 15, emphasis added).

The origins of ecological crisis today may be found in the transition from feudalism to capitalism. This transition encompassed a very long span of time indeed. It is period that stretches from closing decades of the thirteenth century to the dawn of the Industrial Revolution in the eighteenth century. There is of course widespread scepticism that posing the issue in these terms ("feudalism," "capitalism") makes sense;[12] that to do so creates a falsifying (and therefore ahistorical) problematic that obscures the specificities of European societies and social history along with the many substances that made up those curious amalgams of colonial expansion, state formation, the slave trade. To some extent, this is no doubt true. One can never step in the same river twice and the spectre of reductionism lurks everywhere. (And *everywhere*, we should note, includes the very small no less than the very large.[13]) Rivers flood; they change course. The task of

[12] I am quite aware the term "feudalism" has been reasonably unpopular for some time now among historians (e.g. Brown, 1974). And yet the medievalist Rigby argues in a lengthy survey that Marxist and Marxist-influenced medieval historians offer remarkably "sophisticated analyses of the Middle Ages" that recognize a "multiplicity of different causes" (2004: 513, 512). Over the past decade it has also fallen from favor among world historians and historical sociologists (e.g. J.R. Hall, 1999; Frank, 1998; Chase-Dunn and T.D. Hall, 1997). John R. Hall argues that only hidebound orthodox Marxists associated with *Science and Society* adhere to a conception of transition from feudalism to capitalism. It seems to me that this is an instance of wishful thinking. In any event, unpopularity itself is not grounds for discredit. The debate continues (e.g. Blaut, 1994; see the recent debate between Barendse [2003] and Morillo [2003] in the *Journal of World History*). On balance, Rigby's assessment strikes me as very much on the mark: far from a straightjacket, a broadly Marxist conception of feudalism has offered an illuminating angle of vision from which to study medieval and especially late medieval social change. It can hardly be credited or discredited on *a priori* grounds. The proof is in the pudding.

[13] "To *reduce* means not only to simplify schematize, dogmatize, and classify. It means also to arrest and to fix, to change the total into the partial while yet laying claiming to totality through extrapolation; it means to transform totality into a close circle. It means finally to abolish, through the use of logic – without solving the conflicts and the awareness of contradictions – an (ideologized) form of rational thought and productivist, technical action. How can this reductive and fragmentary practice expect at the same time to

discerning the transition from one historical era to another is dismissed at one's peril, not least in such perilous times as these.

In this environmental history of the origins of the modern world, I advance two overarching claims. First, Europe's overseas expansion after 1492 was part and parcel of an epochal shift in nature-society relations. Second, this epochal shift was at once cause and consequence of the rise of capitalism (c.1450-1750). These claims are pursued in the interests of coming to grips with the specificity of capitalism's ecological contradictions historically, and to discern the distinctiveness of today's deepening ecological crisis relative to those that came before it.

The structure of the dissertation's argument can be laid out simply. There is a basic diachronic architecture with multiple (synchronous) points of entry. (And exit.) We begin in thirteenth century Europe and end up in the Atlantic-centered capitalist world-economy of the eighteenth century. While Chapter One serves as a panoptic investigation of medieval Europe's "long" fourteenth century (c. 1290-1450), succeeding chapters are organized somewhat differently. Each opens a new window from which to view the whole. The pillars of the dissertation are a pair of twin chapters on the political ecology of Europe's silver mining and sugar planting "commodity frontiers" (respectively, chapters 2-3, and 5-6). Although Chapter Two is concerned primarily with Central Europe's great silver-copper boom in the century after 1450, the overarching focus of these four chapters is on Europe's territorialist and capitalist expansion *overseas*. These chapters on silver and sugar examine the eco-geographical dynamics that compelled and motivated successive waves of colonial expansion. As we see in Chapters Two and Three, the ecological contradictions of the Central European silver-copper boom were crucial in the relocation of silver production to Potosí in the mid-sixteenth century, and to New Spain in the eighteenth. At the same time, the world-economy's center of copper (and iron) production moved from Central Europe to Sweden during Braudel's "second" sixteenth century (c. 1550-1640). In Chapters Five and Six, we follow the environmental history of sugar's modern surge into the Atlantic, at first on Madeira, thence to Brazil in the later sixteenth century, and onward to the small, then large, islands of the Caribbean in the seventeenth and eighteenth centuries.

These paired discussions of silver mining and sugar planting are interrupted by a return to Europe in Chapter Four. Here I invert the historical-geographical vision of the preceding and ensuing chapters. Where these latter seek to explain the expansion of capitalism from Europe *into* the Americas, in Chapter Four I seek to explain the expansion of capitalism from the Americas into Europe. I follow the flood of American silver as it poured into the European economy, from the vantage point of Amsterdam and the Dutch-centered world-economy of the seventeenth century (c. 1550-1750). What

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integrate?" (Lefebvre, 1969: 28). Dialectically speaking, reductionism is not the crime of collapsing specificity but rather something approach its opposite: collapsing "concrete totalities" such as the capitalist mode of production (Marx, 1973: 101) into endless empirical specificity, shorn "actually existing" historical content. The latter, as Lefebvre indicates, confuses the parts for the whole, without viewing the whole as concrete (as does Marx!) but rather as background, as context. Such mechanical reductionism recapitulates within the intellectual field, as Baran points out, the fragmentation of the labor process and the separation of the worker from the means of production (1961). The dialectical method is in contrast never reductionist in this sense. Rather than ride roughshod over actually existing history but it is method that is centrally *eductive* – that is, its essence is to reveal the more world more fully, to illuminate and allow interpretation of the crucial relations (concrete totalities) of modern world history (Sweezy, 1942).

begins to emerge is a picture of capitalist geographical expansion in northern Europe that is strikingly similar to the story of American conquest. The multiple commodity frontiers of Scandinavia and the Baltic – organized around shipbuilding timber and forest products, metallurgy, and cereals – bear a close family resemblance to the sugar and silver frontiers of Brazil, Peru, and the Caribbean.

Put schematically, the argument runs as follows. Ecological contradictions mobilized by the expansion of commodity production and exchange implied and indeed necessitated regional ecological crises. These were resolved, recurrently, through renewed geographical expansion, often but not always outside of Europe. Such expansion did not spring forth from a fully formed capitalist order but rather was a condition of its very birth. The Americas and northern Europe were not incorporated into an already existing capitalist world-economy; the capitalist world-economy emerged from their articulation.

This expansion was fundamental to the consolidation of the system within Europe, no less than outside it. Thus early capitalism as a whole developed so rapidly *because* it generated successive local ecological crises, not in spite of them. These contradictions developed most rapidly and most extensively in those regions entirely new to commodity production (such as the New World), or in those places where the "natural economy" was historically predominant (such as northern Europe). In these zones, the implantation of commodity production latched onto indigenous ecological wealth (including local supplies of labor power), drawn into the circulation of capital as a "free gifts" (Marx). The ensuing rapid commodification of land and labor pushed these regional ensembles of "fictitious commodities" (Polanyi) to the breaking point. The stage was set for the rapid exhaustion of land and labor, establishing a remarkably consistent cyclical phenomenon of boom and bust. Thence the search for new frontiers began anew, and with it the cycle of expansion, crisis, and expansion.

In commodity frontiers as ecologically diverse and geographically distant as North Sea fisheries, Norwegian timber, Brazilian sugar, Peruvian silver, and Polish cereals, we see regional commodity regimes ascend to strategic primacy in world accumulation over the course of 50-75 years, only to meet with relative decline just as rapidly. (Production therefore did not stop absolutely; rather regional sugar, or timber, or silver complexes became, at best, second-tier producers.) Relative decline called forth the renewed search for "greenfield" zones heretofore insulated from the modern world market, and thence to the rise of new regions to strategic primacy. Brownfields gave way to green, in the sixteenth century no less than in the twenty-first.

These movements, marking simultaneously the geographical expansion of the system's division of labor and decisive shifts within that division of labor, were at the core of the process I call the commodity frontier. (A matter to which I will return presently.) All commodity frontiers were predicated on primary production,[14] and yet many involved some measure of on-site processing – sugar and silver above all were at the vanguard of industrial organization and technological development in the early modern era. It was this combination of extractive enterprise (encompassing unsustainable modes of cultivation along with forestry and mining) and precociously *proto-industrial*

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[14] Metallurgy was, until the diffusion of coal-coke technology for iron smelting in England in the eighteenth century (a process very slow to diffuse), a forest product industry *par excellence*. It was typically easier to find good ore and transport it than it was to find accessible forests, a task that became progressively more difficult over the course of the eighteenth century (see especially, Chapter Two).

economic organization that pushed forward the inner logic of capitalism's "metabolic rift" (Foster, 1999) – the rupture in the nutrient cycling between town and country on an ever-increasing scale and ever-accelerating tempo (Moore, 2000a). The upshot of this metabolic rift has been successive waves of relative ecological exhaustion, precipitating the socio-technical restructuring of production and successive waves of expansions (every historical era carries with it the banner of a "new" imperialism). New zones were therefore continually incorporated into the world capitalist system. This process of geographical expansion was not a manifestation of a particular stage of capitalism ("primitive accumulation") but fundamental to its basic logic, historically and in the present crisis. The endless accumulation of capital, in other words, is the endless conquest of the earth.

If we can agree that the political ecology of capitalist expansion inside and outside Europe compelled ecological degradation, huge questions nevertheless persist. *How* was this degradation was enacted? In what sense and to what degree were the socio-ecological patterns that took shape in the early modern Atlantic distinctively modern? And a question all the more vexing, how did the mounting contradictions flowing from such degradation unfold and meet with provisional resolution? Time and again, such resolutions were stabilized through geographical expansion, only to prove over time unable to appease old demons risen from the ashes of global conquest. In what follows, I answer these questions in two steps. We step first in the direction of the frontier. Next, towards the whole, to take up the question from the standpoint of capitalist transition as world process.

On Global Expansion, Commodity Frontiers, and World Accumulation

Geographical expansion expanded the surplus partly through plunder acquired in the conquest of the Americas. But in short order plunder gave way to production. Enter the commodity frontier (Moore, 2000b; 2003a). Of these frontiers, silver and sugar were pivotal. They were among Modernity's first "mass commodities."[15] There are vast literatures addressing the regional and world histories of these frontiers.[16] What comes to light through the commodity frontier optic — *and what the literatures on silver, sugar, and European expansion have rarely acknowledged* — are the ways in which ecological contradictions were implicated in recurrent waves of European expansion. The silver and sugar commodity frontiers constituted at once a key source of accumulation and a decisive spatializing wedge in remaking the New World's political ecology – a recomposition whose effects were felt on both sides of the Atlantic.[17]

Along these commodity frontiers, ecological sustainability was increasingly subordinated to the imperatives of profit-maximization and empire-building: a strategy whose short-run gains were realized through rising ecological problems over the middle-

[15] A perceptive conceptual turn of phrase on offer from Retort (2005).
[16] Bibliographies of these fields can be found in successive chapters.
[17] This dialectical-feedback moment is bound to a method that identifies local environmental transformations as not simply consequences of European expansion; they were in equal measure constitutive of such expansion, condition as well as consequence.

run.[18] The decisive contradiction can be state simply. These short-run imperatives tended to exhaust local ecological wealth (including laboring bodies), exerting upward pressure on production costs. Over 50-75 years this fettered regional profitability, variously enabling and compelling a shift in the frontier's center of gravity. Thus the commodity frontier materialized modernity's first pattern of "sequential overexploitation" (Gadgil and Guha, 1992), whereby degradation and relative exhaustion in one region after another was followed by renewed global expansion aimed at securing relatively uncommodified sources of labor and land. Far from advancing an ecological crisis-response model, however, the socio-ecological antagonisms crystallized by European expansion found expression in this unusual dialectic of systemic competition "from above" and regional ecological contradictions "from below."[19] Ecological and social relations were at all turns intertwined. These movements of geographical expansion achieved much more than the broadening of the arena of commodity production and exchange. Each such movement represented, it is true, a quantitative expansion of early modern capitalism. To leave it at this, however, would miss the fundamental dynamism of the capitalist mode of production. Each such leap (forward?), from the Erzgebirge to the Andes, from Madeira to Brazil, marked a *qualitative* transformation of the technical and organizational forms of production.

In a pair of twin chapters (2-3, 5-6), I take as my central task the explanation of the sugar and silver frontiers' two major global shifts between 1450 and 1700. I've approached the problem of world-historical and above all world-ecological explanation from a perspective we might call the "political ecology of the world-system" (Moore, 2004c).[20] European expansion was neither narrowly social, as in most accounts, nor narrowly ecological, as in Crosby's famous account (1986), but driven forward by a relational combination of the two. Social and ecological moments of a broader systemic configuration of nature-society relations assumed varying causal weights at different

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[18] Schumpeter once said that even a century could be viewed as the short-run (1954: 163). In this study, I think of the middle-run in terms of Braudel's conception of *conjoncture*, which is not precisely the same as the English-language conjuncture. Rather for Braudel, as in the study of the Mediterranean, the *conjoncture* is roughly "half" of a long century. There is not, for instance, one long sixteenth century, but rather two. One phase of expansion, the first half, and another of crisis and restructuring. Along the commodity frontiers, the spatio-temporal units are compressed further, reflecting the remarkable modernity of the socio-ecological relations in play. Socio-ecological contradictions began to mount in a serious way, in nearly every commodity frontier zone in the early modern era, by the end of a half-century.

[19] Bunker puts this general relation well. "The world-system as unit of analysis is essential… because it provides an explanation of the global processes and dynamics which create, and change, opportunities for exchange and profit for dominant classes from the commodities produced in or extracted from specific regions. *It becomes significant as a unit of analysis for a specific region* (1) to the extent that actors, or groups of actors, derive sufficient power from beyond the local area to reorganization modes of production or extraction; (2) to the extent that local actors reorganize modes of production in response to exchange opportunities outside the local area; (3) in establishing and changing demand for goods which may be produced or extracted in the local area; and (4) in setting prices for goods exported from and imported to the local area. Levels of development and the potential for further development at T2….. Tn can thus be explained in terms of contemporary modes of production and extraction that are partially organized in response to world-system exchange opportunities, but are bounded in their response by the demographic, ecological, and infrastructural parameters set by previous modes of production or extraction and by the present rates of exchange for their exports" (Bunker, 1985: 50).

[20] A play on words. The "political economy of the world-system" (PEWS) is the name of the American Sociological Association group, and the name of the annual conferences and conference volume series.

times, places, and scales. Methodologically speaking, this approach offers an alternative to environmental history's less-than-satisfying "social history + environmental history" perspective (e.g. Richards, 2003; Miller, 2001). In the case of the silver and sugar commodity frontiers, I have put this alternative into practice by stressing the mutually relational and dialectical-feedback character of the relations, say, between ecological relations of production on the ground and the globalizing competitive dynamics between states and capitals at larger scales.

For silver, I follow the commodity frontier from central Europe to Peru, and thence to New Spain; in the case of sugar, from the Atlantic islands to Brazil, and onwards to the Caribbean. What emerges in this world-historical narrative is the striking modernity of European expansion. The sugar and silver commodity frontiers effected an ingenious strategy of capitalist enclosure, reorganizing land and labor on multiple scales in order to satisfy the imperatives of a globalizing commodity system. From this standpoint, European expansion emerges as decisive moment of a broader, historically-geographically specific regime of *socio-ecological relations* whose basic tendencies towards nutrient export, the radical simplification of nature, and recurrent global expansion reveal themselves as distinctively modern (Moore, 2003a, 2003c).

Although assuming distinct forms, the overarching result in each instance was a socio-spatial pattern of sequential overexploitation, whereby the exhaustion of local ecological wealth and human labor (itself a pivotal moment of the former) fettered profitability and created the conditions for a shift in the commodity frontier's center of gravity. This approach allows for something beyond environmental history's standard declensionist narratives (Steinberg, 2004). For the point of the analysis is not simply to identify the scale and scope of, say, soil exhaustion or deforestation, but rather to argue that the "rise of capitalism requires a theory that includes the inability of the soil [along with the rest of nature!] to recover sufficient productivity to maintain a competitive position" (Genovese, 1967: 88).[21] It was precisely the inability of regional socio-ecological formations to regain the competitive edge (once lost) that underpinned early capitalism's profound geographical restlessness. Thus did central Europe's mining centers give way to Potosí in the mid-sixteenth century. Sugar, too, played out this pattern. The fifteenth century colonization of the Atlantic isles produced modernity's first "sugar revolution," crystallizing a unique constellation of socio-ecological forces. African slavery, Portuguese power, and Mediterranean and Flemish capital, all came together to drive the accelerated transformation of island ecologies. These socio-ecological productions set the stage for a great sugar boom that would last to the early years of the sixteenth century, only to undermine the conditions for continued regional primacy by the 1520s. The very pace at which this transformation occurred, complemented by rising European demand and new settlement enclaves in a Brazil replete with ecological windfalls on a massive scale, created the conditions for the

[21] Genovese's comment hits the nail on the head of a key feature of "ecological crisis" in the modern world. The problem is the relation between the *relative* exhaustion of regional ecological wealth and the competitive position of producers drawing upon that wealth. I would add, however, that this antagonism retains its importance well beyond the era of the rise of capitalism: "[T]he more capital is invested in the land, and the higher the development of agriculture and civilization,… the more immense becomes the tribute paid by society to the big landowners in the form of surplus-profits – *so long as the various soils, once taken under cultivation, are all able to continue competing*" (Engels' editorial comment in Marx, 1967, III: 725, emphasis added).

relocation of the sugar complex across the Atlantic. Thence a second and then third sugar revolution, as Brazil gave way to Barbados and the smaller Caribbean islands by the mid-seventeenth century. These smaller islands would be eclipsed in turn by Jamaica, St. Domingue, and Cuba in successive turns over the course of the eighteenth century.

All this may be true, but why return to the language of the frontier? The frontier has been such a slippery and often mushy category because it refers simultaneously to a certain kind of socio-spatial movement *and* to a certain kind of place. This place-process dialectic has confounded American historians of frontier ever since Frederick Jackson Turner's landmark essay (1893 [1961]; more recently, see Cronon, Miles, and Gitlin, 1992a, 1992b; Limerick, 1987). Often as not the dialectic has been displaced entirely by a sort of geo-demographic fetish, inaugurated by Turner's opening reference to U.S. Census reports on population density as the signpost of frontier closure (1961: 37). The notion of the frontier as a zone of low population density today confronts many competitors. The idea is nevertheless surprisingly resilient (e.g. Earle and Cao, 1993; Nelson, 2003). It is of course entirely false, U.S.-centric, and at best problematic even in the North American experience.

For as we shall see, the demographic logic of the frontier was entirely variable. Among the distinctive qualities of commodity frontier expansion relative to pre-modern modes of resource and settler colonialism turned on its relation to a Smithian-Malthusian premodern biological regime. The commodity frontier turned the political ecology of premodern expansion on its head. Population was no longer in the van. Now the thoroughly modern dialectic of state and capital led the way, mediated by emerging world market characterized by intensive inter-firm competition, sustained and protected by state power and inter-state conflict. Demographic expansion now *followed* geographical expansion. It was a dramatic turnaround indeed. After 1450, the decisive impetus for expansion was the enlargement of the arena for capital accumulation, not settlement.

In contrast to recent scholarship in world environmental history (e.g. Richards, 2003; Hughes, 2001; McNeill, 2000; Chew, 2001), then, the commodity frontier approach locates population as a dependent variable. It stresses the essential malleability of population dynamics in the capitalist mode of production. This includes a method that stresses the *primacy* of capital accumulation without denying population movements their material-ecological feedback moment (see esp. Seccombe, 1983).[22] Demographic expansion was the long-run trend, but as often as not, the expansion of capitalism spearheaded demographic *contraction*. This was the case in the Americas in the sixteenth century; it was also in play in South and East Asia during the nineteenth century (Davis, 2001).

What capitalism needed, then as now, was not so much demographic expansion as a tractable labor supply. Preferably one whose socio-biological costs could be externalized. This was among the reasons why modern slavery was such an epochal invention. It was not just that slaves were low-cost and mobile. This much is evident. More to the point, neither European states nor merchants nor planters had to bear the costs of producing – much less *re*producing – this labor force. The upshot is that the European world-economy benefited from an enormous *ecological windfall* at the moment of its great vulnerability. For the slave trade marked not only an economic transfer but also an *ecological* transfer. Planters bought slaves 'grown' in Africa on African food, and applied their labor to the

[22] *Pace* Gimenez's (1977) Marxist but unidirectional handling of the Population Question.

production of carbohydrates for export to Europe (Hugill, 1993: 61). Where African slavery was not feasible on a large scale, as in the Andes, the colonial regime set about creating *internal* Africas. This is what the *mita* and resettlement strategies accomplished (see Chapter Three). Both represented distinct moments of a peculiar kind of metabolic rift, whereby the ecological wealth embodied in human beings was transferred to commodity producing zones, which were under no compulsion to return these people to the point of origin.

It is in this tremendous eco-demographic variability that we come see that even early modern capitalism had begun to sunder Braudel's "biological *ancien regime*" (1981). In successive commodity frontier zones, early modernity's capitalist and territorialist agencies effected wildly uneven (and dramatically combined!) demographic regimes – sometimes confronting virtually unpopulated zones and building slowly, sometimes pursuing a strategy of ruthless depopulation, at still other moments building upon and even constructing from whole cloth (think of African slavery) socio-ecological complexes whose population densities rivaled Europe's great metropolitan centers. (This was Potosí in the early seventeenth century.) Herein do we see capitalism's "special [and especially uneven] laws of population" (Marx, 1977: 784). Far from a static output on the system, as the Turnerian tradition would have it, from the very beginning the demography of frontier capitalism could and did constitute in successive and simultaneous fashion a "gigantic killing machine"[23] *and* an effective means of shaping population in the service of globalizing accumulation.

Having disposed of the geo-demographic fetish inherited from Turner, we may express the place-process dialectic of modern frontier expansion in these terms. A frontier is a *zone beyond which further expansion is possible* in a way that is limited primarily by physical geography and the contradictions of capitalism rather than the opposition of powerful world-empires. The American West? Sure. Southeast Asia? Not so much. In short, the frontier is a specific kind of space defined by the outward movement of the system; it is the spatial coordinate where Hegel's inner dialectic of society drives "beyond its own limits" (Hegel, 1974: 282) Further expansion is possible so long as there remains uncommodified land and labor beyond the frontier. Where external barriers to capitalist expansion initially outweighed the internal ones — as in Africa or Asia during the early modern period — it is probably more fruitful to speak of borders, and not frontiers.[24]

Although deriving inspiration from staple theory and commodity chain analysis, the commodity frontier concept effects fundamental ruptures with both. In the first instance, the commodity frontier incorporates the class and production relations largely absent from the Innis school.[25] Second, in arguing that the very process of capitalism's *geographical expansion* cannot be explained adequately without reference to

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[23] To borrow a nicely turned phrase from Michael Watts (2001: 127).

[24] "The concept of a moving frontier is applicable where a civilized people are advancing into a wilderness, an unsettled area, or one sparsely populated by primitive peoples. It was the sort of land onto which the Boers moved in South Africa, the English in Australia, and the Americans and Canadians in their progress westward across North America. The frontier movements is an invasion of a land assumed to be vacant as distinguished from an invasion of an occupied or civilized country, an advance against nature rather than against men… Inherent in the American concept of a moving frontier is the idea of a body of free land which can be had for the taking" (Webb, 1964: 3).

[25] See Innis, 1956; Bunker, 1984, 1985, 1994. For a useful Marxist critique, see McNally, 1981.

environmental transformations and contradictions, from initial extraction to final product, I call attention to the tendency found in both currents to reduce nature to the status of "resource." Staple theory and commodity chain studies alike – nor are they by any means alone! – tend towards non-relational conceptions of natural resources, giving rising to a substantialist fallacy that fetishizes nature.[26] This first rupture seeks to restore the labor and production processes to the study of capitalism's expansion; the second at giving analytical weight to the production of nature.[27]

In contrast to commodity chain analysis (Friedland, 1984, 2001; Hopkins and Wallerstein, 1986; Gereffi and Korzenewiecz, 1994), which begins with the final product – say electronics or grain flour – the task of tracking frontier expansion requires a focus on the production and extraction of primary products.[28] Commodity chain analysis and the commodity frontier analysis in this sense offer distinct, and indeed complementary, geographical optics. Where commodity chain analysis examines the boundaries and shifting configurations of the world-economy's interdependent division of labor, the commodity frontier optic sheds light on the historical genesis and recurrent spatial extensions of that division of labor. There are, to be sure, useful commodity chain studies of the early modern world-economy that trace the expanding web of, say, shipbuilding-related divisions of labor (e.g. Ozveren, 2000). The problem is that the very methodology of commodity chain analysis seems to favor a social reductionist interpretation that elides ecological transformation. Its focus on the finished product illuminates humanity's alienated relation with nature without explaining it, and this undermines the effort to explain capitalism's distinctive pattern of global expansion.

The commodity frontier perspective moves us closer to such an explanation in four big ways. First, privileging the commodity frontier as a relational analytic gets us around the containerized geography of national, or sometimes imperial-colonial, reckonings of frontier movement. There is a strong sense in which even globally-oriented studies of frontiers tend to see such movements as first about state-formation (or empire-building) and *only then* can the world-historical moment be considered. (A movement predicated on the fiction of world-system as context rather than *place*, see Chapter Four.) Such national-imperial containerization is the geographical conceit of most frontier history, extending even to comparative-historical efforts (e.g. Wolfskill and Palmer, 1983; Hartz, 1964; Mikesell**,** 1960**;** Richards, 2003).[29]

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[26] This sort of substantialist fallacy internalizes and indeed reproduces an alienated reckoning of nature-society relations, one whose origins may be found in the Scientific Revolution (Merchant, 1980). For an astute dialectical conception of resources in relation to classical political economy, see Harvey, 1974.

[27] Harvey ably articulates this Marxist and relational approach to natural resources. For Marx, Harvey contends, "a 'thing' cannot be talked about independently of relations it has with others things. For example, 'resources' can be defined only in relationship to the mode of production that seeks to make use of them and which simultaneously 'produces' that both through the physical and mental activity of the users. There is, therefore, no such thing as a resource which exists as a 'thing in itself.' This relational view of the world is fundamentally different from the usual and familiar Aristotelian view (characteristic of logical empiricism or Ricardian type model building) in which things are thought to have an essence of some sort and are, therefore, regarded as definable with reference to the relationships they have to other things" (Harvey, 1974: 265).

[28] A really compelling study remains to be written, one that would run the thread from the perspective of the commodity frontier and backwards thence from the perspective of the commodity chain.

[29] For a useful critique of comparative history as not only insufficiently world-historical, but in certain respects antithetical to the historical investigation of transnational process, see Tyrrell, 1991.

Second, by focusing not only on the commodity but equally on the laboring body as accumulation strategy (Harvey, 2000), this approach directs our attention to the dialectic of land and labor at two scales: the technical and social divisions of labor. The configurations within these had everything to do with class relations and political power. And this meant these configurations had everything to with the ecological relations of production at multiple scales. To talk of the silver or sugar in this era without pointing to the production process, and most of all the ways in which European colonialism mobilized that labor (the African slave trade, the *mita*, sharecropping, indentured servitude, wage-labor), would be nothing short of unthinkable! For if capitalism in general evinces a strong tendency towards the exhaustion of the laboring body,[30] on the commodity frontier the contradictions were especially stark, and dramatically prefigurative. The silver and sugar *ingenios* consumed slaves as voraciously as they did the soil and the forests.

A third way this frontier perspective sets to work is found in the comparative study of multiple commodity frontiers in the Americas, and also, perhaps surprisingly, in northern and northeast Europe. This implies a comparative engagement of frontiers in a much different sense from what is on offer from the older, containerized geographies of comparative history. Everyone knows that the Americas were made by multiple commodity frontiers — sugar and silver most spectacularly, but also timber (Williams, 1982, 1990), cattle (Jordan, 1993; Baretta and Markoff, 1978), cereals (Cronon, 1991; Gates, 1960; Shannon, 1945), cotton (Genovese, 1967), tobacco (Kulikoff, 1986), furs and deerskins (Wishart, 1979; Dunaway, 1994), fisheries (Richards, 2003). Such movements were also in play in northern Europe, home to the strategic raw materials of the era: shipbuilding and construction timber, iron, copper, potash, and naval stores, not to mention the granary of modernity's first superpower, headquarted in Amsterdam. These were not only commodity sectors; they were commodity *frontiers*, ever in motion, ever extending outwards a commodity-centered division of labor. From the standpoint of national frontiers, the formal comparative method directs our attention first to national environment and national social relations rather than viewing these as emerging dialectically through the movements of commodity frontiers. (Without, however, suggesting that *everything* pivots on the commodity frontier.) The approach on offer in this study situates the relationality of multiple commodity frontiers – and their various spatial productions, including state-formation – as emerging out of (and in turn enabling) the combined and uneven development of world accumulation, itself not mystical by the very concrete dynamic taking shape out of the contestations of imperial powers, business organizations, the producing classes, and an unpredictable biophysical world.[31] In the

[30] "[I]n its blind and measureless drive, its insatiable appetite for surplus labor, capital oversteps not only the moral but even the… physical limits of the working day. It usurps the time for growth, development and healthy maintenance of the body" (Marx, 1977: 375).

[31] Uneven development surely ranks amongst the most elusive concepts in Marxism. Let us begin simply and allow specific formulations to emerge through the explorations that follow.[31] McIntyre (1992) provides one useful starting point for considering combined and uneven development: "I propose a concept that proceeds from basic principles *and* conveys a powerful message: that unevenness is the lens through which Marxian theory 'sees' capitalist development; that we see the development of capitalism as different everywhere because of its (different) interaction with and production of noncapitalist social processes; that this unevenness occurs not only among different historical periods but at a 'point in time'...; and that this unevenness characterizes not only relationships *among* sites but the development *of* sites" (1992: 87). See

scheme of things that I am proposing, then, the commodity frontier perspective allows an analysis of the interrelations between the full range of frontiers, and the unevenness of capitalist expansion.

In analyzing this unevenness, the commodity frontier optic also puts its finger on decisive poles of attraction around which regional political ecologies turned. (Its fourth contribution.) This speaks to the critique levied against the (so-called) "universalizers." The critics rightly argue that the transition to capitalism has assumed different forms in different places. The irreducibility of place and region renders the task of theorizing the diversity within a unified field deeply problematic. World-historical approaches are, in this scheme of things, incapable of theorizing this diversity (e.g. Stern, 1988a, Stern, 1988b; Hall, 1984; Walker, 2001). And while there is no doubt that some share, perhaps even most, of the world-historical tradition has ridden roughshod over regional difference, has not the regional approach equally violated the irreducible specificities of the world-economy as place? Even if this is a largely a matter of the pot calling the kettle black, in itself this hardly invalidates the regionalists' critique. What I would say is that there is a clear distinction between world-scale determinisms that treat regional specificities as mere epiphenomena, and world-historical studies premised on the dialectics of emergence, that view the world capitalist system's emergence and periodic restructuring as the precipitation of fiery tensions between large- and small-scale social and environmental change and conflict.[32]

My argument and method rests on precisely these dialectics of emergence. *Pace* Stern, a dialectical holism offers a whole series of conceptual openings for the agency of sub-global process and place-specific contradictions on *every* scale.[33] (As we shall see later in this Introduction, and indeed throughout this study.) The commodity frontier approach emphasizes the contribution of local commodity production and labor mobilization to broader movements associated with the logic of capital – for instance "long waves" of capitalist development (e.g. Mandel, 1975; Arrighi, 1994; Arrighi and Moore, 2001; Moore, 2000a). The intent is to enable an exploration of the interrelations

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also Brenner (2007); Harvey (2006); Lowy (1981); Mandel (1991); Tomich (1994); Trotsky (1957); Walker (1978).

[32] I have argued elsewhere that Wallerstein's *The Modern World-System I* constructs its narrative in precisely this fashion (Moore, 2003b; 2004d). Often read casually, a closer reading of Wallerstein's classic study reveals that the capitalist world-economy *does not exist as an* a priori *construction*. It is written from the perspective of a world-economy *in creation*. Indeed the whole volume is rightly considered as the account of the rather unlikely, and until the middle of the seventeenth century profoundly unstable and vulnerable, emergence of capitalism over several centuries. Dale Tomich's (1990, 2004a, 2004b) and Philip McMichael's work is also instructive (1984, 1990).

[33] Hall's critique of systemic holism may be taken as representative of historical and comparative sociologists' objection to world-historical frameworks (1984, 1999). In Hall's scheme of things, such "universal histories" assume systemic properties that determine the whole along with its parts. There is of course more than a kernel of truth in this characterization. And yet, the critique proceeds from an assumption of the nature of the intellectual system of "universal history"; namely that such holistic frameworks operate along the lines of a mechanical causality. But is there not more than one way to practice a world-historical and holistic methodology? Hall's critique of holism commits the very error on which he indicts mechanical holisma and world-scale determinism; namely that that there are different roads to holism no less than there different roads of capitalism. Orienting concepts discerning the main outlines of the system in question can be framed in a manner open to multiscalar analysis and narrative (see particularly Moore, 2002b).

between production in particular (local) *places*, and the expansion of capitalist *space* in the era of its global formation.

At its core, this commodity frontier perspective emphasizes the ways that contradictions in production, the world market, and geopolitics undermined the socio-ecological conditions of production so as to lead territorialist and capitalist actors to push against the boundaries of the system. Rather than erase local socio-ecological specificities – as abstract models of regional development (staple theory) or global development (dependency theory) necessarily do – this approach achieves two things. First, it identifies theoretically the contributions of local ecological conditions and relations of production in the formation (and periodic restructuring) of the modern world-economy. And second, it allows for a wide-ranging empirical investigation of the ways in which regional historical trajectories – such as Potosí's silver mines or northeast Brazil's plantations – shaped and were shaped by the contours and possibilities of the early modern world-economy.

The pattern of sequential overexploitation that enabled and indeed compelled Europe's early modern expansion worked its way through landscapes and laboring bodies by way of the commodity frontier. How was this work accomplished? In this study, I've chosen to highlight ten key moments of environmental transformation: 1) the organization of production "from below," pivoting on the metabolism of the labor, from extraction and cultivation to processing; 2) the organization of production "from above," emphasizing changes in enterprise organization and responses to market fluctuations and political forces; 3) land clearance and deforestation; 4) the impact of monocultures on soil fertility; 5) the mobilization of labor, and labor flows between town and country, and from outside the world-economy to inside (as in the case of Africa slavery); 6) the mobilization of energy sources, such as charcoal, for smelting and processing; 7) the creation and expansion of livestock sectors, to supply industrial inputs (such as tallow and hides), transportation, and food; 8) the town-country division of labor at multiple scales; 9) the extension of European, land-extensive cereal agriculture, especially wheat; and 10) socio-ecological transformations of the body as an accumulation strategy in terms of production and demographic regimes.

The story of European expansion through the optic of the sugar and silver commodity frontiers is a narrative of epochal shift. The totality of early modern commodity frontiers set in motion a quantitative trend towards ever deeper, wider, and faster commodification. But this was far more than a story of static reproduction on an extended scale, reproducing a caricatured model of merchant capitalism still popular within Marxist historiography (e.g. Genovese and Fox-Genovese, 1984). Rather, the expanded reproduction of systemwide trends towards widening and intensifying commodification hinged in great measure upon successive innovations within and between some combination of these ten principal sites of environmental transformation.[34] The ensemble of production relations, from colonial governance to technological organization to enterprise structure, was successively reworked in successive frontiers. Every organizational and every technological shift was simultaneously a spatial shift. Where planting and milling were spatially and organizational distinct functions in Brazil's sugar frontier, for instance, these functions were concentrated under the same roof in the

[34] The geographer Galloway (1985, 1989) had laid great emphasis upon innovation in the development of the sugar commodity frontier. His conception of innovation, alas, is dramatically underconceptualized.

Barbados sugar revolution. This innovation would prove decisive to the ascent of Barbados relative to Brazil in the seventeenth century world sugar market.

Not only did each great moment of relocation and expansion entail significant transformations in the organization of production, and the regional formations they set in motion, but relocation itself proceeded through successive phases of transformation. The story of European expansion turns on innovations linked to a "horizontal" phase of capitalist widening followed by innovations enabling a "vertical" phase of capitalist deepening,[35] what I have elsewhere called a dialectic of *global conquest* and *globalization* (Moore, 2007b). For instance, the Spanish conquerors organized a sort of subcontracting system for silver mining in the early decades of their hegemony in Peru, only later to seize control of the production process and radically transform the region's socio-ecology in order to secure the labor needed to maximize production. In both instances, the *capacity* to implement these innovations was in great measure determined by world-scale agencies, Dutch and English capital in the Barbados sugar revolution, the Castilian empire in Potosí's silver revolution.

In sum, the organization and mobilization of labor, linkages with broader agricultural and pastoral economies, the technological apparatus, town-country antagonisms, the supply of industrial inputs, and class structure, to name a few, all were significantly reworked in each moment of these commodity frontiers' global expansion. In this sense, we can speak not only of successive sugar revolutions, but of silver-extractive revolutions, each one a multilayered reconstitution of the ecological relations of production in successive waves of expansion and restructuring within and between regions. What merits special attention in these regional movements of boom and bust is not even boom and bust itself. Rather, what seems analytically central was the articulation of regional rise and decline with *recurrent* waves of global expansion, driven forward by recurrent tensions between local socio-ecologies and Europe's interlocking, and ruthlessly competitive, territorial and capitalist logics.

Ecology and the Transition to *Capitalism*

In what sense can we call these transformations and contradictions *capitalist*? For all its vitality, there is no denying that early modern capitalism was a ramshackle affair. If a capitalist logic of ceaseless accumulation had scaled the system's commanding heights by the sixteenth century, such command was for the moment built on exceedingly weak foundations. One is tempted to say that this was because capitalism had yet to plumb the depths of everyday life. This is what led Braudel to counterpose as discrete socio-historical units an essentially unchanging *biological ancien regime* alongside a flourishing capitalism (1981; also Marks, 2002). And there is more than a little truth in the observation. But appearances can be deceiving. For early capitalism, from its earliest moments in Braudel's "first" sixteenth century (c. 1450-1557), was reworking material life in ways fundamentally different from the medieval period. Part of this was the sheer scale of transformation, as we have suggested. Possibly more significant than scale

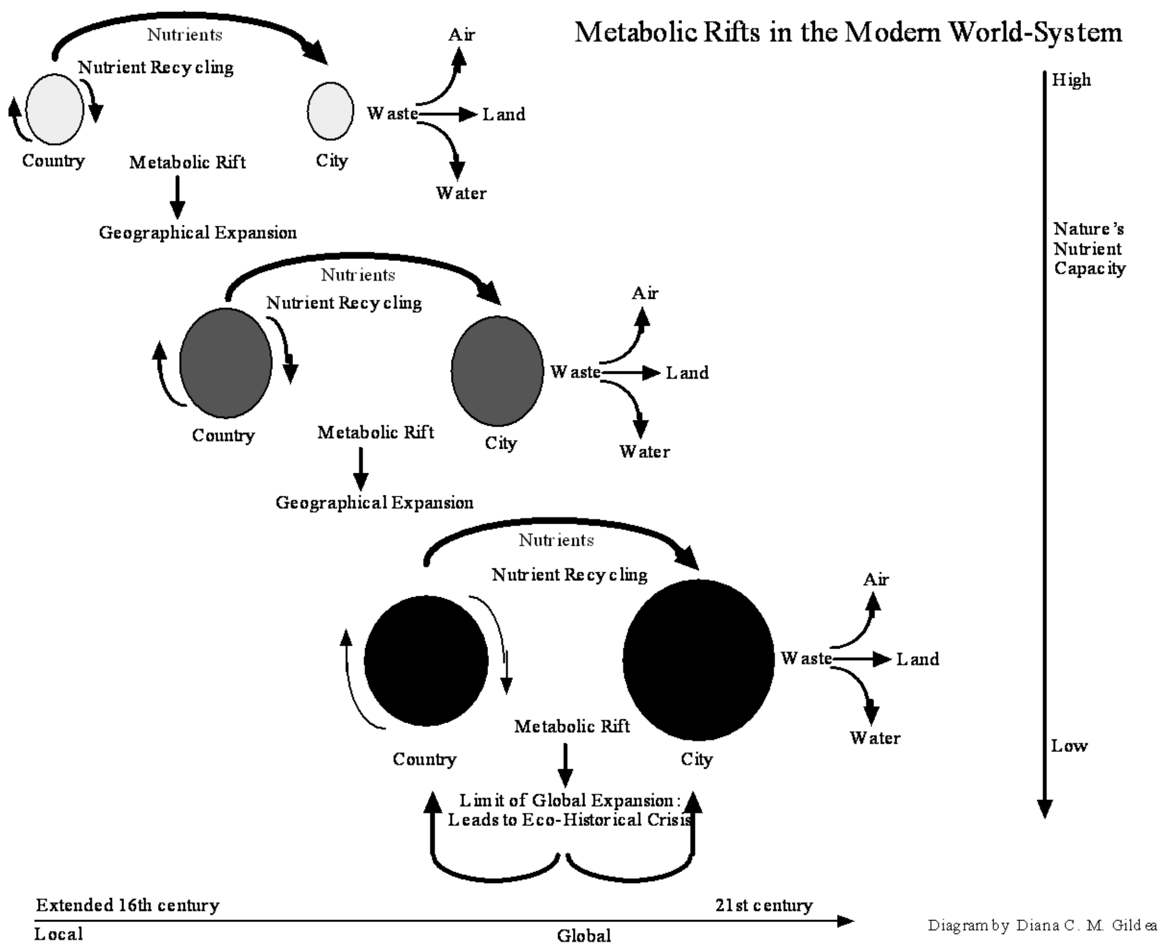
[35] This is my problem with the critique of modern slavery as non-capitalist, owing to its limited flexibility. The fact of the matter is that slave labor, particularly in terms of its geographical mobility, was an enormously supple socio-ecological crystallization *in the era of capitalism's formation*.

however was *speed*. The one reinforced the other. Between 1451 and 1557 we see a remarkable ensembles of technical innovations and geographical shifts: in silver, from the *saigerprozess* of the Erzgebirge to mercury amalgamation in the Americas; in sugar, from edge-runners in Madeira to the two-roller mill in Sao Tome; the appearance of sawmills in timber zones, beginning in fifteenth century Germany, moving in truly revolutionary fashion to Norway in the sixteenth century; the diffusion of blast furnaces for ironmaking (and everything demanded iron) made possible not only larger production figures, but made necessary constant revisions, small and large, in the geography of leading iron centers; new ships (caravels) emerged to transgress and then govern oceanic spaces. Nor should we forget the crucial instruments that would bring bourgeois order to time and space. "The clock, not the steam engine," Lewis Mumford reminds us (1963: 14), "is the key machine of the modern industrial age." Was it coincidence that it was precisely in the "middle of the fifteenth century that spring-driven clocks and watches appeared" (Mokyr, 1990: 50)? It was also a century of revolutionary advances in mapmaking, culminating in Mercator's famous projection of 1569. The cartographic revolution launched in Portugal during the 1430s had found its way to the Low Countries a century later (Brotton, 1998). A Fleming whose name translates directly as "merchant," Mercator was only secondarily a trader. He is better characterized as a skilled engraver and manufacturer, who among other things had perfected the art of mass producing globes.

The theoretical problem may be stated simply. If capital accumulation is about the reworking of social and spatial relations, "the 'raw material' from which they are produced is nature" (Lefebvre, 1991: 84). The problem, then, and it is one that has yet to be tackled head on by adherents of this Braudelien reading of capitalism (e.g. Arrighi, 1994), is the irreducibly material character of capital accumulation (Moore, 2003c; Burkett, 1999) – something Braudel himself felt compelled to admit empirically if not conceptually in his discussions of silver mining and sugar planting (1981: 334-384; 1982: 231-373). Capitalism did not overthrow Europe socio-biological regimes all at once. This much is true. It was nevertheless moving Braudel's "structures of everyday life" in a fundamentally new direction.

Three overarching movements in this new direction immediately suggest themselves. A first concerns the recurrent globalization of socio-ecological problems. This we have discussed at length. The essential relation here is between the unusually intense competitive dynamics in the European states system on the one hand, and the ways in which this competition enforced a rapacious colonial strategy characterized by the relentless exploitation of land and labor on the other. This dialectic (indeed, a dialectic of dialectics!) ensured that over time the socio-ecological reproduction of these wondrous fictitious commodities was undermined, driving up costs and eroding the competitive position of any given region's colonial producers in the world market. To some extent, colonial merchants, planters, mineowners, ranchers, and others could enact modest spatial fixes within their sphere of influence, relocating to fresh land, fresh ores, fresh labor within "their" region. Such internal fixes could and did happen. But in the era of emergent capitalism, the globalizing political ecology of competition from above, coupled with rising costs from below – intersected at multiple turns by social unrest – favored global expansion as the first, best response to socio-ecological crunches, within regions and the world-economy as a whole. Hence the sequential pattern of regional boom and bust that comes into focus through the optic of the commodity frontier.

A second movement turns on the political ecology of the town-country antagonism. This is the "metabolic rift" (Foster, 1999, 2000; Moore, 2000a; see figure below). The competitive relations that pushed colonial producers towards ecological overdraft flowed through the spatial conduits of cities. Just as capital flowed from European to colonial cities, through the latter's hinterlands and backward thence, so colonial ecological wealth flowed from agrarian zones to peripheral cities and thence to metropolitan seats of power. It is hardly a world-historical accident that the first agents of modern colonial expansion, the Castilian and Portuguese states, pursued varied but highly urbanized imperial strategies (Portes, 1977; Russell-Wood, 1972). Here was Marx's "urbanisation of the countryside" in full force. Whereas the cities of Antiquity had been captive to the rural aristocracy, and feudalism was marked by the opposition of town and country, capitalism effects an unprecedented dominance of urban power and the remaking of agrarian life in accordance with the demands of a hyper-urbanizing system of wealth accumulation and commodification (1973: 479; also Marx and Engels, 1970; 1972: 339). It bears repeating that this was first realized on a large scale in the Americas, and that such a realization was possible precisely because the New World lacked a peasantry capable of waging effective resistance.



While town-country conflicts are a hallmark of Civilization from its origins, the European world-economy's early globalization effected two unusual transformations. First, European expansion was itself largely *urban-centered*, ranging from miniscule armed trading posts on the West African coast to massive urban conglomerations such as Potosí, which at its height contained more people that Rome, Paris, or Madrid in the early seventeenth century (Galeano, 1973). Second, metropolitan expansion positively enabled a radical delinking of major urban centers from their immediate hinterlands – the incorporation of Baltic granaries, Norwegian timber, and Scandinavian iron is proof that this expansion was as much internal as external to Europe. Sometimes this made possible local agrarian stagnation, as in Iberia; sometimes this delinking was bound up with revolutionary transformations in the agricultural mode of production, as in the Low Countries (Elliot, 1963; Brenner, 2001). Irrespective of agricultural revolution or retrogression, the essential point is this. Capitalism, in transforming town-country relations through this global expansion, burst asunder the largely sustainable nutrient cycling of earlier city-hinterland complexes, giving rise to what Marx (1981: 949) calls an "irreparable rift" in the metabolism of nature and society. This is not to say that premodern civilizations were edenic, only that their ecological contradictions moved slowed and within a smaller canvass. Viewed from the perspective of colonial expansion and the colonial world, early modern capitalism was establishing, on a progressively globalized basis, a metabolic rift whereby nutrients flowed out the countryside and into the cities at a geometrically increasing volume and pace (Foster, 1999, 2000; Foster and Magdoff, 1998). Nutrient cycling was increasingly disrupted, precipitating one after another "local" ecological crisis — arising frequently from relative deforestation — whose global impacts manifested in recurrent waves of geographical expansion, as capital was compelled to seek out new supplies of land, along with the labor to work it (Moore, 2000a). In this way, early capitalism's ecological contradictions were powerful forces behind the system's global expansion. (The ecological moment was not, it should be said, at all turns the prime mover; it was however always implicated in the crises and crunches of this ascendant but still vulnerable system.)

Finally, colonial ecological regimes evinced a strong – and strongly prefigurative – tendency towards what Worster calls the "radical simplification" of nature (1990). The notion that modernity effects an unusually simplifying or homogenizing mode of producing nature is major theme in environmental history (also Cronon, 1991; White, 1995; Boyd, 2001). This tendency towards radical simplification ranks amongst the more difficult conceptual problems in the explanation of capitalism's ecological contradictions. And yet I think it quite reasonable to locate in the long sixteenth century the origins of a secular trend towards the radical simplification. These simplifying movements, *pace* Worster and indeed most environmental history (also Cronon, 1991; Merchant, 1980, 1989), were only partially driven by commercialization. These movements encompassed such processes as the emergence and extension of large-scale plantation monocultures, the imposition of bourgeois or semi-bourgeois property relations on the land, regional specializations of cereal agriculture and stock raising, large-scale mining enterprises, and even the globalizing rupture between town and country. But describing and explaining are two different things. Environmental historians have been good at the first and not so good at the second, and perhaps as a consequence have tended to internalize a certain neoclassical (or classically liberal?)

sensibility about the motor of socio-ecological change. In the main, environmental historians have succumbed to an essentially circulationist explanation of the processes by which capitalism has progressively decomposed "nature" into discrete elements, the better so as to manipulate them in a system of generalizing commodity exchange.

The alternative for which I've argued turns instead on an even-handed dialectic of production and exchange (Moore, 2000a, 2000b, 2002a, 2003a, 2003b). The world market that emerged in the long sixteenth century was quite distinct from earlier modes of large-scale commerce. Here both the environmental historians and "neo-Smithian" Marxists are correct. (Not to mention Marx's very pointed comments on the matter.) What I wish to argue is that the competitive logic (that is to say, the social relations) that distinguished the emergent modern from the earlier medieval world market compelled the various agents of expansion – colonial producers such as planter and miners especially – to remake the production process in accordance with the demands of this world market. (Even as such local transformations reshaped the contours and contradictions of this world market.)

This emergent systemwide competitive logic pushed metropolitan capitals, overseas empires, and colonial producers towards an epochal innovation, the commodity frontier, that compelled the progressive simplification of human and extra-human nature. Monoculture stands as the clearest (but not only) expression of this tendency. What seems especially noteworthy is the longstanding socio-ecological relation between monoculture and slavery. Control over land and labor was achieved in this way, allowing planters to intensify production.

Here I would draw on two broad conceptual insights in the effort, first, to identify the epochal significance of this emergent land-labor complex, and then to explain it. In the first instance, I would point to the tradition of labor process studies most strongly associated with Braverman (1974). For if I may summarize crudely, a core insight of the Marxist analysis of the capitalist labor process turned on the centrality of control and standardization as the precondition for maximizing the production of relative surplus value (Edwards, 1979).[36] What I suggest is that we extend to environmental history Braverman's great insight, that capital seeks to dissolve concrete forms of labor into "general types of work motions" (1974: 181). The movement of dissolution, predicated on the imperative of maximizing productivity, in general tends to reduce not only concrete labors and but all manner of ecological specificities (of which labor is one moment) to the status of "interchangeable part" (Braverman, 1974, esp. 181-182).[37]

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[36] The recent maturing, or deepening, of this control tendency in the agro-ecological sphere leads Lewontin, among others, to speak of the "farmer as proletarian" (2001/1998; also Liodakis, 2003).

[37] My approach here follows the spirit of Braverman's interpretation of the labor process, which necessarily (although Braverman did not see this) entails a radical simplification not just of concrete labors but of the ecological wealth that the former reshapes: "We see that this abstraction from the concrete forms of labor… which Marx employed as means of clarifying the value of commodities (according to the share of such general human labor they embodies), is not something that exists only in the pages of the first chapter of *Capital*, but exists as well in the mind of the capitalist, the manger, the industrial engineer. It is precisely their effort and métier to visualize labor not as a total human endeavor, *but to abstract from all its concrete qualities in order to comprehend it as universal and endlessly repeated motions*… [I]n this form [labor] comes ever closer to corresponding, in life, to the abstraction employed by Marx in analysis of the capitalist mode of production" (1974: 181-182, emphasis added).

In so doing, capital seeks to create in the actual process of production the immanent logic of value accumulation, in which ecological and social particularities are dissolved in money form, the great standard bearer of abstract social labor. It is here that the meta-insight of Marxist labor process studies dovetails with recent analyses of the ecological contradictions of the law of value. Particularly useful is Burkett's (1999) observation that Marx's value analysis is so ecologically compelling because it illuminates the contradiction between the accumulation of value as abstract social labor (its social form) and the accumulation of value as material process (its spatial form). From this standpoint, money emerges as the general equivalent of value, mediating the contradiction between value's "social generality" and its "material particularity" — *between the abstraction of social labor and the specificities of the external environment and the concrete labors that work it up*. Money "solves" (however temporarily) this contradiction by "abstracting from the qualitative differentiation of useful labor as conditioned by the material diversity of human and extra-human nature — the true sources of wealth" (Burkett, 1999: 84). Money enables, in Marx's words, the endless "cutting up [of privatized nature] into countless fragments and consuming it piece by piece" (1973: 871). The chief material form of this temporary solution has been the successive, and ongoing, reordering of nature in a way that facilitates increasing control, achieved largely through the progressive decomposition of nature in discrete socio-ecological moments: land parcels, animal breeding, genetic codes, and so forth.[38] Harvey, too, argues in a similar vein. But with a twist. Although characteristically privileging the moment of circulation, Harvey sees the logic of value accumulation effecting its decomposition of nature through bourgeois property rights, that is implicitly through enclosures broadly conceived:

> Money prices attach to particular things and presuppose exchangeable entities with respect to which private property rights can be established or inferred. This means that we conceive of entities as if they can be taken out of any ecosystem of which they are a part. We presume to value the fish, for example, independently of the water in which they swim. The money value of a whole ecosystem can be arrived at, according to this logic, only by adding up the sum of its parts, which are constructed in an atomistic relation to the whole (Harvey, 1993: 6).

For my purposes, the crucial turn of phrase in this passage concerns the ways in which the relation between monetary accumulation and radical simplification is mediated "with respect to which private property rights *can be established or inferred*" (see also Thompson, 1991: 164). For what Burkett elides and Harvey only suggests, is that capitalism's secular trend towards radical simplification operates *principally* through the law of the value only very late in the game, not until the twentieth century and even then quite unevenly. (The entry of such phrases as "biopiracy" into the register of global political debate suggests that value accumulation has already entered a new phase of crisis.)

In the early modern era, what I think we have is the combination of three self-reinforcing (and mutually constituting) vectors of competition and conflict: within and

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[38] See Boyd's (2001) very impressive paper on this matter.

between states, capitals, and classes. This early modern competitive dynamic cannot be reduced to the market, and yet found its clearest expression in this globalizing world market that emerged in the long sixteenth century. Appearances notwithstanding, this is hardly a controversial assertion. Historical capitalism is centrally about the extension and deepening of commodification, and therefore about commerce, which is not however to say that the modern world market was in all cases the independent variable. In contrast to the environmental historians, my emphasis on the world market is only surficially neo-Smithian. As we have learned from Scott (1998) and others, it is not only economic motives narrowly conceived, but equally the modern logic of territorial power that drives the rationalization and simplification of nature. It was this competition that effected an ecological dynamic that on the one hand *mimicked* the law of value in its efforts to reduce and recombine socio-ecological particularities, and on the other constituted preconditions for the emergence and extension of value relations proper in the long nineteenth century. In this way we might account for the long-run continuities in modernity's ecological contradictions as well as ruptures *within* the capitalist system over the *longue durée*.[39]

On World-Historical Method and the Question of Evidence,

Just how one goes about doing world-historical research is a difficult question. It is something different from the writing textbooks and primers, although at times these overlap. It is an elusive question because virtually all research in the historical social sciences that is not strictly theoretical or methodological is devoted to the study of social change in arenas smaller than the world-system. In itself this is entirely reasonable. Traditionally, these arenas have comprised the community or region, although there has surely been no paucity of research on national transformations (many of which however are composites of regional studies) and today, increasingly, of transnational networks.[40] To the extent that research into large-scale social change has gained a foothold within the historical social sciences, it remains largely a comparative enterprise premised on the formal independence of national or regional cases. For Charles Tilly, arguably the most important representative of this tradition today, the world-system is simply too big (1984).

The methodological contribution of the world-historical perspective – in contrast to Tilly's comparative-historical emphasis – has been to mobilize the dialectical method for the study of large-scale, long-run social (and now, socio-ecological!) change.[41] It is an approach premised on the primacy of relations, a task easier said than done. In this study, I have pursued this goal by privileging the world-historical (and globally expansionary) cluster of relations that compelled massive, rapid, and in time self-limiting,

[39] This seems to me more satisfactory than Arrighi's distinction between an early modern, Smithian logic of capitalism, and a post-1800 Marxist logic of capitalism.

[40] Within world environmental history, surely the most influential of this latter is Grove's groundbreaking *Green Imperialism* (1995).

[41] The classic formulation of this method goes back to Marx's "The Method of Political Economy" (1973: 100-108). In the long twentieth century, influential statements on dialectical method can be found in Derek Sayer (1987), Levins and Lewontin (1986), Ollman (1971, 1993), Sweezy (1942: 11-22), and Lukacs (1971) above all. Within the world-historical tradition, see Hopkins (1982), Bach (1982), McMichael (1977, 1990), Tomich (1990), Silver (1994).

environmental transformations during the rise of capitalism. The relational approach manifests in two, specially important, ways. Geographically, rather than construct a series of formally independent regional objects (sugar regions, silver regions, and so forth), I have followed the history of the capital-nature antagonism as it flowed through successive regional zones, whose specificities shaped the specific contours of world capitalism's early modern ecological regime – a regime that would ultimately reach a crisis point in the eighteenth century and set the stage for the epoch-making ecological revolutions of British-led capitalism over the long nineteenth century. In terms of the relations (*qua* motive forces), I have seized every opportunity to construct such "social" forces as imperial expansion and world accumulation as simultaneously social and ecological, each moment enabling and constraining the other in multiple, patterned, and also at times unpredictable and unexpected, ways.

I should like to begin with some reflection on holism and systems. From the outset it is worth saying two things about the language of systems. My approach is in the first instance a dialectical one. Systems, from this standpoint, are *emergent*, dynamically self-propelling, and over time self-limiting. They are living entities. Wallerstein likens social systems to coral reefs – a doubly appropriate metaphor in this time of crisis – and this has always struck me as a penetrating metaphor (1974). Coral reefs are vast living entities, durable but not eternal. Like social systems, reefs make organic, not mechanical, wholes. This stands in stark contrast to "systems theory," with its acknowledgement of complexity and feedback loops, but its inability to move beyond stationary concepts whose *historical development* (of the concepts themselves, as signifiers, and what they signify) would continually threaten the integrity of the models in play.

The language of "systems theory" must as a consequence be addressed from the outset. We may first take the signifier, "world-systems theory." It is a phrase commonly attributed to the work of Immanuel Wallerstein and his fellow travelers. A few of these latter have adopted the phrasing (Chase-Dunn, 1989), but many have not. Most have argued against the positivist transformation of the world-historical perspective from mode of analysis to "systems theory" (see especially Taylor, 1987). Insofar as historical social scientists are interested in the long-run development and crises of historical capitalism, systems theory as such is spectacularly unsuitable. Although systems theory admirably seeks to capture the "motion in the system" through feedback loops, the loops themselves are secondary to the concepts in the model, which are themselves ahistorical, subject to quantitative but not qualitative variation (e.g. Meadows, et al., 1972: esp. 97-134). That is to say, system theory's stationary concepts violate the central premise of the dialectical method, namely that both concepts and model are historically transient; that the concept "boxes" in a feedback loop model are themselves in motion, provisionally stabilized but tending towards either escalating cohesiveness (centripetal tendencies) or towards systemic disintegration (centrifugal tendencies), all of which turns on a part-whole dialectic that itself is characterized by laws of motion distinctive from that of the parts (concept-boxes).[42]

Wallerstein himself has argued strenuously against systems theory, arguing that the core of his project must be understood as a "mode of analysis" critical of, and an alternative to, the structures of knowledge inherited from the nineteenth century (2004,

[42] Useful elaborations of this line of critique may be found in Harvey (1974), and Levins and Lewontin (1986).

esp. 83-108). "World-systems analysis" is therefore a more appropriate category. The main line of argument from this Wallersteinian reading of world-historical method has turned on the application of a dialectical approach to "totalities" (sometimes capitalism as a whole, but frequently these encompassed more bounded sets of relations, such as business organization, social revolutions, geopolitics, and so forth) to much broader geographical arenas than was typically imagined possible before 1968. If the world-historical perspective's dialectical reworking of system in this sense was fundamentally geographical – and therefore historical because the geographies that emerged were no longer naturalized, but viewed as constructed – it is worth highlighting a second profound, but also less visible, source of confusion. The language of world-system has frequently been misunderstood, by practitioners as well as critics, as synonymous with the world- or (today) global-scale. But from a dialectical perspective such a scalar determinism is impermissible. Dialectically, systems (totalities) attain their coherence through the patterns that emerge through the interaction of their parts – although the patterns are not reducible to these interactions. The patterns are often invisible (or look significantly different) when viewed from the standpoint of the parts themselves, but are incomprehensible without the movements (agencies) of those same parts. And so it is worth saying that "system" is not a precise synonym for the world-*scale*. (A matter to which I will return presently).

All of which this makes for two sorts of appeal to the reader. In the first instance, I would say that while the whole is more than the sum of its parts, it is also surely less.[43] While there is considerable investment in specific regional trajectories throughout this study, there no effort to construct regional narratives as case studies (although they may be read as such). Rather these regional geographies are constructed in dialectical relation with, and as expressive of, the emergent capitalist system's crystallization of socio-ecological power and process. Now, "expressive of" is a tricky phrase. It has often been read as "determined by." But this would be undialectical. It is of course the case, and indeed it is one of my central claims in this study, that local-regional transformations generated powerful contradictions that shaped in decisive ways the geography and timing of systemwide crisis and restructuring. The parts shape the whole. The whole shapes the parts. But never equally so.

My second appeal is for distinct kind of holism. Following Arno Mayer (1981: x), I admit to being a "'lumper'… rather than an avid 'splitter'." I therefore ask (to use Mayer's words once more) for a "patient hearing" so that the study may be judged as a whole rather than in its discrete parts. The word that historians use for efforts such as these is "synthesis." But I am not certain that this is the best description for the study that you are reading. For all work involves synthesis. It may be that the phrase is a sort of polite euphemism for distinguishing between the work of "real history" (the monograph derived primarily from original sources), and other sorts of historical writing that tend to range across more expansive terrains of time and space, and therefore do not pivot on original documents in the same fashion. (In my undergraduate days I was reminded, more than once, that Wallerstein was not a "real historian.)

Within world environmental history, there is no shortage of books that are essentially synthetic overviews of the survey variety. John F. Richards' *The Unending Frontier*

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[43] With thanks to Locher: "One should not confuse totality with completeness. The whole is more than the assembled parts, but it is surely also less" (1954: 15 quoted in Wallerstein, 1974: 8).

(2003), which covers some of the same ground as this study, is an important example. For Richards does indeed appear to be collecting and synthesizing the extant literatures on everything from Tokugawa Japan to colonial Brazil, and producing a series of case studies that effectively stand as discrete and independent cases, to use the language of comparative social science. Richards is interested in identifying patterns organized within tidily drawn (and alas, relentless abstract!) descriptive meta-categories: commercialization, state-building, population, biological exchanges, and so forth. But the cases do not appear as moments in the construction of an emergent totality so much as verifications of the quantitative movements of meta-categories. It is an approach quite similar to that of systems theory.

An alternative approach is on offer from J.R. McNeill (2000) and Mike Davis (2001). Both take, in a broadly historical sense, the world-system as their object of analysis – not the world-system of stationary concepts, but the world-system of emergence, development, and crisis (or possible crises). For all their differences, McNeill in his (distinctly non-Marxist) world environmental history of the twentieth century and Davis, in his (emphatically Marxist) global political ecology of the "origins of the third world" in the late nineteenth century, represent a line of march that treats the world-system as deserving a historical specialization of the first order. These landmark contributions to the vast but weak development of world environmental history share a common approach that promotes the (so-called) "secondary literature" to the status of first-class citizen. It is not that primary sources are forsaken. Quite the contrary. But it is quite clear that world-historical studies necessarily proceed from a documentary repertoire distinct from than that of the conventional historical monograph.

Sources of Evidence and World-Historical Method

The relational approach not only shapes the substantive methodological orientation of this study. It also reworks the approach to evidence. There is, of course, the age-old distinction between "primary" and "secondary" sources. The presumption that inheres in this venerable distinction is that primary sources are best and indeed always preferable regardless of the geographical scale of investigation. I am not so certain that the distinction is a particularly helpful one for the task at hand. What I would like to do instead is highlight the four principal forms of evidence that I've mobilized in this study: primary sources, regional historical studies, world-historical studies, and quantitative evidence derived from all of the above. None of these, on its own, offers a critical mass of evidence that would make the argument persuasive. Together, however, they make for a brief not easily dismissed.

Of these four categories of evidence, our first encompasses the primary sources. Primary materials are of course desirable and should always be engaged to the extent that it is feasible. They are indispensable to world-historical investigation. These figure more or less prominently according to some mixture of relevance, accessibility, and my own language-skills. My intent has not been to "humanize" the narrative, in the tradition of social and cultural history – although this is sorely needed in a narrative that follows the de-humanizing and de-naturalizing thrust of capitalist advance – but rather to bear witness to the remaking of worlds, Old and New, in the early modern era. It is an approach that draws perhaps less heavily on my world-historical forebears in this respect, and perhaps more to an older tradition of economic history, one that took primary sources as seriously as it did numbers.[44]

It is a difficult balance to strike, and I shall have quite a lot of say about the issue of numbers very soon. In a study whose geographical range extends from the eastern shores of the Baltic to the Newfoundland fisheries, from London and Amsterdam to Bahia, Potosí, and Luanda, it is impossible to rely primarily on primary sources. I have, as a consequence, ranged far and wide in a poaching expedition – sometimes systematically, sometimes haphazardly – transgressing disciplinary boundaries, and specializations within those academic formations, with little concern for convention. Such expeditions do not, of course, relieve one of the responsibility to learn the topography of specialized fields – it would be difficult, for instance, to study colonial Brazil and the Portuguese Atlantic without reference to Prado, jr., Schwartz, Boxer, and Mauro. Neither do such expeditions render the engagement with primary materials unnecessary – for example it would be unwise to ignore Antonil's study of sugar plantations in late seventeenth century Brazil (1711). And yet, for a world-historical study of this sort, it seems unwise (and indeed counter-productive) to privilege, *a priori*, one type of source over another. In both cases, the exercise is one that pivots on the creative appropriation of the regional narratives on offer, along with the evidentiary bases of these narratives.

If our second type of evidence is found largely in the work of regional historians, we can locate another in the work of world historians. Frequently characterized by historians (and others favoring a more idiographic approach) as scholars in search of a flattened world, world-historical scholars often find key movements of recurrence, evolution, and unevenness across time and space that are visible only from the point of view of the world-scale. (Just as certain features of the city, invisible to an observer at street level, become visible to a person looking out from a perch on high up in the building overhead.) It is world history's version of the duality of light as particle and wave. Leaving aside for the moment that world-historical investigation is neither determined by, nor reducible to, the world-*scale* – this is arguably the commonest geographical misreading of the perspective – the crucial point is that world-scale patterns matter for peasants, slaves, and mineworkers no less than they do for empires and the accumulators of capital. Yes, world-scale patterns are made by actors operating at multiple scales (yes, the local affects and effects the global), but in a regime predicated on the endless accumulation of capital the world-scale is in many ways primary. (Many, but not all.) Put differently, regional- and world-scale agents both contribute to the forging and subsequent unraveling of the successive structures the make these patterns, although not all in equal measure and not under conditions of their own choosing.

So what I have done is to take seriously (and put to work) Stuart Schwartz's pregnant observation that colonial trajectories (in his case Brazil) "were determined not only in the court at Lisbon or in the countinghouses of Amsterdam and London but also in the forests and canefields of America" (1985: 72). Schwartz's point, if I have understood him correctly, is that history looks different; we see *different movements and relations*, when we bring into focus the Brazilian *safra* or the Amsterdam Bourse. It is emphatically not that one is more important than the other, but rather that both are indispensable moments

[44] Richard B. Sheridan's work on Caribbean sugar is most proximate to the themes of the book (1969, 1970, 1972, 1973). On a broader canvass, I am thinking of the work of Nef (1932, 1964), Tawney (1960/1926), and Hobsbawm (1954a, 1954b), among others.

of an organic whole. My approach in this study is to shift from the canefields, the mines, the villages, to the ebbs and flows of world accumulation and world hegemonies not once or twice – a chapter here, a section there – but rather to adjust the scalar optic repeatedly throughout the narrative. An environmental history of silver mining without reference to the world price of silver (or of its importance to commodity production and exchange broadly) strikes me as unduly partial. So does an economic history of Dutch capitalism that abstracts from the environmental histories of North Sea fisheries, Norwegian timber, or Polish cereals. While there are always points of emphasis for the purpose at hand – in this case, the environmental history of the rise of capitalism as an organic whole – there ought to be no structured bias that characterizes either local transformations as inevitable expressions of forces "from above," a narrative approach whose mirror image we find in regional studies bent on reducing imperial- and world-scale transformations to the status of "context."

The task in this study is a particularly delicate one, precisely because we are dealing with an era in which the patterns of historical capitalism were only beginning to take shape. There is no abstracted model of accumulation in the era of large-scale industry to orient us, which is at once unnerving and liberating. It allows, in my view, for a much more historical conception of capitalism, not merely for the early modern era but for successive phases of capitalist development. The extant models of early modern capitalism – above all the diversity of interpretations that unfolds under the banner of "merchant capitalism" – have been eschewed, although not ignored. By invoking the signifier "capitalism," I am referring to the progressive (albeit discontinuous) generalization of the commodity relation, to the geographically extending web and ever-deepening grip of commodity production and exchange. I am referring to the historical reality of the "capitalist system" *becoming more capitalist over time as a condition of its very existence*. Nevertheless, laying all such caveats and cautions aside, there appears, even at the early juncture of the sixteenth century, a number of world-historical tendencies that materialized repeatedly (if unevenly) in successive regions across the space (and spaces) of early capitalism. These would include: 1) the rapid geographical extension of town-country relations, creating ruptures in nutrient cycling at multiple scales (Foster's "metabolic rift"); 2) the deployment of state power to enclose commons, or to create new kinds of commons in the service of accumulation (as we shall see in the case of Andean "open fields" in Chapter Three); 3) the rise and institutionalization of world financial and commodity markets whose consistency and spatial breadth outstripped anything seen before (Antwerp, then Amsterdam); 4) the emergence of *overseas* empires, not merely as competitive entities but revealing a systemic pattern towards the enlargement of scale in successive eras, empires whose successes and failures pivoted on commodity production and exchange; 5) the recurrence of "commodity frontiers" on an ever-extended scale, organized around silver mining, sugar planting, cereals, and forest products, encompassing and incorporating regions stretching from Poland to Brazil.

A final form of evidence is quantitative, and this merits some discussion.[45] We are, and there is no getting around this, dealing with an era in which all manner of

[45] There is a distinction here to be made, between the use of quantitative evidence, and the "quantitative method" as usually understood within the social sciences. The latter codes a great many cases to derive patterned interactions from which to infer causality (Ragin, 1994). My approach in contrast falls within a

quantitative data must be understood as speculative. This is not to say that these data are fiction. But for all the sturdy appearance conveyed by the numbers, it strikes me as unwise to give them too much credit. By the same token, I think is also unwise to give them too little. (As many environmental historians have done.) We are dealing, in a manner of speaking, with what economic historians like to call "stylized facts."

From very beginning of this project, my intent was to interweave – and attain a more effective synthesis between – the concerns of economic history and environmental history. (Both broadly conceived.) Economic history proper has become an exceedingly narrow enterprise since the 1970s, one tightly focused on price movements to the exclusion of pretty much everything else – Patrick O'Brien and a few holdouts at the London School of Economics excepted[46] (also de Vries and van der Woude, 1997). This does not mean, however, that price history can be ignored. In capitalism we are dealing with a social system that seeks to attach a price to everything. And we are dealing with an environmental and social history of that system that flows in great measure from the struggles over commodification, that is to say the struggles over the power of the market to colonize every nook and cranny of everyday life. And so I would say that attention to price movements is quite imperative, even if they are not the straightforward expression of environmental changes. One writes an environmental history (at any scale) without reference to prices at one's peril. I have therefore sought to connect world and regional price movements with environmental transformation.

But this is a half-measure at best if what we seek is a new synthesis of environmental history and economic history, of historical capitalism as political ecology and political economy. Environmental history, for its part, has occasionally ventured into the terrain of quantitative history, although rarely has it taken seriously the concerns of a historically-informed political economy. Some of the contributions to the landmark compendium *The Earth as Transformed by Human Action* (Turner, et al., 1990) – papers by the Richards (1990) along with the historical geographer Michael Williams (1990) deserve special note – sought to quantify the dimensions of environmental transformation effected by crucial commodity sectors, such as the expansion of agriculture and deforestation. If economic history has been focused on prices, environmental history has understandably focused on volume and area.

The quantitative approach offers the illusion of solidity but is, in the final analysis, neither more nor less interpretative than analyses that draw on qualitative sources. All world economic history is based on guesswork; for the early modern world-economy this is especially true. And yet it can be an exceedingly useful form of guesswork. Especially for the world environmental historian interested the geographies of environmental transformations in the centuries between the first Voyages of Discovery and the Steam Engine. The quantitative reckonings we do have manifest, in the main, as scarcely more than back-of-the-envelope estimates – for instance Chaunu's observations that the world-economy more than doubled in size, from three to seven million square kilometers between 1535 and 1680 (1959: 148). It is arguable that to attempt more than this is an act of extraordinary foolishness or profound chutzpah. I have pushed this envelope because

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very broadly defined comparative methodological perspective. I use quantitative evidence in order to make arguments about the patterned continuities in a handful of cases, over time and across large space.

[46] See O'Brien (1982, 1983), and above all O'Brien and Keyder (1978). The LSE's Global Economic History Network an important institutional expression of this modestly heterodox tradition with economics.

the exercise can provide some clues in tracking down the origins of today's ecological crisis. The numbers do not tell the whole story, but it is impossible to tell the whole story with them.

I arrived late to this realization. Ragin (1987) once offered the methodological dictum that quantitative analyses were most fruitful once the meta-questions of the research problem had been, if not resolved, at least thoroughly explored. Up to this point (a matter of interpretation, naturally), studies of a primarily qualitative nature would tend to be most fruitful. My own experience in the slow work of excavating the environmental history of the transition to capitalism tended to support this line of thought. At a certain point, however, it became apparent that the scale and speed of environmental transformation after 1450 could neither be comprehended, nor communicated, without some measure of quantitative exercise. Even a rudimentary approach, if combined with multiple evidentiary sources and a world-historical method that viewed nature and society in the modern world as a differentiated unity, would represent a productive step forward in the study of world environmental history.

To cut to the chase, the quantitative guesswork[47] in what follows conveyed a remarkable picture of successive regional transformations, in sugar and silver mining above all. Initially, I was reassured. Then, I was surprised. For much of the twentieth century, there has been a debate over the environmental "footprint" of early modern European economies.[48] (Indeed, there was some measure of environmental concern even in the seventeenth century, most famously associated, in England, with Evelyn's work [1664], and in Saxony, with Lehmann's [1699].) I found, on the one the hand, little support for the cornucopian interpretation, that problems of resource supply (including fuel supply) were at best a nuisance. On the other hand, even when one habitually introduced highly conservative estimates (for example, favoring fuel efficiency and nature's bounty), the quantitative estimates outstripped by a considerable margin the guesswork that I'd evolved out of reading the primary and secondary materials. That is to say, most of the guesswork on offer by the social and environmental historians of the regions in question dramatically underestimated the scale and speed of environmental change. The extent and rapidity of environmental transformation in successive commodity frontier zones, sugar especially, was simply beyond anything I had expected. To cite but one example, which I investigate in some detail in Chapter Six, the sugar-driven deforestation of Brazil's Atlantic Rainforest in the seventeenth century exceeded Warren Dean's oft-criticized estimates by 500-1,000 *percent*. What emerged from the quantitative analysis, in the case of northeastern Brazil, was the sylvan equivalent of the New World's demographic collapse after 1492.

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[47] I am reluctant to call it more than this, but I have found qualitative guesswork neither more nor less useful.

[48] In the twentieth century, Nef's work (1932-34) ignited the cycle of debate on the question that continues to this day. The minimalist position on early modern capitalism's ecological footprint has been ably expressed, in successive cycles, by Flinn (1958, 1959) and above all Hammersley (1973), and by Allen (2003) and Miller (2001). The maximalists include, most prominently, Sieferle (2001) and Malanima (2006). Michael Williams, in his groundbreaking *Deforesting the Earth* (2003) has moved towards a middle position, along with Paul Warde's important contributions, which argues that local crises existed, but without significant implications for accumulation of capital – it is position that tends to support the minimalists theoretically, but (as we shall see) the maximalists empirically.

I have called the economic historians' emphasis on price movement a half-measure. Price data tell us something about the political economy of capitalism but little of its political ecology. For this, price movements must be interwoven with quantitative data on land transformation, and the eco-material demands of basic sectors such as sugar, iron, and shipbuilding. How might we begin to weave the two moments together? At a minimum, we would want to include: 1) estimates on the productivity of the land, for the full range of "primary" production, including, centrally, forest productivity and agricultural yields; 2) estimates on the bulk/volume requirements of various processing activities, such as ironmaking, shipbuilding, silver smelting, or sugar boiling; and 3) estimates on profitability for a diversity of economic actors, and price movements at multiple scales. Much of what I have done in this study draws on other scholars' estimates of this last, and seeks wherever necessary and possible to construct reliable estimates of the processes implicated in the first two categories. The intent has been, to the extent possible, to treat the estimates as not only guesswork, but also provisionally stabilized at best – an act of "freezing" history in order to account for the movement of the trends over time.

What does this approach look like? Let's take one of early capitalism's strategic economic sectors, ironmaking. Here we begin with a series of guesstimates, answers to questions such as: How much iron was produced in specific region? What kind of iron? How much charcoal did it take to produce a ton of highly malleable (and therefore directly useful) bar iron? How much wood did it take to produce a ton of charcoal? How much wood could be extracted from a given hectare of forest? How did this change according to forest type? How did this change according to timber use, say firewood relative to construction timber? To what extent do the answers to the foregoing allow us to extrapolate relative forest exhaustion over time? How much of a difference did primitive forms of forest management – coppicing and so forth – make? And as forests receded, which they did nearly everywhere across the pan-Atlantic world-economy in the early modern era, what were the possibilities for profitably extracting more fuel from increasingly distant forests, given the low ratio of bulk to price for wood and the fragility of a fuel such as charcoal? How did all these estimates change over time in a specific region? And what were the ramifications for the geography of the system as a whole?

A bewildering array of questions to be sure! (And this a far from exhaustive collection.) The answers emerge slowly. Two issues emerge right away. First, even if we have reasonably valid estimates for all of these, the best case scenario that emerges from the answers to these questions is a *geometrical* representation of environmental history. It is historical geometry, not historical geography. It says very little on its own. If, however, we proceed from the assumption that such geometrical calculations can serve to discipline the narrative, even as the narrative disciplines the geometry, then we have a situation very close to that of the historian working from the archives. For the archival sources speak for themselves little more (well, *perhaps a little more*) than such geometrical calculations, but in the final analysis the historian enters into a dialectical conversation of give and take with the sources themselves.

As near as I can tell, however, there has been little conversation with the diversity of relevant sources in this sphere. That is to say, students of early capitalism's ecological footprint have tended to rely on an exceedingly small sample of sources for their quantitative estimates of environmental transformation. (Seldom more than one or two.)

Let us take perhaps the most famous argument against Nef's classic argument that progressive deforestation lay behind England's shift to coal as the primary energy source in the seventeenth and eighteenth centuries. Hammersley, in a 1973 *Economic History Review* essay still central to the debate today (see Williams, 2003: 189-190, 292; Clark and Jacks, 2007), deploys at the center of his analysis an estimate of forest productivity for England that is, *at a minimum*, 100 percent too high. I will get into the details of this in Chapter Two. For the moment, however, the issue I would like to highlight is the way in which Hammersley arrived at his estimate – which incidentally is higher than that worldwide average productivity for managed tree plantations *today* (Brown, 2001). Hammersley constructs his signal contribution to the debate around a single source (Taylor, 1945), which is taken as self-evidently valid. It is approach that no historian would tolerate when it comes to engagement with archival sources. And yet it remains common among students of early capitalism's ecological footprint (e.g. Allen, 2003; G. Clark, 2003; Sieferle, 2001).

Cracks in this approach became increasingly apparent with the appearance of Michael Williams' *Deforesting the Earth*. Given the historical and geographical breadth of the study – deforestation in human history on a world scale – he necessarily drew upon multiple sources to construct his qualitatively-embedded estimates of world deforestation in successive regions and eras. Given the sheer breadth of his study, however, Williams was unable to move beyond the basic identification (and towards explanation) of key nature-society antagonisms in the early modern era. What I have done is to take seriously an elementary proposition. Namely, it always preferable to validate the evidence by cross-checking against available estimates. It is a methodological dictum as profoundly banal as it is frequently disregarded in ecohistorical studies. I have collected the various estimates for the questions posed above (and many more beyond this, as you will see), and explain how these overlap and differ with quantitative reckonings (such as Hammersley's) that have won benchmark status in the literature. In nearly every case, I have collected a minimum of two sources for every major estimate (often more than three), backtracking to the original sources wherever feasible. Primary sources are especially useful, although they did not *necessarily* prove more reliable than those on offer from historians, especially students of technology. When it came to forest productivity, figures that inform one of the central quantitative claims of this book, I've leaned on the discussions of forest scientists no less than forest historians. While I've opted to refrain from extensive technical discussions in the chapters that follow – although there may still be too much for some readers – I have engaged and cited the range of estimates, and the reasons underlying my preferences, in the footnotes. The reader will find the narrative of world environmental history in the principal text complemented by technical and theoretical discussions in the footnotes. The sources are not self-evident, but rather must be engaged if the overall architecture is to sustain its structural integrity.

I have said much here about method as dialectics, and method as data collection. But neither says much about modernity without a method that bounds large-scale meta-processes to the making of the modern world. The decisive methodological contribution of historical sociology to world-historical inquiry is the straightforward idea that there are "angles of vision" through which the analyst can discern and explain key moments of modern world history. The angles of vision are multiple. For Perry Anderson, this was

Absolutism (1974b); for Immanuel Wallerstein, the dialectics of class, state, and the geographies of world accumulation (1974); for Skocpol, social revolutions (1979); for Arrighi, the geopolitics of accumulation (1994); for Tilly, warmaking (1990). In this study, it is the dialectic of world accumulation and environmental transformation. It is an approach that inverts the traditional relationship between relational process and the empirical phenomena under investigation. Rather than begin with a region, say Brazil or Bohemia, I began with process and selected cases accordingly. But distinct from the formal comparison favored by Tilly and Skocpol, the world-historical antagonisms inscribed capitalism's nature-society dialectic do not unfold *within* the regions (*qua* independent units) so much as they create the regional formations under investigation. The units of analysis are incorporated into the theoretical premises of the study itself (McMichael, 1990; Hopkins, 1982). The world-historical vision, then, turns on the identification of crucial shifts in decisive meta-processes of the modern world-system.[49] Method and theory are, then, dialectically bound in the closest possible fashion through: 1) the task of bounding; 2) explaining simultaneously the significance of the processes being bounded; and 3) discerning and explaining the patterns of recurrence and evolution within those bounded processes (including those self-negating contradictions) over long historical time and large space.

What I have done that differs from the orientation of world environmental history, as it presently stands in any event, is to organize an environmental history of the modern world through an argument that modernity's dynamism rests on the endless accumulation of capital and the long struggle to remove obstacles to accumulation for accumulation's sake. This involves pinpointing those economic sectors strategic to the accumulation of capital, and exploring ruptures and continuities with medieval patterns of environmental transformation.

To these ruptures and continuities we can now turn.

[49] This is not the same as explaining everything, but rather explaining those grand movements and transition to which everything (or rather, nearly everything) relates. To explain the origins of photosynthesis is not to explain everything in the history of life on Planet Earth; but it would be exceedingly difficult to tell such a story without recourse to this pivotal moment.

CHAPTER ONE
The Long Fourteenth Century
Ecology & the Unmaking of Medieval Europe, 1300-1450

The transition to capitalism in early modern Europe is amongst the most widely-studied phenomena in historical studies. Its environmental history is not. The problem is not so much that environmental factors have been ignored. The demographic interpretation of medieval history widely acknowledged that ecological tensions were fundamental to feudal agriculture.[50] But is safe to say that environmental transformation – induced by human social relations as well as climatic and other changes – has been exogenous to interpretations across the spectrum of debate. There have been exceptions. Immanuel Wallerstein probably went farthest, crafting his account of the fourteenth century crisis around the notion of a "socio-physical conjuncture" (1974: 35).[51] In Wallerstein's hands, the emergent relations of capital and class in the long sixteenth century shaped, and in turn were shaped by, transformations of the earth. More commonly, the environmental history of large-scale social change has been subsumed under various environmental determinist approaches (Jones, 1987; Diamond, 1997; Landes, 1998), with some combination of climate and topography offered as major factors in the "rise of the West."

An alternative approach, one that develops and extends the implications of Wallerstein's notion of a socio-physical conjuncture, offers a fresh vantage point from which to explain why and how feudalism gave way to capitalism. Such a transition was a most unusual turn of events in human history. (Something all-too-easy to forget in an era of market triumphalism.) The transition to capitalism – comprising those movements that sought to remove barriers to the endless accumulation of capital – had been attempted many times, only to end in failure. (Marx once wondered why these tendencies had not gone further in the Roman Empire.) It bears repeating that a successful transition to capitalism was not inscribed in feudalism's socio-ecological contradictions. It was not a necessary outcome. While medieval Europe contained its share of proto-capitalist elements, this was hardly unusual. Indeed, "'proto-capitalism' was so widespread one might consider it to be a constitutive element of all the redistributive/tributary [systems] the world has known" (Wallerstein, 1992: 613). As the subsequent history of capitalism bears out, agrarian ruling classes in such tributary formations had good reason to fear the coming of capitalism. In such a system, the "ceaseless accumulation of capital inevitably permits new persons to challenge existing power, to become part of it, and does so ceaselessly" (Wallerstein, 1992: 613). Nevertheless, towards the end of the long fourteenth century (c. 1300-1450) and the beginning of the long sixteenth century (c. 1450-1640), Europe's ruling strata adopted strategies that favored a capitalist rather than

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[50] Postan (1972) is the most famous representative of this interpretation.

[51] "[F]actors of the physical environment... should be assessed and given their due weight... [I]ntruding the variables of the physical environment does not undo our previous [social] analysis. It enriches it by adding a further element to help explain a historical conjuncture so consequential in the future history of the world" (Wallerstein, 1974: 33, 36). My consideration of Wallerstein's world-historical political ecology across the successive volume of *The Modern World-System* (1974, 1980, 1989) may be found in several essays (Moore, 2000a, 2003a, 2004).

tributary solution to the crisis of feudalism – even as some key actors vigorously pursued the latter. (Most famously, Charles V in the sixteenth century.[52])

If there was no inexorable telos driving the transition from feudalism to capitalism, it impossible to explain the transition in terms of a unifying logic. The crisis of feudalism was by nature chaotic; the order that would emerge from it was fundamentally unknowable in advance. Such is the nature of transitions from one mode of production to the next.

Three tasks immediately come to the fore. First, what were the socio-physical vectors of crisis within the feudal mode of production? The answer to this question clarifies the conjuncture through which the medieval order unraveled during the long fourteenth century. Second, how did the many-sided crises of the fourteenth century render the restoration of the *status quo ante* impossible? Some observers now prefer to think of the early modern period as one of "recomposition" rather than transition,[53] but it is hard to square this notion with a whole series of socio-spatial ruptures that characterized the period after 1450. Of these, surely at the top of the list would be two. One is the failure of western Europe's ruling strata to reimpose serfdom. The second was the emergence of an alliance between states and the capitalists – in which the latter increasingly determined the rules of engagement, even when they did not get their way – and this alliance's really revolutionary turn towards *global* expansion, in which expansion strengthened the very forces and conditions that gave rise to it.

Our third task turns on the explanation of these forces and conditions. The failure to reimpose serfdom in western Europe might well have been resolved through an upward revision in the scale of surplus extraction. The lord-peasant relation might have given way to the state-peasant relation. And this did in fact occur (de Vries, 1976). But for all the similarities, the state-peasant relation did not come to occupy the strategic pivot of surplus production. This pivot would become the cash nexus, materialized through the continual (if discontinuous) movement towards the generalization of commodity production and exchange. How did the cash nexus win out? What did it have to do with interests pursued by states, seigneurs, and capitalists in the unusual conjuncture of the era of transition? And how were environmental transformations that issued from these interests – interests that were sometimes conflicting, sometimes complementing – implicated in a virtuous circle of cascading socio-ecological crises, crises that far from limiting capitalist development, would serve as a decisive spur to the broadening and deepening of the capitalist division of labor?

Put simply, in what follows I offer, first, an explanation of the socio-ecological contradictions that gave rise to the crisis of feudalism. Second, I pursue a historical-geographical explanation for the convergence of interests among Europe's leading strata — above all the states, the seigneurs, and the city-state capitalists — in favor of endless geographical expansion and the creation of a capitalist world-economy.

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[52] Wallerstein's account of this struggle for imperium represents one especially gifted account of this process, written from the standpoint of the "world-economy *in creation*" (1974: 165, emphasis added; 165-221 passim.)

[53] This is the argument John R. Hall sets forth in an important contribution to the debate (1999).

On the Nature of Transition: Reprise and Preview

There is a substantial environmental history literature that takes European expansion and the rise of capitalism (in some form) either as its starting point or key *problematique* (e.g. Arnold, 1996; Brockway, 1979; Dean, 1995; Foster, 1994; Merchant, 1980; Richards, 2003). In the main, the emphasis has been laid upon the *consequences* of the transition. Its underlying preconditions have remained conceptually, and often empirically, invisible. As a result the whole category of "transition" has been undertheorized in environmental history – in large-scale questions of capitalist, agricultural, and industrial revolutions as well as regional-scale transitions. This unfortunate state of affairs within environmental history contrasts sharply with the prevailing winds within world-historical studies.[54] In these latter, the Transition Question remains of central importance, although scarcely more than a whiff of environmental history can be detected. There is, then, something of a crucial divide between the two fields, one that mirrors (and dare I say reproduces?) the nature-society divide that is the hallmark of the modern gestalt (Merchant, 1980). Put simply, the world-historical perspective remains preoccupied with the origins of modernity but with little concern for its ecological moment, while environment historians have focused on modernity's ecological consequences but with little concern for their origin. There is fertile ground here for cross-fertilization, and it is on this territory that the present study stakes it claim.

While the agro-ecological contradictions of feudalism and capitalism both have been widely recognized, the ways in which the former gave way to the latter have not. Ecological conditions and relations have appeared as strangely pivotal, and yet curiously epiphenomenal, in accounts of the transition from medieval Europe to the modern world. On the one hand, nature-society relations have long figured prominently in explanations of Europe's late medieval crisis. The ecological moment perhaps loomed largest in explanations offered by demographic-oriented historians such as Postan, who saw a long-run tendency towards soil exhaustion (1972; Postan & Hatcher, 1985). In this scheme of things, landlords reproduced their social position by expanding rather than improving their estates, thereby limiting investment in a technological regime that might sustain rising productivity. At the same time, population expansion impelled the steady conversion of forest and pasture to arable, and thence to contraction of pasture and the animals who grazed upon it: these livestock constituting the major pillar of soil fertility in dry-farm cereal zones until well into the nineteenth century.

Postan had put his finger on an important problem, and Marxist historians of medieval Europe did not ignore this.[55] For Hilton, the political ecology of feudalism did

[54] Within a broadly conceived historical sociology, most recently see Lachmann's influential study (2000), in addition to key texts by Arrighi (1994, 1998), Brenner (1977, 1985a, 1985b, 2001), Frank (1967), Hilton, (1976), Wallerstein (1974), and Wolf (1982). Within economic history, de Vries (1976), Jones (1982), Landes (1998), and North and Thomas (1973) are key.

[55] Brenner's great critique of the demographic and commercialization interpretations of the transition indeed began with an *acceptance* of Postan's demographic crisis model of the medieval economy (1985a: 31-46). It is possible that this has been obscured to some extent by Brenner's reluctance to grant *any* dialectical-feedback movement from population to capitalist development (1985a). Brenner is entirely correct in arguing for the *primacy* of class struggle in capitalist development. But this does not mean that demographic patterns – socially produced to be sure – have *no* causal significance. Such a line of reasoning is, to say the least, undialectical. Worse still, as Bois cogently argues, it also cedes the ecological-material

indeed drive peasant agriculture towards exhaustion, but the chief contradiction turned on the relation between class and ecology. Declining productivity in the waning decades of the thirteenth century "was not simply the result of increasing population… [but] *also the result of the pressure of landowners for rent*," whose rising intensity "removed all cash surpluses and prevented even the most elementary investment" (Hilton, 1985: 128; also 1973, 1976b). It was this fundamental class antagonism that found expression in the historical geography of medieval demographic expansion and technological stagnation. Not, as the Postan thesis would have it, the other way around.

If ecological factors have loomed large in explanations of medieval crisis, not so when it comes to explaining the rise of capitalism. Only rarely has the socio-ecological moment of Europe's medieval crisis been linked to an ecologically-informed accounting of the rise of capitalism. When I began to investigate the Transition Debate with an eye towards environmental transformation, Wallerstein's Braudelien-Marxist accounting of nature and society struck me as quite distinctive (1974).[56] Here was an argument that feudalism's socio-ecological crises empowered western Europe's peasantry to the point where *globalizing* territorial expansion was for the first time an epoch-making accumulation strategy. This seemed to me a promising point of departure indeed! What Wallerstein's thesis opened up, it seemed to me, was an opportunity to consider how Europe's territorial and capitalist agencies reshaped "world ecology" in ways that would secure a fragile capitalist system against unfriendly winds, and then sustain accumulation over the *longue durée*. Such an angle of vision would allow scholars to articulate capitalism's globalizing mode of environmental transformation with feudalism's socio-ecological antagonisms as a means of explaining the transition.

For over a quarter-century, Wallerstein's suggestive formulation of the problem had little impact (Moore, 2000a).[57] Ecological insights within the world-historical perspective bubbled up from time to time (e.g. Bunker, 1984, 1985), but these had little purchase on the tradition's basic conceptual repertoire. World-historical insights made their way into environmental history, but again, there was little effort to think through the longer-run and large-scale patterns of modern environmental history. On this matter, there seemed to be little difference between environmental historians practicing their craft within the social sciences or history. Ponting (1991), for instance, offers a searing ecohistorical indictment of industrialization after 1800. The possibility of an earlier epochal shift is suggested empirically but elided theoretically. Foster's survey, an appreciative Marxist response to Ponting, neither evades nor addresses the question of ecohistorical transition. In this scheme of things, the rise of capitalism in the sixteenth century "irretrievable

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terrain to the neo-Malthusians (1978). The problem is not the identification of demographic patterns as causally significant but rather than the neo-Malthusians' neglect of class relations and undue primacy attached to population as an independent variable. Seccombe is quite good on this, emphasizing an "active feedback" moment between the mode of production as a whole and its demographic patterns, even as we recognize the primacy of the whole relative to its constituent parts (1983).

[56] See my initial reckoning in Moore, 2000a. There were also important hints on the nature of the important in Marvin Harris's provocative *Cannibals and Kings* (1979: 271-284).

[57] And not world environmental historians alone. Even within the world-historical perspective, the consensus held that Wallerstein's appropriation of Braudel abstracted the ecological moment. This was, as I've demonstrated, a misreading (Moore, 2000a, 2003b).

Many environmental historians have ignored the issue altogether and treated capitalism as arising rather unproblematically from medieval Europe (e.g. Hughes, 2001; Worster, 1990).

altered… the traditional balance between humanity and nature" (1994: 40). True enough. But the ways in which feudalism's specific crystallization of this "traditional balance" may have favored a capitalist rather than "tributary" solution to the late medieval crisis is nowhere to be seen.

For their part, the historians have done much the same. In her pioneering *The Death of Nature* (1980), for example, Merchant recognizes feudalism's socio-ecological antagonisms but is reluctant to link these in explanatory fashion to the rise of capitalism. Merchant draws effectively on Hilton among others to present a class-based and environmentally-informed explanation of feudal crisis. When it comes to the rise of capitalism, however, she changes horses midstream. Capitalism is chalked up to the commercializing impulse. (An increasingly shaky proposition in the wake of recent research indicating widespread and effective markets in contemporary East Asia [Pomeranz, 2000].) Most recently Richards (2003), in his magisterial environmental history of the early modern world, couples Merchant's commercialization model with a state-building one.[58] This may or may not be a good idea in principle, but in neither instance does he grapple with the socio-ecological crises that preceded this early modern efflorescence of commercial expansion and state (re)formation. (Nor does state formation or commercialization appear as anything other than narrowly social processes, their respective inner dialectics of nature and society ignored in favor of an outer, mechanical dialectic.) At all turns, the *question* of transition has been erased.

This lacuna is what *Ecology and the Rise of Capitalism* aims to fill. In so doing, I have decided against the conventional treatment of the "*rise* of capitalism" in which the historical-geographical specificities of feudalism's ecohistorical crisis are obscured or elided altogether. Rather, my analysis situates the emergence of a capitalist world-economy on the terrain of feudalism's systemwide crisis. The latter enabled the former in crucial respects, even as feudalism's "redeployed and recharged" state machineries threatened to extinguish this "vast but weak" world-economy in favor of imperium (Anderson, 1974b: 18; Braudel, 1961: 260; Wallerstein, 1974: chs. 3, 5). From this vantage point, the *rise* of capitalism may be more adequately explained through an accounting of the *transition* from feudalism to capitalism.[59]

Feudalism, What's In a Name?[60]

"Feudalism" means many things to many people. One camp limits the concept to "the hierarchical relationship between a lord and his vassals" (Lefebvre, 1976: 122). In this tradition, "[h]istory was not just written *from* the perspective of the top but was also limited to studies *of* the top" (Kaye, 1984: 73; e.g. Ganshof, 1964). The critique of this

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[58] Richards also deploys an unformulated but persistent emphasis on population dynamics.

[59] This draws on Marx's observation of the "*formation process* of capital ["capital in general"]"… [as] the *dissolution process*, the *parting product* of the social mode of production preceding it" (1971: 491). The era of primitive accumulation encompasses both the "pre-history" of capital and its "point of departure" (1977a: 873). On the one hand, the transition from feudalism to capitalism occupies one lengthy epoch (ca. 1300-1640). On the other, "the process of capital becoming capital or its development *before* the capitalist production process exists, and its realisation in the capitalist process of production itself *belong to two historically different periods*" (1971: 491, second emphasis added).

[60] With thanks to Shakespeare, and to Hilton (1976c).

narrow conception of feudalism was spearheaded by, among others, Rodney Hilton (1949, 1973, 1985) and Marc Bloch (1961). The historians began with the recognition that "feudal Europe was not all feudalized in the same degree or according to the same rhythm and, above all, that it was nowhere feudalized completely" (Bloch, 1961, II: 445). At the same time, they deployed a broader conception of feudalism that sought "to describe a whole social order whose principal feature was the domination of the rest of society, mainly peasants, by a military landowning aristocracy" (Hilton, 1976: 30).[61]

It is this broader conception of feudalism that most strongly influenced the world-historical perspective since the 1970s (esp. Wallerstein, 1974). The major exception to this generalization is Giovanni Arrighi (1994, 1998), who in key respects returns to the earlier, narrower conception of feudalism. In Arrighi's scheme of things, feudalism is limited to rural social relations in medieval Europe. While feudal relations are

> no doubt very relevant to an understanding of English, French, Polish, Swedish and many other 'national' histories of the European world[,] [t]hey nonetheless are largely if not entirely irrelevant to an understanding of the origins of world capitalism for the simple reason that world capitalism did not originate within the economic activities and social relations [of territorial Europe]. Rather, [capitalism] originated in the *interstices* [the city-states] that connected those territorial organizations to one another (1998: 126).

Thus, following Postan's (1972: 239) famous statement that "[m]edieval towns were… non-feudal islands in the feudal seas," Arrighi narrows the conception of feudalism to exclude urban centers in order to designate them prime movers in the transition to capitalism. In so doing, Arrighi runs the risk of tautological reasoning: the origins of capitalism are explained in terms of capitalist city-states (see also Mielants, 2000).

Tautology aside, this line of argument tends to reproduce a sterile dualism, pitting the capitalist city against the feudal natural economy. But if the broader conception of feudalism is deployed, city and countryside, market and production, are viewed not in isolation but rather dialectically. From this perspective, production and exchange are "points of departure" for the investigation of large-scale "social economies" (Tomich, 1997: 299). From this standpoint,

> production and exchange are no longer conceived as discrete entities divorced from their broader contexts, separated from and opposed to each other as external objects; nor are they treated as identical. Rather, production and exchange are understood as relations that presuppose, condition, and are formative of one another as distinct parts of a whole. If we conceive of the social economy in this way, the relevant unit of analysis is defined by the extent of the interrelated processes of

[61] We can certainly identify a number of regions, such as the Low Countries, where the peasantry enjoyed relative freedom from seigneurial power (de Vries, 1973; de Vries and van der Woude, 1997). Nevertheless, even these peasantries were embedded in a broader system of power in which tributary relations predominated over enclaves of both proto-capitalism and peasant natural economy.

> production, distribution, exchange, and consumption (Tomich, 1997: 300; also Merrington, 1976; Marx, 1973: 83-100).[62]

Feudalism's historical geography was shaped decisively by the agrarian class relations that enveloped the mass of the population. As Hilton argues persuasively, the "struggle for rent" was the "'prime mover' in feudal society" (1976b: 115). The struggle between landlords and peasants for shares of the agricultural surplus tended to generate modest (but always constrained rather than ceaseless) pressures for increased productivity and simple commodity production. The expansion of

> medieval market centres and towns from the tenth or eleventh century were based fundamentally on the expansion of simple commodity production. The spectacular developments in international trade, the industrialisation of Flanders…, the growth of big commercial centers like Venice… are chronologically secondary to the development of the forces of production in agriculture, stimulated in the process of the struggle for feudal rent (Hilton, 1976b: 116; also Lewis, 1958).

From this standpoint, we may now investigate feudalism's socio-ecological crisis tendencies in some depth.

Expansion and Crisis: Feudalism's Socio-Ecological Contradictions

Our story begins with the golden age of European feudalism. Between the eleventh and fourteenth centuries, medieval Europe experienced rapid population growth, leading to new settlement throughout Central and Eastern Europe. Successful military campaigns – which became known as Crusades – were waged against non-Christians in the Baltic, Iberia, and Palestine. Cities grew. There was significant growth of manufacturing and cash-crop agriculture, part and parcel of a generalized wave of commercial expansion throughout Afro-Eurasia. The states consolidated their power against feudal lords.[63]

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[62] This approach seems consonant with the spirit (and often the letter) of Marx and Engel's (1971, 1979; Marx, 1973) broad conception of feudalism. Marx and Engels emphasize the system's historically- and geographically-specific class relations and its town-country division of labor, which determined specific forms of wealth production and accumulation. Some degree of confusion typically arises over the term "mode of production" (e.g. Chase-Dunn and Hall, 1997; Mielants, 2000), which Marx used in at least three different ways: 1) to refer to "the actual methods and techniques used in the production of a particular kind of use value"; 2) to refer to "the characteristic form of the labor process under the class relations of capitalism," whereby the capital-labor relation constitutes "an abstract representation of a reasonably narrowly defined set of relationships"; and 3) to refer, "holistically and for comparative purposes… to the whole gamut of production, exchange, distribution and consumption relations as well as to the institutional, juridical and administrative arrangements, political organization and state apparatus, ideology and characteristic forms of social (class) reproduction. This all-embracing but highly abstract concept is in some ways the most interesting, but it also creates the greatest difficulties" (Harvey, 1999: 25-26). It is this third meaning of the concept mode of production that I deploy in comparing capitalism and feudalism.

[63] The language of "states" must be used very carefully here. I am sympathetic to Strayer's (1970) line of argument, which dates the origins of the modern state to 1100. But this approach is most useful as a heuristic guide, not a statement of historical-geographical fact. Prior to the twelfth century, "parcellized sovereignty" (Anderson, 1974b: 15) held sway to such an extent that "by the year 1000 it would have been

Social and technological innovations — especially in sea transport, financial mechanisms, and business organization — encouraged new divisions of labor between previously distant regions.

But sometime around 1300, things started to go wrong.[64] Terribly wrong. Seigneurial revenues began to contract. Peasants started to revolt. Famine proliferated. And famines paved the way for even more deadly epidemics. The inroads made by the states against the landlords were reversed. Merchants and financiers in the city-states began to lose money. And the states went to war. Feudalism, as a social system no less than a system of production, was in crisis.

The origins of this crisis are found in feudalism's relation to the land. Pivoting on the political extraction of surplus, yet (in most cases) recognizing the peasantry's customary rights to the land,[65] feudalism provided neither the coercion nor the incentive necessary to ensure rising productivity over the long-run. On the one hand, the peasant proprietor could only rarely be ejected by the lord — even more rarely could market forces displace him. He was therefore compelled to *produce* to survive, rather than *sell* to survive. It is in this narrow sense that "the crucial feature of feudalism... [is] *production for use*" (Sweezy, 1976: 35). On the other hand, productivity gains, such as they were, tended to be undermined by feudal exactions (Dobb, 1963: 42-44). Rising peasant surpluses were subject to appropriation by the seigneurs and the states — indeed, the appropriation of surplus through levies and taxes was the primary means of increasing ruling class revenues. (This of course dampened the seigneurs' incentive to increase productivity, since rent and levies were not directly tied to agricultural improvement.) Within certain limits, then, feudal income could increase, even if the aggregate surplus stagnated or contracted. And this is what seems to have occurred by the early fourteenth century (Hilton, 1985: 129-130).

Feudalism consequently limited the surplus available for investment in agricultural improvement, which tended to undermine soil fertility (Postan, 1972; Duby, 1972; Anderson, 1974a: 197-199). This was the underlying political ecology of Bois's declining rate of seigneurial levy (1978: 63).[66] Put simply, the lord-peasant relation was

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difficult to find anything like a state anywhere on the continent of Europe" (Strayer, 1970: 15). Even after 1100, "the states were never strong in Europe… But they were stronger at some times than at others. The expansion of the economy in Europe between 1000-1250 which created new revenue bases for the states and new needs for internal order, on the one hand, and the outward expansion of 'Europe' (the Crusades, colonization in the east and far north) which called for some military unification, on the other, combined to create a new life for nascent state-machineries" (Wallerstein, 1992: 603-604).

64 "Precisely when the slowing occurred depends on what region we examine and what sector of the economy. The comprehensive picture is one of sluggishness in productivity in some sectors from the 1250s, more generalized sluggishness from the 1270s, and very slow growth from 1285" until sometime in the first half of the fourteenth century (Jordan, 1996: 12).

65 While the seigneurs legally "owned" the land, the peasants "possessed" it (Milonakis, 1993-94). On the one hand, peasant customary possession placed limits on the degree to which the direct producer could be compelled to pay higher rents, whether labor, in-kind, or monetary. On the other, the relative (if still very limited) autonomy of the direct producers under feudalism constituted a real productive advance over slave systems of production. Feudalism limited but did not remove incentives for increased productivity.

66 "In the feudal system the rate of seigneurial levies shows a tendency to fall which originates in the structural contradiction of small-scale production and large-scale property. When economic expansion draws to an end (around the *middle of the thirteenth century*) the fall in the rate of feudal levy is no longer offset by the establishment of new tenures, with the result that seigneurial income in its turn tends to decrease" (Bois, 1978: 63, emphasis added). Brenner's reply to Bois on this question is, I think, best

fundamentally antagonistic to long-run ecological sustainability. Feudalism's ecological cycle was a vicious circle indeed: "Few animals had provided little manure; little manure had meant low [grain] yields; with low corn yields per acre, every possible scrap of land had to be ploughed for corn; so there was little winter feed for animals, and few animals…." (Davis, 1973: 113).

Even as the feudal system limited opportunities to plough the surpluses back into agriculture, it favored population growth as a means of generating surpluses.[67] Throughout Europe, population growth under feudal class relations tended to fragment smallholdings through partible inheritance. Peasant households therefore faced contracting living standards — although of course a few did well — and tended to compensate, much like peasant families today, by opting for larger families. Over time this holdings fragmented still further, and this began to fetter productivity (Brenner, 1985b: 230; Dobb, 1963: 47; Milonakis, 1993-94). Consequently the peasantry's position tended to deteriorate over the course of the middle ages, even in the absence of rising seigneurial demands. But the seigneurs' demands did tend to rise. For the seigneurs were locked into a demographic regime strikingly similar to that of the direct producers. The development of feudalism therefore favored not only a rising population for the masses, but also an enlarged ruling class:

> [T]here was a tendency… for the number of vassals to be multiplied, by a process known as sub-infeudation, in order to strengthen the military resources of the greater lords. This, combined with the natural growth of noble families and an increase in the number of retainers, swelled the size of the parasitic class that had to be supported from the surplus labour of the serf population (Dobb, 1963: 45).

So it was that the feudal system of production exhausted the soil, which led to malnutrition, which prepared the ground for epidemic disease, and in short order, a terminal systemic crisis.

There were three main responses to this contradiction within the feudal mode of production. All were self-limiting.

One solution was to increase land productivity. Every durable mode of production has been shaped by a distinctive agricultural revolution. Feudal Europe was no exception. In technical terms, medieval Europe's agricultural revolution took flight from the diffusion of the heavy plough, and the shift from a two-field to a three-field rotation within western Europe (White, 1962).[68] It was a dynamic combination. The horse-collar plough enabled a substitution of horsepower for labor power (which raised labor productivity), and heavy ploughing discouraged weed growth (which raised land productivity) (Cooter, 1978:

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viewed as complementary (1985b). The tendency of the declining rate of feudal levy was subject to all manner of counter-vailing forces even as it established certain limits to feudal accumulation.

[67] "The long-term tendency, therefore, appears to have been towards over-population, leading to increasing demand for land, creating the *possibility* of extracting growing rents, *without* direct resort to extra-economic pressures or controls" (Brenner, 1985b: 230).

[68] We should take care not impose too rigid a definition here: "[T]he distinction between the two systems is unreal. The basis of medieval rotation systems was rather the *cultura* or furlong than the field" (White, 1962: 98).

466). Meanwhile, the new rotation allowed an expansion of cultivated acreage by as much as fifty percent.

Much less frequently observed in discussions of medieval agriculture is the agronomic shift from spelt wheat to "bread wheat" that played out in northwestern Europe in the centuries after the fall of Rome. The new cereals faced few competitors initially, from pests and weeds alike, a transition period that Dark and Gent characterize as a "yield honeymoon" (2001: 74). This honeymoon would provide an indispensable surplus to early feudalism.

The diffusion of the three-field rotation is easily overstated. The new rotation did not work well in Mediterranean and northern European climes. Even in Western Europe its diffusion was highly uneven. And it demanded relatively more fertilizer than its predecessor – although rising nutrient demands would have been offset by expansion into the forests, whose soils offered a short-run fertility windfall (Cooter, 1978).[69] At the same time, the three-field system reduced the land available for pasture by as much as a third, thereby reducing the livestock necessary to replenish the soil's nutrients at the very moment when nutrient demands were rising (Miskimmin, 1975: 18-19, 24-25; Dobb, 1963: 43-44; Postan, 1972: 63-67; Duby, 1972: 196; Braudel, 1981: 109; Bowlus, 1980: 89; White, 1962: 69-76).[70] (Even if these problems could be overcome, feudal class relations, as we have seen, discouraged sustained productivity gains.)

The reduction of pasturage implied in the shift to the three-field system only intensified feudalism's expansionary impulse. Thus efforts to increase productivity were typically bound up with a second strategy, which found its expression in various movements of internal and external expansion. Among the chief moments of internal expansion was the conversion of forests to pasture.[71] During the first three centuries of the new millennium, cultivation "more than doubled" in western Europe, much of it at the expense of forest (Montgomery, 2007: 91; Darby, 1956). The pace of expansion was even more vigorous in the east (Lewis, 1954). For a time offsetting the contraction of pasture in favor of arable, forest clearance proved increasingly self-limiting. New pasture could be reclaimed from the forest, it is true. But so long as feudal demographic regime remained sound, the overarching tendency was the successive conversion of these new pastures to arable land, and thence to more forest clearance (Ponting, 1991: 121-122; Bloch, 1966: 7-8). By favoring conditions for intensified soil *erosion*, as we shall see, the resulting deforestation compounded rather than attenuated feudalism's tendency towards soil exhaustion. Altering local hydrologies through forest clearance, this mode of internal expansion elevated at a minimum the *potential* for the increased the frequency and severity of flooding. (The shift towards wetter weather in the fourteenth century would make the risks all too clear.) It was, moreover, not merely that local hydrologies were

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[69] The expansion into the forests was a two-step process. In the first phase, peasants would collect forest litter for composting, and graze pigs in the forest common. Next came clearance and transformation of forest into field (Cooter, 1978).

[70] "Everything leads us to suppose that the food needs of the ever-increasing population had necessitated an abusive exploitation of the land, and that the land was nearing exhaustion. The continual exhausting of undermanured, overworked, and under-rested arable land seems to have been an *inherent feature of the agrarian system of medieval Europe*" (Duby, 1972: 198, emphasis added).

[71] We would also include polderization in the Low Countries, reclaiming land from the sea, and various efforts to drain marshland, in Italy and elsewhere (de Vries & van der Woude, 1997; Bloch, 1966; Braudel, 1972).

altered through forest clearance, but also that settlement in many areas moved upwards into the mountains (Mather and Fairbairn, 2000: 401; Rohr, 2002: 14). These zones, once deforested, were exceptionally vulnerable to wind and water erosion; they were doubly vulnerable insofar as high altitudes zones were arable in the first place because of the Medieval Warm Period and therefore extraordinarily sensitive to any shift towards colder weather (Lamb, 1982: 202-204; Pfister, et al., 1998). There were consequently strong tendencies within the feudal mode of production that multiplied the possibilities for serious and indeed catastrophic episodes of soil *erosion*, above and beyond deepening soil *exhaustion* (Hoffmann, 1996; Lopez, 1967: 397). These problems were intensified with the arrival of colder and wetter weather in the fourteenth century.

These inner frontiers were complemented by outward territorial expansion. While the Crusades served to integrate northern and southern Europe, and to draw this "competitive alliance" into the broader network of Eurasian commerce (Abu-Lughod, 1989: 46-47), settler colonialism was far more important to feudalism's survival. Because the feudal system generally restrained productivity, at a fairly early point economic growth hinged on geographical expansion. Although the balance of class forces might favor peasants or landlords at different times and places, the general rule was that seigneurial revenues increased as long as the population continued to grow. This meant that settlement tended to expand, all other things being equal. And this was precisely the case between the eleventh and thirteenth centuries, an era of "classical frontier development" (Lewis, 1958: 475). Successive waves of settler colonialism occupied Eastern Europe, large sections of reconquered Iberia, and Wales, Scotland, and Ireland.

Urbanization offered a third way out. The countryside's surplus population could be absorbed by the cities, even out of all proportion to urban growth, given the latter's notoriously high death rates.[72] The cities grew as long as rising revenues — made possible by modestly rising agrarian output and geographical expansion — fueled demand for urban manufactures. At the same time, the growth of the non-agricultural workforce increased demand for agricultural produce. This brought further pressure to bear upon the land, and greater pressure for territorial expansion.

By 1300, these strategies – increasing productivity, settlement expansion, and urbanization – were no longer working. "Two centuries of uncontrolled expansion had been purchased on credit using as collateral Europe's natural resources, which were being rapidly depleted" by the dawn of the fourteenth century (Bowlus, 1980: 94; also Cooter, 1978; Jordan, 1996; Lewis, 1958: 480). Agricultural innovation (such as it was) and geographical expansion were unable to keep pace with population growth and the rising demands of the states and seigneurs. The central problem was the very soil exhaustion engendered by feudalism's class contradictions, which at once encouraged population growth and discouraged the agricultural investment necessary to sustain the demographic expansion. By the early fourteenth century, feudal agriculture had significantly degraded the land within western and central Europe's fertile core areas. In England, yields per acre may have declined by as much as one-third between the thirteenth and fifteenth centuries (Dobb, 1963: 44, n. 1). As we have seen, in this settlement core, new land was

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[72] "[T]he cities had a lower marriage rate and birth rate than the country villages. Since all together produced at best only a very gradual increase, it is obvious that the cities did not replace their population and thus were dependent on the countryside" (Russell, 1972: 64; also Stecker, 2004: 218-219).

reclaimed from the forests, whose soils were quickly exhausted.[73] And on the frontiers, especially but not only in Eastern Europe,[74] colonization brought more and more people onto less and less productive land at the geographical margins of the system. In both areas, yields — and revenues with them — stagnated or declined (Bowlus, 1980: 96; Ponting, 1991: 123).

Because virtually all of medieval Europe's surplus product flowed from the countryside, declining seigneurial revenues were a serious problem indeed. The agrarian recession that spread throughout the early fourteenth century Europe, then, threatened not only the landlords, but also the states, who faced contracting tax revenues, and the city-state capitalists, who faced contracting markets. But agrarian recession is one thing. Crisis, another.

What turned this contraction from recession to crisis had everything to do with environmental history. In the first instance, by the end of the thirteenth century the weather got colder.[75] *A lot colder*. It began with a run a cold winters between 1303 and 1328 – that is, cold by the standards of the past millennium. The winters of 1305/6 and 1322/23 were historically severe; only two winters since (one of them coinciding with the French Revolution in 1788/89) have been comparable (Pfister, Schwarz-Zanetti, and Wegmann, 1996: 101-102). It was the beginning of the "Little Ice Age" (Grove, 1988; Lamb, 1977, 1982; Matthes, 1939).

From the vantage point of agrarian life at the dawn of the fourteenth century the implications of climate change were immediate. The margin of survival for the European peasant had always been razor thin. Rising population densities, conditioned by the feudal agro-demographic regime, had given rise to overexploitation in the heartland and overextension at the margins. It was a system that had become vulnerable to exogenous shocks, and that by the end of the thirteenth century was extraordinarily dependent on favorable weather (Utterstrom, 1955: 5). The good weather did not last. Even before the transition from the medieval Warm Period to the Little Ice Age had reached its tipping point in the early fourteenth century, the vulnerability of peasant agriculture was registered in deteriorating diet alongside declining yields. "Amino-starvation" prevailed as grains displaced animal proteins between the twelfth and fourteenth centuries (White, 1962: 75; Boldsen, 2005).

Everywhere in Europe the growing season became shorter, Lamb thinks three weeks shorter on average by the early fourteenth century, with more pronounced contractions in the north (1982: 202-204).[76] The combination with relative soil exhaustion was deadly. Dreaded "green years," when crops did not ripen, arrived one on top of the other. The spectre of crop failure, banished for most of feudalism's golden age, now returned as Grim Reaper, scythe in hand (Bowlus, 1980: 95-96; Hughes, 1996: 66; Lamb, 1982: 204).

[73] "By about 1200 most of the best soils of western Europe had been cleared of forest and new settlements were increasingly forced into the more marginal areas of heavy clays or thin sandy soils on the higher ground and the heathlands" (Ponting, 1991: 122).

[74] Medieval settler expansion was particularly vigorous along the southeastern Baltic, whose sandy soils were especially prone to exhaustion (Anderson, 1974a: 247).

[75] "By 1500 European summers were about seven degrees Celsius cooler than they had been during the Medieval Warm Period [ca. 800-1300]" (Fagan, 1999: 194).

[76] Norway's grain harvest in 1300 was fifty percent greater than it was in 1665 (Lamb, 1982: 204).

The problem was not simply that the Little Ice Age was cold. Cold could be weathered without precipitating disaster. Reinforced with torrential downpours, the story becomes different. Beginning in 1314, Jordan reports, "nearly all contemporary or near contemporary authors emphasize the abnormal persistence of the rains," during the crucial summer months above all (1996: 17-18). In France, the years between 1315 and 1319 were the wettest of the half-century (Fagan, 2000: 80). The intersection of climate change and mounting agro-ecological tensions within feudal agriculture would in 1315 "provoke a production crisis and complicate distribution" (Jordan, 1996: 21). The "Great Famine" ensued, decimating rural and urban population from France to Russia between 1315 and 1322. Far from an isolated occurrence, this was simply the worst of a series of devastating famines throughout the fourteenth and fifteenth centuries (Braudel, 1981: 74; North & Thomas, 1973: 72-73). So severe was the agrarian crisis that by 1300 "almost every child born in Western Europe faced the probability of extreme hunger at least once or twice during his 30 to 35 years of life" (Miskimmin, 1975: 26-27; also Braudel, 1981: 73; Montanari, 1994: 68-70).

Crop failures were all the more catastrophic as they intersected with relative soil exhaustion (which we have discussed) and soil erosion (which we have not). As long as the weather held, crop failures and the gradual progress of soil exhaustion posed the greatest threat to peasant well-being. But the shift to colder and wetter climate met up with deforestation and the expansion of cereal agriculture to produce catastrophic soil erosion. Prior to the eleventh century, "annual erosion rates never exceeded 10 tonnes/ha." In the first half of the fourteenth century, however, erosion rates skyrocketed. The 1340s, on the very eve of the Black Death, saw an acceleration of soil erosion to rate *twenty-two times* the prevailing norm of the first millennium. The proximate cause was "extensive river flooding" throughout central Europe in 1342, driving the ruin of harvests throughout the region (Brookfield, 1999: 6). It was a millennial event: "more than thirty percent of the total soil erosion of the past 1500 years occurred" in this year alone in what is now western Germany (Bork, 2003: 42-43). Not surprisingly, "some areas stripped by sheet erosion were never again farmed" (Brookfield, 1999: 6).

The conjuncture of unfavorable weather and agrarian recession produced more than increasingly severe and widespread famine. It set the stage for the Black Death, which would wipe out somewhere between one-third and one-half of Europe's population in the middle years of the fourteenth century. These conditions played out on two fronts. The agro-ecological crisis led to widespread malnourishment. And the weather itself would play a key role, in concert with feudalism's far-reaching environmental transformations, including deforestation, but also related centrally to urbanization and the grain trade on which the cities depended.

We can begin with the link between the climate and the social environment. In the comparatively arid Mediterranean zone, increasing precipitation after 1300 proved especially favorable to plague. The rat population so often associated with the virus already enjoyed favorable demographic conditions thanks to the rapid urbanization of previous centuries (McCormick, 2003: 20). Surveying the zooarchaeological evidence, McCormick points to "hugely expanding rat populations [in Europe] around the fourteenth century" (2003: 14).[77] Meanwhile, extending our gaze to the countryside,

[77] McCormick's thesis runs contrary to David E. Davis's contention that the attribution of a decisive "role of the rat [in the Black Death] may not be justified" (1986: 455). McCormick's thesis, which of course

rapid forest clearance eliminated owls and other birds of prey, thereby removing one of the "natural checks" on rodent proliferation. Meanwhile, the movements that simultaneously favored the expansion of cereals at the expense of forest and pasture radically expanded the rats' "food of choice" (McCormick, 2003: 22).

The creation of these disease-favorable landscapes dovetailed with the agro-ecological crisis and widening malnutrition. It is certain that malnutrition – Steckel aptly describes it as "net nutrition decline" (2004: 216) – was the trend, beginning sometime during the thirteenth century. The translation of declining net nutrition to various forms of crisis remains, however, a matter of debate (e.g. Herlihy, 1997; Kjaergaard, 2000). Northern Europe was the canary in the coalmine. Average height, which corresponds quite closely with net nutrition, declined steadily throughout northern Europe, beginning in the thirteenth century (Steckel, 2004: 216). Boldsen sees a similar connection between cerealization (White's "amino-starvation) and dental attrition (2005). Through famine, and amino-starvation, agro-ecological crisis undermined the population's capacity to resist disease. These conditions by the late thirteenth century, certainly by 1308, "recurred so insistently… that they became incorporated into man's biological regime and built into his daily life" (Braudel, 1981: 73-74). Thus feudalism's ecological contradictions gave rise not only to soil degradation but also to a dietary regime that virtually guaranteed epidemic disease (Montanari, 1994: 70-71; Slicher van Bath, 1964: 84, 88-90; Dobb, 1963: 48-49; Braudel, 1981: 78).[78] It is no coincidence that those regional populations — such as the Low Countries — marked by the greatest agricultural productivity (Brenner, 2001), and the greatest freedom from seigneurial oppression, were among those most resistant to the new disease vectors (de Vries, 1973; Slicher van Bath, 1964; DuPlessis, 1997: 25-27).

From the standpoint of agro-ecology, nutrition, and disease resistance, Montanari rightly cautions against drawing "a *direct* causal link" between "widespread malnutrition" and plague (1994: 70-71, emphasis added). Nevertheless, "it is equally clear… that the standard of living of a population… plays an important role in favouring or blocking individual defences to infection" (Montanari, 1994: 70-71). Jordan agrees that malnutrition itself was not directly responsible. In his view, the crucial source of epidemiological vulnerability is to be found in the Great Famine of 1315-1322. The nutritional biology of sustained and severe famine was such that those who lived through it as children, survived with underdeveloped immune systems:

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conforms to a longstanding conventional wisdom regarding the rat-plague connection, seems more plausible on several counts. First there is the zooarchaeological literature on rat populations, most of it published subsequent to Davis's article. Second, McCormick makes a strong case for why there are so few mentions of rats in medieval primary sources. And third, McCormick offers a rudimentary but plausible political economy perspective on what he calls *ecological history*: "The history of rats is *tightly interwoven* with the economic rise and fall of the ancient world [Rome], as well as the expansion of the medieval [European] economy" (2003: 1).

[78] "The repeated incidents of nutritional stress suffered by the European population in the first half of the fourteenth century engendered a state of widespread malnutrition and physiological weakness which prepared the way for the plague epidemic… Clearly there is not a *direct* causal link between the two phenomena: each has its own life and history… It is equally clear, however that the standard of living of a population… plays an important role in favouring or blocking individual defences to infection" (Montanari, 1994: 70-71).

> The horrendous mortality of the Black Death in northern Europe in part should reflect the fact that poor people who were in their thirties and forties during the plague had been young children in the period 1315-1322 and were differentially more susceptible to the disease than those who had been adults during the famine or were born after the famine abated" (Jordan, 1996: 186).

We've already mentioned medieval Europe's now-famous wave of forest clearance and its relation of feudal agriculture proper. McCormick highlights the epidemiological implications of this movement. Widespread deforestation would have

> caused a decline in the numbers of certain types of owl and other birds of prey, as well as rat-eating foxes and weasels. This removal of the natural checks on rodents occurred as burgeoning settlements multiplied [the rats'] commensal opportunities, and spreading cereal fields increased their food of choice (McCormick, 2003: 22).

To make matters worse, the great trade expansion of the eleventh and twelfth centuries knitted together not only Europe, along with most of Eurasia, more tightly than ever before. A new "disease pool" (McNeill, 1976), unprecedented in geographical breadth, had taken shape through the long medieval expansion. Chinese peasants, central Asian pastoralists, and European artisans were increasingly breathing the same air, epidemiologically speaking.

Agrarian recession, bad weather, and a new disease pool proved a fertile conjuncture for the bacillus that carried the Plague from Southeast Asia to Europe in 1348. Within three years, one-third of Europe's population, some 25 million people, perished. Other epidemics followed. The enormity of the loss boggles the mind.

Feudalism's fate may already have been sealed prior to 1348. Less certain, however, was the nature of the social system that would succeed it. More than any other event, the Black Death signed feudalism's death warrant and favored a capitalist rather than tributary solution to Europe's crisis. This had a lot to do with feudalism's class contradictions. On the one hand, feudal class structure rested upon rising population densities, whose agro-ecological contradictions were attenuated through the geographical expansion of settlement. A relatively high labor-land ratio reinforced seigneurial power by tending to reduce labor costs, increase aggregate value appropriated in the form of feudal rent, and as a result, augment revenues. Conversely, a relatively low labor to high land ratio tended to reduce the surplus derived from the land, raise real wages, and depress seigneurial revenues (Duby, 1972: 213; Dobb, 1963: 49; Britnell, 1990).[79] By the mid-fifteenth century, rents in England, Germany, and Italy were 40 percent lower than a century earlier; wages for laborers were as much as 400 percent higher (DuPlessis, 1997: 21-22; Anderson, 1974a: 204; Hodgett, 1972: 208-209; Bloch, 1966: 116). By

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[79] "[T]he smallholders and landless men profited perhaps more than any other group [from the consequences of the Black Death], for those with under 2.5 hectares… were in a position to acquire more and the landless benefited from the high wages and were often able to obtain some land." (Hodgett, 1972: 208-209).

dramatically shifting labor-land ratios in favor of the direct producers, the Black Death at once empowered the peasantry and weakened the seigneurs.[80]

On the other hand, the crowning achievements of the feudal mode of production — commercialization, urbanization, and state formation — also enhanced the peasantry's potential class power, even after (*especially* after) the states, the seigneurs, and the capitalists fell into crisis. Anderson states this well:

> the penetration of the countryside by commodity exchange had weakened customary relationships, and the advent of royal taxation now often overlaid traditional noble exactions in the villages; *both tended to centralize popular reactions to seigneurial extortion or repression, into major collective movements* (1974a: 202, emphasis added).

From the early fourteenth century, once-local peasant revolts began to appear on a regional, even national, scale (Hilton, 1973). The class power of the western European peasantry had developed to such an extent that the re-establishment of serfdom became exceedingly unlikely, particularly if less costly alternatives were available.

Before considering those less costly alternatives, however, we might turn our attention momentarily to the somewhat different situation in Eastern Europe.

In Eastern Europe, Poland above all, the crisis was delayed. Here was feudalism's distinctive logic of combined and uneven development in play. There were some similarities to the situation in Western Europe. Wages for day-laborers increased, and peasants benefited from the declining value of money rents. This favorable situation for the direct producers would persist into the mid-sixteenth century (Malowist, 1959: 182-183). But there were also important differences with the West. The issue of timing was paramount. The agro-ecological contradictions that mounted first in the established heartlands of European feudalism set in motion cascading movements of settler expansion. Poland was settled much later than the West, and therefore the contradictions of the feudal order did not reach a boiling point in the fourteenth century. Poland, for instance, was largely exempt from the ravages of the plague (Ziegler, 1971: 116). The balance of class forces therefore resembled that of the West in the tenth century rather than the fourteenth. This was partly a result of the plague's modest footprint, even more so because commercialization and state formation were only weakly developed. The peasantry was therefore weaker, more fragmented, and feudal relations were maintained or reimposed in what has become known as the "second serfdom."

This is an important part of the story, and one also that has quite a bit to do with feudalism's agro-ecological contradictions, as well as the transition to capitalism. Eastern European feudalism took shape out of the great demographic expansion of the eleventh

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[80] "The troubles of [the fourteenth century]… forced the landlords to be less exacting towards their tenants and bondmen, even though they themselves were affected by the calamities and perhaps more in need of money than ever before. Their problem was to persuade the peasants to stay on their lands, to repopulate them when they were deserted, and to put them back in order… Some landlords attempted to tighten the bonds of servitude and tie the workers [peasants] closer to the soil; they failed: it was too easy to abscond; and this emigration contributed towards the total disappearance of bondage in most of Western Europe… The only way to keep or attract tenants… was to give in to their demands and lighten their dues. Peasant families were much less numerous; they handed over an ever decreasing share of their working profits: hence the period saw a considerable fall in seigneurial income" (Duby, 1972: 213).

and twelfth centuries, a movement driven by rising population densities and environmental pressure in west-central Europe. Relative to Western Europe, three decisive features stand out. In the first place, peasant village solidarity was weaker in the East, reflecting the region's development as a "colonial society" (Brenner, 1985a: 42). Colonization in the East was led by landlords. As a result, village self-government was limited. This seems to have been the political expression of the underlying agricultural geography. In contrast to the West, common lands were typically absent. Settler colonization produced consolidated rather than fragmented holdings, which reinforced tendencies towards "individualistic farming" (Brenner, 1985a: 42).

Second, the towns were weaker in the East, and they suffered more from the agrarian recession.[81] (Even as the countryside suffered less.) Although towns may not have uniformly supported peasant revolts, there does seem to be a strong correlation between urbanization and the possibilities for effective peasant resistance to serfdom. In both the East and West, peasant revolts clustered around the towns — the main difference being that there were many more powerful, relatively autonomous towns in the West (Anderson, 1974a: 253; Brenner, 1985b)!

And third, the weakness of the East's towns entailed a weakly-developed woolens industry, and it was this sector that had come to the rescue of "hard-pressed lords in England and Castile" (Anderson, 1974a: 252). Consequently, Eastern landlords could not shift so easily from arable to pasturage as a means of responding to rising labor costs and a (temporarily) stagnating cereals market. The first two contrasts minimized the possibilities for effective resistance by the peasantry; the third contrast maximized the likelihood that the seigneurs would opt for a reimposition of serfdom.

If the seigneurs ultimately succeeded in reimposing serfdom in the East, they failed in the West. But not for lack of trying. Throughout Western Europe, the nobility's "immediate reaction was to try to recuperate its surplus by riveting the peasantry to the manor or battering down wages in both towns and countryside" (Anderson, 1974a: 201). The seigneurs, in concert with the states, waged an all-out campaign to intensify feudal control of the peasantry — issuing repressive legislation in England in 1349-51, France and Castile in 1351, Germany in 1352, Portugal in 1375. Only now, as never before, these measures provoked explosive peasant revolts on a much larger scale (Hilton, 1973; Britnell, 1990; Anderson, 1974a: 201-2). Indeed, by turning to the State, the very measures the seigneurs' hoped would increase feudal exactions tended to unify discontent, "because the target of the discontent was no longer the individual lord alone, but also the local officials of the government" (Hilton, 1949: 132; also Duby, 1972: 214).

If the producing classes were rarely successful in political terms — only in Switzerland did the peasantry bring the seigneurs to their knees — they made it crystal clear that a feudal solution to Western Europe's agrarian crisis was impossible. This clarity was reinforced by developments in the cities — those autonomous urban enclaves that were perhaps feudalism's greatest accomplishment. In Western Europe's most heavily urbanized areas, Flanders and Italy, artisans and even wageworkers staged revolts that toppled the urban patriciate — most notably in Ghent (1309) and Florence (1378). The strength of the cities had three major effects on the peasantry's class power. First, the

[81] Not only were eastern Europe's towns weaker, but their control over their respective hinterlands was considerably more restricted than their northwestern and southern European counterparts (Anderson, 1974a: 252).

urban semiproletariat leant support to peasant revolts, as occurred in London during the 1381 uprising or in Paris during the 1358 Grand Jacquerie (Anderson, 1974a: 202-204). Second, the cities provided a means of escape from feudal bonds themselves. And finally, the commercialization of the countryside, in addition to its role in centralizing resistance as we noted above, also profoundly threatened subsistence-oriented peasant society. It appears that in the fourteenth century no less than in the twentieth, those areas most prone to revolt were neither fully commercialized (prior to capitalism no area could be) nor entirely subsistence-oriented, but rather those areas that lay somewhere inbetween.

Global Expansion: A Spatial Fix to the Crisis of Feudalism

All of which meant that an "internal fix" to feudalism's problems was infinitely more costly than an "external fix." Provided one could be found. In terms of the hard-fought and zero-sum character of the late medieval class struggle, trans-Atlantic expansion was the path of least resistance, given the reality of overlapping crises. Previously at odds, the feudal crisis pushed together the interests of the states, the seigneurs, and the city-state capitalists in favor overseas expansion. "The only solution," argues Wallerstein, "that would extract western Europe from decimation and stagnation would be one that would expand the economic pie to be shared, a solution which required, given the technology of the time, an expansion of the land area and population base to exploit" (1974: 24). It is this process of geographical expansion — made possible by the converging interests between the states, the seigneurs, and the city-state capitalists — that made possible the transition to capitalism. The outline of this convergence in favor of geographical expansion runs as follows.

First, the states, which had made great strides between the eleventh and fourteenth centuries — owing to increased revenues from the internal expansion of settlement and the politico-military unification which resulted from the Crusades — now suffered greatly from the economic contraction, which began a full half-century before the Black Death (Strayer, 1970; Wallerstein, 1992). Beginning in the fourteenth century, the states faced a deepening "liquidity crisis" (Wallerstein, 1974: 21), as they struggled to exact higher taxes from the peasants in the interests of waging war. The big states tried to conquer smaller states, but given the widespread diffusion of military technology and techniques, alongside the equally widespread access to the money capital needed to wage war,[82] the possibilities for conquest were continually frustrated. Between the years of Black Death and the eve of the seventeenth century's "general crisis," states fought but seldom won very much on the battlefield: England could not conquer France; France could not conquer Italy; Castile could conquer neither Portugal nor England (indeed, it could barely hold together its own rickety "nation" within Iberia); and perhaps most significantly, the Austro-Iberian Hapsburgs could not conquer Europe. Moreover, the rising costs of war meant increased borrowing, and this strengthened urban capital against the states.

Second, the seigneurs faced a deepening crisis in the wake of the Black Death. As we have seen, the downward readjustment of labor-land ratios effected several crucial

[82] Indeed, capital was *more* widely available for warfare because profitable investment opportunities had dried up as a result of the agrarian and demographic crises (see Arrighi, 1994).

changes in the balance of class forces, particularly in Western Europe. Internal efforts to restore seigneurial revenues were ultimately self-defeating. Political measures to reimpose serfdom sparked peasant revolts. Efforts to convert arable land to pasturage allowed some landlords to shift from labor-intensive cereals production — whose profitability declined precipitously in the wake of the Black Death — to more profitable, and land-extensive, stock raising.[83] Sheep (and cattle) not only required fewer hands relative to agriculture, it yoked the seigneurs to the world market, who were as a consequence inclined to support measures that favored the further expansion of that market.

The resulting widespread displacement of cereal agriculture by animal husbandry not only entailed a more specialized division of labor on a world-scale (Helleiner, 1967: 68-69). It also biased the European world-economy in favor of further expansion because of the geographically expansive character of the European livestock economy. (It is no coincidence that Europe's greatest overseas empires were forged by those very states — England and Castile — most involved in sheep farming.) Moreover, the shift from arable to pasturage militated against a rapid population recovery by reducing grain acreages, and therefore limited the very demographic expansion that might have shifted the balance of class power back in favor of the seigneurs. Finally, the livestock economy was not only expansive but *expansionist*, by virtue of its strong tendency towards land degradation and consequent demand for new land (Clough, 1959: 146; Klein, 1919). Thus, the seigneurs were triply motivated to expand geographically, by virtue of the peasantry's continued class power, diminishing returns on cereal production, and the ecological contradictions of stockraising.

At the same time, the peasantry's newfound power led the seigneurs to turn their attention to the states,[84] who were forced to recognize the former's voice in policy-making.[85] The seigneurs' political turn meant they could expand their revenues, but only so far as "their" states prospered. And yet, the very nature of feudal crisis limited such prosperity to the extent that intra-European warfare was privileged over geographical expansion. Thus an uneasy compromise prevailed between the states and seigneurs in favor of statism and overseas expansion.

Finally, the city-states were equally beset by contradictions that favored geographical expansion. Economically, urban capitalists were doubly squeezed. On the demand side they faced the contraction of the domestic European market owing to declining seigneurial revenues. On the supply side, they suffered from the contraction of Eurasia's

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[83] The ranks of Castile's wool-producing sheep swelled from 1.5 million to 2.7 million between 1350 and 1450 (Mielants, 2000: 266, n. 81).

[84] Hilton sees a direct link between the economic crisis and rising seigneurial interest in the state: "[D]emesne profits… [were] disappearing very rapidly, especially after the 1370s. No wonder that in the second half of the fourteenth century we see not only the economic aspect of the crisis but its political consequences. These, taking the form of intensified factional struggles among the landed aristocracy, largely over the control of the state and its fund of patronage, connected with declining landed income" (Hilton, 1985: 132-133).

[85] The opportunities of the seigneurs within western Europe were at once limited and augmented by the formation of powerful territorial states. State fiscal policies of debasement and increasingly effective taxation systems undermined feudal arrangements in the countryside by devaluing fixed rents and extracting surplus from the peasantry. But by creating various assemblies and selling state offices, new opportunities were opened for the seigneurs to advance their interests through the state.

great commercial networks. The port of Genoa's tax receipts, to cite but one example, dropped nearly 50 percent between 1293 and 1334 (Lopez, 1967: 399).

Socially, the city-states faced increasingly serious threats to internal order from the producing classes (Wallerstein, 1974: 52). In Florence, where one out of three people depended on the city's woolens industry, the economic crisis curtailed output by more than two-thirds in the four decades after 1338. The social unrest that followed "culminated in the so-called revolt of the *Ciompi* [1378]… when impoverished clothworkers seized state power and put a woolcomber… at the head of the republic's government" (Arrighi, 1994: 101; also Miskimmin, 1975: 98-99). Florence's crisis was overdetermined by a deepening agro-ecological crisis in the 1330s, which among other things saw the price of wheat jump by 300-500 percent; no small matter for a city that relied on grain imports for seven months of the year (Hughes, 1996: 66-67).

The generalized contradictions of the city-states generated specific antagonisms that favored overseas expansion. By the later fourteenth century, Venice proved militarily strong enough to pursue an internal fix to this contraction, driving Genoese capital from the eastern Mediterranean and monopolizing what remained of profitable trade with the East (Arrighi, 1994: 114-115).[86] By the middle of the next century, however, Genoa was able to turn an apparent position of weakness into one of strength. As Genoese capitalists turned west, looking to replace the investment outlets they had lost in the economic contraction and the ensuing conflict with Venice, they became the bankers to the Portuguese and Castilian crowns. In so doing, they hitched their collective wagon to the very powers that would expand the geographical arena necessary not only for renewed commercial expansion, but also for the emergence of a world-system predicated on the endless accumulation of capital. What Genoa had lost in the East could be won back in the newly "discovered" West of the emergent Atlantic economy.

Ecology, Crisis, and Global Expansion: The Strange and Precocious Case of Portuguese Imperialism

Genoa's strength was its abundance of capital. Genoa's weakness was that it could offer *only* capital. Only an alliance of conquerors and capitalists could realize and sustain the peculiarly modern thrust of European expansion – a modernity prefigured in the "merchant-warrior" tradition of medieval Europe (Brady, 1991). For European expansion to "work" – that is for expansion to resolve the crisis of revenues and attendant underconsumption squeeze on urban capital – overseas expansion needed to combine the globalization of commodity relations with armed might, such that over the long haul the latter remained subordinate to the former. A delicate imbalance to be sure.

Genoa's expansion therefore depended crucially on Europe's two most precociously modern states, Castile and above all Portugal. It was Portugal, intertwined with Genoese capital and technical knowledge, that pioneered the pivotal structural relation in the

[86] Genoese capital was also deprived of investment opportunities in its *contado*, relative to its rivals, Venice above all. In an era when Italy's urban capitalists aggressively colonized the surrounding countryside (Braudel, 1972), Genoese capital encountered a powerful rural aristocracy, who posed "an insurmountable social barrier to the domestic expansion of [the urban merchant classes'] wealth and power" (Arrighi, 1994: 111). In sum, the intersection of Genoa's town-country division of labor and class structure further biased Genoese capital towards global expansion.

formation of the Atlantic economy: the slave-sugar nexus. I will trace the environmental history and political economy of this nexus in Chapters Five and Six. For the moment, let us examine, through the particularities of Lusitanian Absolutism's expansionary dynamics, the ways in which the crisis of feudalism gave way to the globalization of cash-crop production.

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While Europeans had grown sugar in the Mediterranean from the time of the Crusades, Portugal's incorporation of the Madeiras and Azores in the 1430s inaugurated a new phase of world environmental history. Though small, the Atlantic islands "were as important as continents" (Mauro, 1961: 4). Madeira, the first modern sugar colony, would loom especially large.

But why Portugal? Did Portuguese expansion have anything at all to with a "crisis of feudalism" and its ecological contradictions? For if the argument holds that the crises of late medieval Europe favored a capitalist rather than tributary solution, and that this capitalist solution turned fundamentally on the strategy of the global spatial fix, the explanation of Portuguese expansion and its environmental history must relate in important respects to political ecology of systemic transition.

Earlier we saw that the growing power of the Western peasantry in the aftermath of the Black Death was crucial in driving Bois's declining rate of seigneurial levy past the point of no return. In Portugal, as throughout feudal Europe, the ruling strata experienced a sustained agrarian crisis as monetary deflation "considerably diminished feudal rents" (Malowist, 1964: 33). This was of course largely an expression of rising labor scarcity and therefore rising wages (Pearson, 1987: 7).[87] The resulting squeeze on aggregate surplus was amplified further by the relative absence of adscriptive serfdom and the possibility of flight to the towns, which peasants apparently did in great numbers (Anderson, 1974a: 171-172; Pearson, 1987: 7). The share of people living in cities *doubled* (from two to four percent) between 1350 and 1450 (Valerio, 2002: 11). To make matters worse for the accumulators of agrarian surplus, prices were rising quickly for urban manufactures and the consumables of long-distance trade, and falling sharply for primary products. This was, then, a crisis that hit everyone hard but the direct accumulators of agrarian surplus hardest.[88] It bears repeating that this situation, in many ways driven by plague, was created not by demographic movements as such, but rather by the socio-ecological contradictions at play in the feudal crisis (Malowist, 1964: 33, 22).

To what extent did these Portuguese developments express feudalism's systemwide ecological tendencies? This is a decisive question. For my argument has proceeded from a *rejection* of an axiomatic rendering of the rise of capitalism and its global expansion from the ashes of feudalism. There was no telos that determined the transition in advance. The rise of capitalism itself must be explained. Above all modernity's distinctive environmental history needs to be situated in relation to the distinctive environmental history of medieval Europe.

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[87] Real wages in Castile – which may be taken as a reasonable proxy for Portugal in this instance – *quadrupled* in decade after 1348 (Anderson, 1974a: 204).

[88] For Portugal, see Malowist (1964: 33); for Europe, see Miskimmin (1975: passim and esp. 29-31).

Let us consider this environmental history from the standpoint of the Portuguese socio-ecological formation. We have some suggestive evidence concerning Portugal's environmental history from the long fourteenth to the long sixteenth centuries – the era of transition, not only from feudalism to capitalism, but also from (medieval) resource frontiers to (modern) commodity frontiers. First, there is biophysical evidence of medieval settlement extending upwards into the mountains – in particular the Serra de Estrela range in east-central Portugal – that precipitated "complete deforestation and massive soil erosion" between the eleventh and fourteenth centuries (van der Knaap & Van Leuween, 1995: 210, esp. 207-210; Sobrino, Ramil-Rego, and Gutian, 1997: 231-232; Mendes, 2002: 11). This evidence suggests a broad synchroneity with contemporary developments elsewhere in Europe, for instance, with mountain colonization and deforestation in medieval Switzerland (Mather and Fairbairn, 2000), and catastrophic soil erosion in mid-fourteenth century Germany (Bork, 2003). Martinez Cortizas and his colleagues (2005) find late medieval deforestation and soil exhaustion even in remote Galicia (2005: 704). All of which gives some teeth to the broader applicability of Bloch's "great age of clearing" (1966) and the notion that this ecological tendency was immanent in the feudal mode of production, without any necessity of erasing the latter's historical-geographical complexity (Bloch, 1961, II, p. 445). Second, Portugal experienced multiple crop failures with the rest of Europe in the half-century after 1300 (McAlister, 1984: 44; Jordan, 1996). This even at a comparatively low population density, which nevertheless wore even more intensively on the land owing to the persistence of the two-field rather than three-field rotation.

Finally, there is legislative evidence. The toll on the forests was sufficiently severe – at least from the standpoint of shipbuilding timber – that the Portuguese crown took an active interest in forest management from the first moments of the early modern expansion, in 1450 establishing an office to manage the royal forests of Leiria (Sardinha and Richards, 1998: 293).[89] Nearly a century and half earlier, the Crown ordered widespread pine tree planting in these same forests (Mendes, 2002: 11). What changed between the early fourteenth century and the middle of the fifteenth centuries was the articulation of local-scale forest management with a globalizing forest regime.[90] Already by this later date foreign timber had become "indispensable" to Portugal, imported from northwestern Europe and shipped in growing quantities from the Madeiras (Malowist, 1964; Serrão, 1954; Barker, 2001; Perlin, 1989). Such forest regulation – really, an initiative to enclose the forest from the unregulated incursions of peasants and manufacturers – was invariably an indicator of scarcity, although to say it was deforestation would be going too far. In themselves, efforts to limit peasant access to the forest commons were not new (Birrell, 1987). Globalizing efforts to secure new supplies

[89] Portugal in this respect shares an important connection with Venice, both exceptionally "modern" states for the fifteenth century – and both, not accidentally part of Braudel's "global Atlantic" then in the making (1972). Venice had begun forest legislation in 1350 but presumably the demographic contraction rendered fuelwood and timber supplies more easily obtained for a century; its renewed territorial and legislative attention to timber and fuel supplies dates from a cluster of initiatives between 1442 and 1476 (Appuhn, 2000, 2002). Both states sought to protect forest spaces vital for the reproduction of the "national" society.

[90] There were to be sure state initiatives to protect forests during the medieval era (Birrell, 1987). These were, however, emphatically *not* articulated with overseas expansion and the tendency towards sequential overexploitation. This has something to do with a transition from parcellized sovereignty to modern forms of the state, including but not limited to the absolutist variant.

through trade or colonial expansion were. What is striking about the 1450 measure is its timing. All things being equal, the demographic setback of the fourteenth century ought to have created relatively greater ecological "slack" than it did. The absence of such ecological slack accounts in part for what Pereira calls the "urgent imperialism" of Portuguese expansion between 1450 and 1525, one characterized the rapid "activation of the resources of the realm and the islands" and their ensuing "paradoxical exhaustion" (Pereira, 2006: 10).

The attenuation of seigneurial power in the countryside was reflected in a persistent state of food insecurity. The peasantry was sufficiently strong that the state and seigneurs were unable to compel them to generate an adequate food surplus for the cities.[91] As Braudel tells it, the Portuguese ruling strata abandoned market-oriented grain production because it had become "basically an unprofitable domestic activity" (1972: 586). What Braudel does not tell us is that it was unprofitable precisely because of the altered balance of class forces in the countryside, which themselves stemmed in part from the environmental contradictions of the feudal era.

Throughout the medieval period "Lisbon had been a hungry city" (Birmingham, 1999: 2). By the fifteenth century, imports of grain no less than timber, often arriving from northern Europe, had also become indispensable (Malowist, 1964: 12; Braudel, 1972: 196-197, 586; 1984: 140).[92] Thus did Lisbon's hinterland grow to encompass Sicily, Flanders, and the Baltic (Braudel, 1972: 196-197). Portugal's first colonial initiatives, at first in Ceuta and aimed at the north African plains, and then in the Atlantic, preceding even sugar as we shall see, aimed at internalizing cereal production within its territorial domain (Serrão, 1954).[93]

It was not the peasants only but the seigneurs also who caused serious dislocations to the feudal accumulation process. The demographic contraction essentially eliminated the feudal analogue of the reserve army of labor within its territorial domain. Within the feudal relations of production and reproduction, the more tightly packed the population, the greater the seigneurs' bargaining power in the struggle over the surplus. (All things being equal.) With the downward revision in labor-land rations, the problem of relative surplus population was inverted. Not only were the producing classes too small in number (from the perspective of the seigneurs and states), but the ruling classes were too *large*. Overseas expansion therefore defused one of the more troublesome elements of the

[91] Probably in part because demesnial production was comparatively quite limited in medieval Portugal, and therefore the ruling strata had comparatively little direct involvement in production (Anderson, 1974a: 171-172).

[92] On a larger scale, the ascendant territorial states and their political centers forged geographically expansive town-country relations. Portugal, at one time a grain exporter, was by the later fifteenth century growing "increasingly uncertain of its daily bread" (Braudel, 1972: 586). Under pressure of an expanding world market, "[o]rchards, olives, and vines were taking up more and more room," displacing cereal agriculture. (Evidence of a trend towards agricultural specialization, even monoculture, throughout the central and western Mediterranean by the sixteenth century [84, 155].) "The need for grain, grain 'imperialism,' drove the Portuguese to seize control of the markets of the wide Moroccan plains… But the most satisfactory solution was to buy grain from outside, *to abandon what was basically an unprofitable domestic activity*" (1972: 586, emphasis added). And so Lisbon's hinterland expanded far beyond Portuguese territory, to include parts of Andalusia, Castile, Sicily, Flanders… even the distant Baltic (196-197; also 1984a: 140)

[93] "In the early fifteenth century Portuguese expansion *was always in large part a search for food, for Portugal was always a grain importer*" (Pearson, 1987: 6, emphasis added; see also Braudel, 1972).

late medieval crisis by opening a vast new geographical arena for a bloated stratum of relatively impoverished and potentially troublesome seigneurs (Wallerstein, 1974: esp. 51).

In Portugal and Castile, there emerged a highly bloated stratum of *fidalgos* and *hidalgos*, younger noble sons who stood little chance of presiding over large feudal estates, and who could (and did) cause rather serious problems for domestic order (Pearson, 1987: 6). These culminated in what Vitale (1968) calls – with some exaggeration – the "first bourgeois revolution" and the subsequent rise of a statist "monarchical capitalism" (Godinho) after the 1385 Aviz revolution.[94] The social basis of monarchical capitalism emerged partly out the ecological contradictions of the feudal regime. The Black Death concentrated property into the hands of the religious Orders, as dying landholders bequeathed their estates in an effort to "buy salvation." But the Orders were unprepared to reorganize agriculture (Marques, 1972: 112-113; Ziegler, 1971: 115). This quite naturally depressed agrarian revenues still further and as a consequence disoriented the agrarian basis of seigneurial power beyond its already untenable position. This was amongst the proverbial straws laid on the camel's back of Portuguese feudalism, already a brittle edifice thanks to the "extreme centralization of feudal property" specific to Portugal (Anderson, 1974a: 172).[95] By 1383, Church and Crown enjoyed anywhere from four to eight times the seigneurs' aggregate revenues (Castro, 1970: 135-138). The latter's landholdings would be redistributed by João I following the expropriation of pro-Castilian seigneurs after the victory of Aviz-led forces against Spanish invaders at Aljubarrota in 1385 (Boone, 1986: 860). A feudal regime with nobles but precious few feudatories – many of whom were newcomers to the aristocracy – and who themselves possessed precious little economic strength was bound to become one of several weak links in the pan-European feudal chain.

The disorientation of the agrarian economy in the wake of the Black Death also drove the peasants from the countryside to the towns. (It wasn't simply disease, since the plague hit the towns hardest.) This was of course not specific to Portugal, but it does appear to have manifested with special force in Lusitania. As we have seen, the big towns – Lisbon, Evora, Oporto – grew bigger, at least for a time, in the decades after the Black Death. (Which was in fact accompanied by successive waves of plague, here as elsewhere, in 1356, 1383-85, 1415, 1423, 1432, 1435, 1437-38, and 1458 [Marques, 1972: 110; Hanson, 2001: 75].) But the social order of the towns was itself hardly prepared for such an influx. Neither was the urban agro-ecological regime, as food shortages plagued the cities in the 1370s and '80s (Hanson, 2001).

A tipping point was reached sometime in the second half of the fourteenth century. The new migrants from the rural interior fused with pre-existing artisanal and laboring strata to form "a typical modern proletariat" (Marques, 1972: 110). These working classes were to play an important role in the Aviz Revolution of 1383-85 (Boxer, 1969:

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[94] For Portugal in particular see Scammell (1989: 56); Elbl (2001); Greenfield (1977: 545).

[95] At what point did this extreme centralization of *feudal* property become one of *bourgeois* – or perhaps we should say proto-bourgeois and *increasingly* bourgeois – property? This is not clear. But it is perhaps instructive to note that Portuguese capitalism in the 1950s was dominated by a very select group of "consortia," including the Companhia Uniao Fabril, which owned *ten percent* of the country's industrial capital (Blackburn, 1974: 7). Ultra-colonialism and the extreme centralization of capital – dialectically bound for sure – do not appear as aberrations from the longer view of European expansion. (Special thanks to Anderson [1962] for the category of ultra-colonialism.)

11; Marques, 1972: 128). (Their role in social unrest too, as with the seigneurs, would be defused by the overseas expansion enabled by the Aviz ascendancy [Marques, 1972: 110].) It is from this perspective that the Aviz revolution emerged as one of several very serious fissures in the apparatus of feudal domination occurring throughout Europe at the turn of the fourteenth century. Crucially, these fissures appeared in those very zones that would give rise to the most dynamic capitalisms of the long sixteenth century – Genoa (1404), Florence (1378), Flanders (1379-85), northern France (1358), and England (1381), along with Portugal.[96] Portugal, along with Venice (whose commercial-military victory in the eastern Mediterranean provided for relative domestic tranquility[97]), was most advanced. "It would perhaps be an exaggeration to describe Portugal at the end of the fourteenth century… as a modern state; but all things considered, it was already halfway there" (Braudel, 1984: 140).[98]

This proto-absolutist – *and proto-bourgeois* – formation[99] in turn enabled the Crown and the seigneurs to reorient from a feudal internal fix strategy to a capitalist external fix strategy:[100] "Under these conditions, the aggression against Africa, the colonisation of the Atlantic islands, and finally the creation of a great colonial empire, offered the nobility tremendous opportunities to make a profit" (Malowist, 1964: 33, also 32; Mauro, 1987: 40). Thus did the seigneurial unrest of the fourteenth and early fifteenth centuries give way to a pervasive "attitude of loyalism…[that] was advantageous for both parties" with the overseas movements of the long sixteenth century (Malowist, 1964: 33; also Elbl, 2001: 95-98; Serrão, 1954; Pearson, 1987). And we might add another, perhaps macabre detail to Malowist's reasoning: by 1550 *one-quarter* of Portugal's noble sons who reached adulthood would perish in imperial adventures (Boone, 1986: 820). In the final accounting, however, the big question is whether or not geographical expansion actually realized an economic expansion that counter-acted the crisis of feudal accumulation. In this latter category must be included the revenues of the Crown and the Catholic Orders, as the country's largest landowners. Valerio (2002) offers a useful proxy in his estimate of Crown revenues. These increased fivefold (held constant for inflation) between 1477 and 1506, and another fifty percent by 1519 (2002: 13), an increase all the more impressive given the generalized price inflation of the era (Braudel and Spooner, 1967; Munro, 1994, 2003b).[101] Of this enormous growth in Crown revenues, the colonial trade

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[96] For Genoa and Florence, see Arrighi (1994); for England and France (Hilton, 1973); for Flanders (Dumolyn and Haemers, 2005).

[97] The classic English-language study is Lane's magisterial *Venice: A Maritime Republic* (1973).

[98] Boxer says much the same, although he chooses the backdoor rather to do it: "[I]t is an exaggeration to write of Portugal (as another authority had recently done] as possessing 'a powerful commercial class largely emancipated from feudal control' in 1415 *unless with the caveat that this class was virtually limited to Lisbon and Oporto*" (1969: 9, emphasis added). Quite the caveat indeed! Were these not the very cities that encompassed and dominated virtually the whole of Portugal's economic life after 1415?

[99] I remain somewhat sceptical on the general applicability of Anderson's concept of absolutism as a "recharged and redeployed apparatus of feudal domination" (1974b: 18). Lachmann's essay (2002) on this point is instructive.

[100] It surely helped that the 1375 legislation aimed at reimposing serfdom had manifestly failed by the turn of the fifteenth century (Anderson, 1974a: 202).

[101] On the strength of the monarchical capitalism solution to its feudal crisis, the Crown was able to stabilize the *cruzado* in 1489, and for the next half-century it remained one of the most stable currencies in Europe (Godinho, 1969: 168). The strength of the *cruzado* (a silver coin) was of course linked to many factors. Foremost among these, from the standpoint of material life and environmental history, was the

accounted for two-thirds of *all* Crown revenues (and therefore presumably nearly all growth) by the opening decades of the sixteenth century (Mauro, 1987: 41).

If the Aviz Revolution of 1385 was, as Vitale suggests, a bourgeois revolution, the decisive strata of the bourgeoisie were not Portuguese at all. They were, rather, Genoese (Malowist, 1964: 12)! The Genoese capitalist diaspora would be crucial to turning the possibilities for colonial expansion into reality. For the decisive slave and sugar trades, "the necessary capital was raised in the banking houses of Genoa" (Birmingham, 1999: 3; also Arnold, 2002: 20). Such capital was deeply embedded in the globalizing circuits of capital of emergent world-economy. Genoese "firms" such as the Centurione family in the later fifteenth century, for instance, employed agents in the Crimea, Majorca, Lisbon, Rouen, Antwerp, Bruges, and yes, Madeira (Bovill, 1928: 22). But this was not only a matter of merchant capital buying cheap and selling dear, *pace* Wood (1999) and the Genoveses (Fox-Genovese and Genovese, 1983). For one thing, the Genoese diaspora – merchants to be sure but not merchants only – seems to have been quite active in productive activities. Indeed increasingly so. Where 83 percent of the trade with northwestern Europe was in Portuguese ships between 1835 and 1456 (Boxer, 1969: 7), by the end of the fifteenth century nearly two-thirds of the Madeira sugar trade was "controlled by Italians" (Barata, 2005: 215). Shipping was, we would do well to note, a crucial productive sector and one that was underpinned by shipbuilding and sugarmaking, among many other industrial activities. Thus did the Genoese diaspora control not only liquid capital but some of the era's most strategic productive forces. The Portuguese *Cortes* would protest this state of affairs to the Crown in 1471 and again in 1492, but to no avail (Deerr, 1949: 101).

European Expansion: Environmental Determinations

If there were strong social forces pushing medieval Europe towards an external rather than internal fix to feudal crisis, there were also powerful geographical factors favoring such an outcome. But rather than succumb to environmental determinism, which has experienced something of a renaissance in recent years (Diamond, 1997; Fagan, 1999; Landes, 1998; Jones, 1987), we should remember that geographies are as much made as they are given.

The first of these factors was Europe's political geography. In contrast to China, Europe contained not one but many states. As the fourteenth century crisis deepened, these states went to war, seeking to recoup through battle what they had lost in the agrarian recession.[102] As competition between the states intensified, so did the search for sources of power that would give one state a competitive edge. This was true no less for city-state capitalists than for larger state-machineries. It was, after all, the great Venetian-Genoese rivalry that pushed the latter into an alliance with the Iberian states and

connection with German silver, which was obtained through the exchange of African gold obtained, in turn, through Portugal's re-export of trade goods, Antwerp produced textiles especially, manufactured in northwestern Europe (Vogt, 1975). Antwerp, in turn, was a leading entrepot of silver and copper exported from Central Europe (Vlachovic, 1963).

[102] "In an age when the economy was stagnant, if not regressive, the easiest way for a ruler to increase his income and power was to try to gain control of new territories, even if those territories lay within the boundaries of an already established state" (Strayer, 1970: 59-60).

encouraged the search for an alternative route to the Indies. In a social system where revolutionary increases in productivity were not (yet) feasible, this search for power necessarily entailed geographical expansion — at first to the Atlantic islands and coastal Africa, subsequently to the Indian Ocean and the New World. Not only did this political geography provide incentive for expansion, it removed a significant barrier to it. China's great overseas voyages began in the early 1400s but were called to a halt by the Empire by the 1430s. But Europe was a region of multiple states. No trans-European authority could restrain the expansionary impulses of the Iberian powers and their capitalist allies.

Much of this is widely recognized. Less obvious is the relationship between this unusual political geography and Europe's physical geography. Europe's geographical position was in sharp contrast to that of China, whose civilization took shape around the two major river valleys (the Yellow and Yangzi) and was consequently vulnerable to recurrent waves of Central Asian invaders. In western Europe there were multiple fertile "core" areas separated from each other by mountains or other natural barriers (Pounds & Ball, 1964) — Portugal from Spain; Spain from France; England from everyone; Italy from Germany; Sweden from Norway (both protected by sea); the northern Netherlands separated by riverine marshes from the relative openness of Flanders; and so forth. (Eastern Europe is another story, and this partly explains, among other things, Poland's sorry history.) The effect of this physical geography was to raise the costs of continental empire-building, and in corresponding degree, to reduce the costs of overseas empire-building. So the matter of Europe's physical geography in providing a certain bias to geographical expansion should not be minimized.

I don't think we should make too much of this, as does Eric Jones (1987) and other environmental determinists. At the same time, I don't think we should make too little of this, as does the great critic of Eurocentric historiography, James Blaut. While the environment determined nothing — the durable outcome of Europe's fourteenth century crisis was not discernible until well into the sixteenth century — neither was Europe part of a Eurasian-wide "landscape of even development," as Blaut would have it (1992: 22). Environment matters, but where many look for determinisms, we would do better to look for how classes make history (and geography), but not in eco-geographical situations of their own choosing. We are dealing here with environmental determin*ations*, not determinisms.

A second major bias to overseas expansion is found in Europe's agronomy. Medieval Europe was a society of wheat,[103] medieval China, a society based on wet-rice farming. Partly as a consequence, China's agronomy leant itself much more easily to internal fixes. (This is the small but important kernel of truth in the otherwise flawed theory of hydraulic societies [Wittfogel, 1957].[104]) Wet rice yields were vastly higher, typically five

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[103] "[A]s soon as one looks at the question of grain, one realizes what a complicated phenomenon it is. It would be better to put it in the plural — *los panes*, as so many Spanish texts say… [W]heat was never grown by itself. Despite its great age, even older cereals grew alongside it" (Braudel, 1981: 109). Rye, a poor man's crop, was especially important. On balance, there are not sharp ecological differences between the various cereal grains. Yield ratios between European grains did not strongly vary (Braudel, 1981: 121-122). At the same time, relative to rye wheat tended to be more vulnerable to climatic shifts, for instance to the cooler, wetter weather that arrived in the early fourteenth century, and it tended to demand more fertilizer (Fagan, 1998; Bloch, 1966: 25; Lamb, 1982: 204).

[104] Chaudhuri (1985: 29) compares wheat- and rice-growing zones in medieval and early modern Asia: "Wheat land, the making of bread, and the caravan trade were connected together by an invisible net,

times greater than European cereals (Braudel, 1981: 151). Moreover, the revolution in wet rice farming, based on early maturing rice varieties and multiple cropping (Braudel, 1981: 154-55; Ho, 1956), seems to have occurred right around the same time as the introduction of the three-field rotation, iron mouldboard, and horse-drawn ploughs in Europe. Given the relatively smaller and more tightly-knit wet rice zone in the south, agricultural innovations likely diffused much faster in China (Elvin, 1973, ch. 9). Wet rice farming does not face wheat's problems of soil exhaustion. As long as river ecologies are regulated adequately and not unduly disrupted, the nutrients are replenished. Climate permitting, multiple cropping is possible on the same land for centuries on end. There also seems to have been a much more sustainable metabolic relation between town and country in China, whereby urban wastes were returned to the soil (Braudel, 1981: 155, 486). During periods of crisis, the state could focus on maintaining or restoring the hydraulic infrastructure — above all, the canal system linking the two great river valleys — as an internal fix. In Europe, no such internal fix was possible, given the necessarily fragmented character of its wheat-livestock agronomic complex. Given this agronomic variation, it comes as little surprise that China recovered from the Black Death so much faster than Europe.

Rice's great advantage was its tremendous productivity on minimal land. Its great disadvantage was its high labor requirements.[105] Wheat's advantage, such as it was, ran in

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woven by climatic, social, economic, and even political relationships. Centralised governments in the wheat- and millet-growing areas faced a perpetual struggle to bring the lesser chiefs of the independent-minded agricultural communities under a single authority. In the rice-growing lands, the control or destruction of the water channels, the dykes, or even the nursery beds of young seedling rice placed the terrible weapon of mass starvation in the hands of the war lords. The collective effort needed to plant and harvest rice and its favourable land:yield ratio forced centralized Asian government to consider the welfare of cultivating villages much more than was the case with the extensive farming techniques associated with wheat and millet."

[105] Palat (1995) takes this line of reasoning even further. In a sort of agronomic variation of the Brenner thesis, wet rice not only demanded more labor than rain-fed grain, its labor process impeded capitalist development:

> [F]undamental differences in agricultural techniques [were] dictated by the dominant crops and the specific conditions of production in [China and Europe]... Whereas the substitution of labor-power by animal and mechanical power represented technological progress in societies with low densities of population [as was the case in Europe], the technical conditions of wet-rice cultivation dictated the substitution of simple tools for more complex instruments. This implies that, rather than moving toward large-scale consolidated farming operations, the dynamics of change in societies based on irrigated rizicultures increasingly privileged small-scale operations. Or, as Thomas Smith [1980: 105] puts it so well, 'To speak metaphorically, rather than impelling farming forward to a manufacturing stage of production, [operations associated with wet-rice agriculture] served to strengthen its handicraft character.'
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> Once emphasis was placed on the skill of the cultivators rather than on increasingly complex instruments of production, as was the case in early modern Europe, there was a tendential decline in the intervention of landlords in the production process. This implied that though producers may remain formally subordinate, no attempt was made by landowners to revolutionize and transform constantly the labor process. These conditions imposed severe impediments to a ceaseless accumulation of capital since landlords were unable to realize an increase in relative surplus value by constantly reducing production costs. At the same time, the increasing premium placed on skilled labor even constrained their ability to realize an increase in absolute surplus value. There was hence no tendency toward an increasing real subsumption of labor to capital" (Palat, 1995: 56-57, 70).

the opposite direction. It was highly consumptive of land but not labor. "Wheat's unpardonable fault was its low yield," observes Braudel (1981: 120). It "devours the soil and forces it to rest regularly" (Braudel, 1977: 11).[106]

These distinct agronomic complexes implied different kinds of livestock economies, with distinctive spatial logics. While China's wet-rice cultivation maintained high yields without animals, used primarily for draught purposes (Grigg, 1974: 75-83), wheat's ecology required livestock to maintain fertility. While in principle livestock replenished fertility and therefore encouraged sustainability, the fourteenth century crisis turned this logic inside-out. As we have seen, Western Europe's landlords responded to the agrarian crisis by enclosing common lands and shifting from cereal cultivation to stockraising, especially sheep-raising. At the same time, the renewal of economic expansion in the mid-fifteenth century relied heavily on horses for haulage and transport. More "horses meant a greater demand for fodder... [and land] used to grow fodder is obviously no longer available for crops to feed men; therefore, if the cultivated areas remains the same, an increase in the number of horses reduces the quantity of cereals for human consumption" (Slicher van Bath, 1963: 195). At the onset of the long sixteenth century, then, Europe's livestock economy reinforced wheat's spatially expansionary ecology.

This expansionary logic was reinforced by a marked shift in the social division of labor. If cereal agriculture and livestock evolved in close quarters during the long medieval expansion, what developed over the course of the feudal crisis is a wheat-livestock complex in which cereal agriculture and stock raising become geographically specialized. These were economically interdependent but no longer ecologically articulated. As animal husbandry was ecologically hived off from cultivation, local nutrient cycling was significantly disrupted. Cereal and sugar monocultures would take root in Poland and Brazil while sheep farming would predominate in Castile, England, and Mexico. By the sixteenth and seventeenth centuries, there was widespread soil erosion, soil exhaustion, and deforestation in all these regions (Wallerstein, 1980: 132-133; Klein, 1919; Melville, 1990; Moore, 2000b; Westoby, 1989). Thus did new divisions of labor within the countryside undermine the conditions for ecological sustainability, even as population pressure on the land was greatly reduced.

The landlords' widespread shift from arable to pasturage reduced the land available for grain cultivation in Western Europe. The Black Death reduced labor-land ratios, and thereby allowed more land per capita, which should have allowed for a fairly rapid demographic recovery. "[A]lthough fewer men should have meant more food since the landmass remained the same," the shift to pasturage led to "a reduction of caloric output" (Wallerstein, 1974: 35-36). Fifteenth century Europe was partially "decerealized," as stockraising occupied a landmass five to six times greater than did cereal agriculture for the same caloric output (Helleiner, 1967: 69). Western European wool production may have increased between three- and five-fold in the fourteenth and fifteenth centuries (Anderson, 1974a: 208). By the sixteenth century, then, pasturage not only became "regionally specialized"; this regional specialization was linked to widening land

[106] "Wheat cannot be cultivated on the same land for two years running without serious harmful effects. It has to be rotated" (Braudel, 1981: 114).

degradation on the one hand, and deteriorating peasant diets on the other (Wallerstein, 1974: 109, 44).[107]

In sum, wheat's low yields and soil-exhausting properties conditioned Europe's reliance on cattle, sheep, and horses — who "ate" men nearly as often as men ate them.[108] The upshot: Europe's agronomic complex encouraged extensive development (Wallerstein, 1974: 56-63). It was this bias that "condemn[ed] the greater Mediterranean area to the conquest of the Earth" (Chaunu, 1969: 338-339). Between 1535 and 1680, the European world-economy more than doubled in size, expanding from three to seven million square kilometers (Chaunu, 1959: 148). The labor-land ratio declined even more sharply, falling some 80 percent between 1500 and 1650 (Webb, 1964: 17-18).

A final geographical bias concerns locational advantage. It is certainly not the case that late medieval European seafaring technology was superior, although it was certainly well-adapted to Atlantic conditions (Chaudhuri, 1985: 138-159; Abu-Lughod, 1989: 326-327, 353-354). Europe's crucial seafaring advantage was locational. In the first place, Europe was closer to the New World than any other maritime civilization. Once Portugal and Spain had colonized the Atlantic islands, whose sugar plantations worked by African slaves prefigured later developments, the Americas were even closer. But that would not have mattered much if the Atlantic Ocean's currents carried European vessels in the wrong direction. Fortunately for Columbus and those who followed, these ocean currents would not only carry European vessels to the Caribbean, Brazil, and North America, but carry them back home as well. From the experience of sailing to the Atlantic islands, and fishing voyages probably as distant as Newfoundland, Columbus and others

> knew that the trade winds (or easterlies) would assist him outbound and had good reason to believe that the westerlies would assist the return voyage. The point here is a matter of strong probabilities. Overall, it is vastly more probable that an Iberian ship would effect a... round trip to America than would an African or Asia ship in the late fifteenth century (Blaut, 1993: 181-182; see also the maps in Landes, 1998: 80-85).

Making matters even more favorable, Europe's only possible seafaring rival was west Africa. But west Africa's political and economic geography was unfavorable to overseas expansion. Like China, west Africa was a zone of wet rice cultivation (Carney, 2001). Its leading urban centers were oriented to land, not sea. Where Africa's coastal trade was an extension of inland trade, Europe's inland trade was an extension of seaborne trade. West and central Africa's great empires were located inland, and the primary trade routes lay northward to the Maghreb and Mediterranean, and eastward to the Nile and the Middle East. The Maghreb's great trading cities possessed a strong maritime tradition, but faced serious military threats from the Ottomans and Iberians (Blaut, 1993: 183; 1994: 373, n. 16; Thornton, 1992: 13-21).

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[107] "The most important thing to note about pasturage in the sixteenth century, especially livestock, was that it was becoming increasingly a regionally specialized activity. *More cattle here, an advantage to large landowners, also meant less cattle elsewhere, which often meant a reduction in peasant consumption of meat and dairy products, a deterioration in the diet*" (Wallerstein, 1974: 109, emphasis added).

[108] Europe's wheat-livestock complex — especially stock raising — proved especially well-suited for the conquest of the New World (Crosby, 1972: 98-99; Parry, 1963: 244-247; Wolf, 1959: 197-199; Melville, 1990).

Conclusion

Feudalism degraded the environment in significant ways. Although primarily a system of production for use, which would seem to favor sustainable development, the medieval lord-peasant relation limited the possibilities for reinvestment in the land. As a consequence, European feudalism tended to exhaust the soil and the labor power from which it derived revenues. The feudal system's best response to this socio-ecological contradiction was an anemic spatial fix, which took the form of internal and external colonization, such as land reclamation in the Low Countries, or settlement expansion in the East. The global external fix that this eventually led to beginning with the colonization of the Americas, had capitalist commodity production and exchange inscribed within it. Capitalism, however, was an entirely different animal from the feudal beast that preceded it. Where earlier ecological crises had been local, capitalism globalized them. And it did so at a pace that outstripped all previously existing historical systems.

At the root of this ecohistorical difference between capitalism and feudalism is the role of commodity production in the two systems. To be sure, there was commodity production under feudalism. There were, for example, important antecedents of the modern plantation system in the medieval Mediterranean (Solow, 1987; Verlinden, 1970). But however *widespread* this commodity production may have been, there was no ineluctable tendency towards its *generalization*. Why? Because a society organized around the progressive generalization of commodity production undermines relations of domination based on tribute. Social strata that benefit from this system are likely to oppose any change that might favor generalized commodity production. In the end, however, they had little choice. The crisis of feudalism led to a convergence of interests among Europe's ruling strata in favor of a significant expansion of commodity production, most dramatically in the New World.

Geographical expansion was so important because it incorporated vast new agrarian zones into the emergent pan-European world-economy. Creating new agrarian spaces for commodity production, outside the peasantry's western European stronghold, encouraged Europe's beleaguered ruling strata to reshape the town-country division of labor in ways that favored capitalist development. Above all through the agency of the sugar plantation and the massive silver mining enterprises of Potosí and Zacatecas, early capitalism spearheaded the generalization of commodity production through overseas expansion, the fruits of which fueled capital accumulation in Europe's leading cities (Moore, 2000b, 2003; Blaut, 1993). In turn, this accumulation made possible the extension of capitalist town-country relations and the deepening of commodity relations within Europe. Control over American silver during the era of the Price Revolution, for instance, allowed Dutch merchants to subordinate Poland's grain producing landlords to the world market, essentially creating a system of "international debt peonage" (Wallerstein, 1974: 121-122).

Mining enterprises and sugar plantations funneled ecological as well as monetary wealth from increasingly-distant rural areas into the metropolis. Thus did the "development of underdevelopment" and capitalism's *metabolic rift* form a dialectical unity. Perhaps nowhere was this more evident than in the emergent sugar plantation complex. First in the Atlantic islands and later in Brazil, the capitalist sugar plantation in the fifteenth and sixteenth centuries ravaged the island landscapes it occupied, and the laborers who worked them. With sugar, we have a classic instance of capitalism's metabolic rift — whereby the products of the countryside (especially but not only in the periphery) flow into the cities, which are under no obligation to return the "waste" products to the point of production (Foster, 1999, 2000; Foster and Magdoff, 1998). Nutrient cycling is consequently ruptured, as nutrients are pumped out of rural areas and transferred to urban centers. In this sense, we can see these earliest expansionary movements as illuminating the origins of *modern* agriculture, sustained and expanded "by increasing overdraft on the fertility of our soils" (Sauer, 1981: 360). The waves of European expansion inaugurated by the crisis of feudalism therefore set in motion new ecological crisis tendencies on a world scale. With the creation of a world market and a trans-Atlantic division of labor in the sixteenth century, feudalism's localized ecological problems gave way to the modern globalization of environmental problems.

To these successive movements of global expansion, within Europe as well as outside it, we now turn.

CHAPTER TWO
Mining the Earth for Capital, 1450-1540
Central Europe in the Rise of Capitalism

The long medieval crisis would come to an end by the middle of the fifteenth century. By 1450, Europe had begun a long expansion that would at once recapitulate key moments of the earlier medieval expansion, and diverge radically from it. It was this tension, sometimes moving in favor of artisanal and feudal modes of production, but more often in the direction of commodification, that lays at the heart of Braudel's "long sixteenth century." Where the overall thrust of social relations in the crisis years of the long fourteenth century was *de*commodification, the opposite movement has prevailed ever since. (Even with all the periodic reversals that have surely occurred.)

Just when was this long sixteenth century? For Braudel, there was not one, but *two* sixteenth centuries (1953). As the first ended in the middle years of the sixteenth century – let us say 1557 to pick a moment of financial crisis as important to its era as 1929 was to the twentieth century – a "second" century of relatively slow growth ensued. There would be, however, no systemwide rollback of the commodity production and exchange. The grip of the commodity system would tighten, not relax as it done during the fourteenth century. And this was accomplished, above all, by extending the geographical arena of commodity production and exchange in a way entirely different from the great frontier movements of the feudal era.

The geographical *result* of capitalism's spatial fix strategy during the second sixteenth century has been ably studied – the conquest of the Americas, the penetration of the Indian Ocean's spice trade, the African slave trade. But the social and spatial contradictions *within* Europe responsible for the full flowering of these globalizing conquests have often flown under the radar. The spectacular advance of European territorial and capitalist power in the century after 1550 can only be adequately understood in terms of the contradictions that compelled such advance. The historical geography of the first and second sixteenth centuries was indissolubly bound.

Everyone knows the textbook story of European expansion. Columbus. Da Gama. Spices. Slaves. Gold and Silver. Sugar. And European expansion surely was all this. But it was not only this. If the expansion of "Europe" – and fractured and fractious Europe must not be reified – meant anything at all, it was expansion in search of power and profit, interlaced and inverting the privileged position of the former in the feudal dynamic. And given the peculiar constellation of class power in western Europe, as we have just seen, this implied and necessitated outward geographical expansion. But these dramatic and epoch-shattering movements of overseas expansion were vitally dependent on the less dramatic, but no less epoch-shattering, movements of "internal" transformation.

The reorganization of agriculture would move much too slowly to ensure a transition to modern economic growth in the long sixteenth century. There were exceptions – the maritime Low Countries above all – and these exceptions were closely linked to commercial and manufacturing expansions in early modern Europe (Brenner, 2001, de Vries and van der Woude, 1997). If agrarian life remained the epicenter of Braudel's "biological *ancien regime*" (1981), in his scheme of things changing imperceptibly on a continental scale until the dawn of the Industrial Revolution, mining and metallurgy provided its world-historical counterpoint. Europe's agricultural revolutions were measured in centuries, its metallurgical counterparts, decades.

From the 1450s, Central Europe's booming mining and metals regions were sites of huge capital investment, large-scale industrial production, and aggressive monetization. They were closely and strategically articulated with the leading agents of capital accumulation, foremost among them the Fuggers (Banaji, 2003; DuPlessis, 1997; Ehrenberg, 1963; Long, 1991; Molenda, 1976a, 1988; Nef, 1941, 1964; Lynch, 2002; Rice, 1970; Kellenbenz, 1974, 1976; Sella, 1974; Strieder, 1916; Vlachovic, 1963). "[I]n no other branch of the economy did early forms of capitalism develop so fast or entrench themselves so firmly as in the mining industry" (Kellenbenz, 1976: 80; also Strieder, 1914, 1929).

These iron- and above all copper- and silver-producing regions were at the heart of an emergent and specifically *capitalist* configuration of nature-society relations in the "vast but weak" (Braudel, 1961) capitalism of the first sixteenth century. Here was an inaugural episode in a long series of global conquests no less crucial to the rise of capitalism than the sugar plantations of Brazil, the silver mines of Potosí and Zacatecas, the slave entrepôt of Luanda, or the semi-colonial extraction of Norway's timber and the Vistula's grain in the second sixteenth century.

This series of global conquests found its motive power in the ecological dynamic of capitalism itself. It principal features may be indicated briefly. For all of its composite and deeply varied nature, capitalism is before all else a historical system premised on the endless accumulation of capital. This is, as Marx famously observed, Moses and the prophets (1977). Capital is that social and ecological composite in which nature is treated as a "free gift,"[109] its particularities dissolved in the abstractions of monetary capital. The presumption of endless accumulation presumes in turn the limitless consumption of human labor power and its ecological substrate. Because endless accumulation turns on, and is periodically exhausted and thence reconstituted by, competition between enterprises, states, and all manner of hybrids between the two, there has always been unrelenting pressure to maximize the economic surplus, in the form of monetary capital directly or, in the case of state revenues, indirectly. (*Modern* states have always had to compete for mobile capital no less than enterprises.) Now, surplus maximization has been pursued in all sorts of ways over the past five centuries. Pride of place in marxist and non-marxist approaches has the role of productivity-maximizing innovations, technological and otherwise. But there is more to it than this. Surplus maximization always plays out through geographical expansion. Most spectacularly in the early modern

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[109] The phrase, often credited to Marx, is more precisely that of the English translator of the edition of Capital, Vol. III, published by Charles H. Kerr & Co. (1909) and subsequently reissued by International Publishers (1967, III). (The translator, curiously, is unidentified in the International Publishers edition.) In discussing the tendency of capitalist agriculture to exhaust the soil ("the decreasing productiveness of the soil"), Marx observes that "natural elements entering as agents into production, and which cost nothing, no matter what role they play in production, do not enter as component of capital, but as a free gift of Nature to capital, that is as a free gift of Nature's productive power to labour, which, however, appears as the productiveness of capital, as all other productivity under the capitalist mode of production" (1967: III: 745, Chapter 44). David Fernbach's useful translation phrases this language of free gift somewhat differently. Here, Marx is translated as referring to such free gifts, instead, appearing as "free natural power of capital" (1981: 878-879).

era, the extension of Europe's capitalist-territorialist dynamic to the rest of the globe dramatically "liberated" for capital accumulation vast new sources of tractable labor power, fertile soil, and vital resources. Indeed, socio-technical intensification and geographical expansion form a single historical process. The two have always been dialectically bound in the closest possible fashion. And one or the other movement has always enjoyed primacy in successive long waves of capitalist advance. Only in their uneven combinations can we begin to make sense of this long arc, from the sixteenth century to the present.

We can now state the matter simply. The principal spatial expression of endless capital accumulation is the endless conquest of the earth. Limitless economic expansion premised on the rising productivity of labor is limitless geographical expansion premised on the low-cost exploitation of human and extra-human nature. Because the system has been ruthlessly competitive, there is an inescapable temporal counterpart to this geographical tendency – not only the endless conquest of the earth but the conquest and incorporation of the earth *in the most rapid way possible*.

The upshot is an unusually rapacious form of "metabolic rift," to use Foster's felicitous phrase (1999). In Foster's hands, Marx's conceptions of the town-country antagonism and the soil-exhausting character of capitalist agriculture are systemically combined (see especially Marx, 1977: 636-638). The insight is an important one, highlighting the rupture in nutrient flows between countryside and city. Nutrients flow from the countryside to the cities, which are under no obligation to return them, eventuating the progressive exhaustion of the soil and those who work it. Capitalism, of course, invented neither the town-country antagonism nor the metabolic rift that afflicted agrarian empires everywhere outside the wet rice belts of eastern Asia (Moore, 2003b). Nor did modernity invent large cities with extraordinary nutrient demands on surrounding and distant hinterlands. (Consider Rome's extortionate grain levies in its era.)

This new ecological mode of production effected two world-historical ruptures of signal importance after 1450. The first rupture was centrally concerned with reworking time, the second, with revolutionising space. In the first instance, ecological wealth – from forests, fields, mines, and communities (qua labor power) – would be extracted in the quickest way possible. (Extracted, we should note, from these agrarian spaces and conveyed into urban-centered production and accumulation.[110]) Waste was of little concern so long as it failed to enter the register of profitability.[111] The rapid movement of ecological overdraft tended to undermine the socio-ecological conditions of production and therefore, eventually, the conditions of profitability – typically within 50-75 years in any given region. Once the extraction of this regionally-delimited ecological wealth faltered – perhaps from the scarcities resulting proximately from commodity production, but more likely scarcities differentially created by social resistances intertwined with ecological shifts and market flux – this modern instanciation of the metabolic rift compelled the search for new commodity frontiers. This was and was not at the same time about the escalating *scale* of demand. The environmental history of the rise of

[110] To state the basic tendency. Agrarian manufactures – so-called proto-industrialization – were of course an important part of the story (Scott, 2002a, 2002b).

[111] A conservative objection to ecological waste in the spread of capitalist production, such as trees cut down and left to rot because they did not meet specific economic requirements, would remain an enduring feature of the modern world well into the late nineteenth century (e.g. White, 1980).

capitalism turned decisively on *economies of geographical concentration and "economies of speed."*[112] While economic growth was sustained through geographical expansion and therefore the era's ecological regime is rightly called *extensive*, the uneven synergies of generally rising demand translated to agro-extractive strategies of hit-and-run. Hit where the ecological wealth was most accessible (cheapest), extract it as fast as possible, then move as quickly as possible once declining ecological returns registered a significant contraction of profitability. Thus Antwerp's and then Amsterdam's successively more expansive metabolic rifts, and the commodity frontiers they entrained, cannot be comprehended solely in quantitative terms of, say, demand for raw materials and grain. Rather their full import can only be assessed in light of an ecohistorical matrix compelling ceaseless efforts to reduce turnover time in concert with maximal resource-extraction, therefore speeding up the rise and demise of raw material zones beyond anything known in previous modes of production. The upshot was a succession of commodity frontiers in many basic sectors of the European economy – from forest products to grain to metals – which means the primary expression of local environmental pressures at a systemwide level was not (*could not be*) rising prices but rather *the geographical expansion of the world capitalist system*. This lies at the heart of modernity's *first* metabolic rift – several have followed – and therefore at the heart of early capitalism's rapacious global ecological fix strategy. Once greenfields turned brown, the search began anew.

This chapter builds out the story of the rise of capitalism and its socio-ecological contradictions in four steps. I begin with an outline of the broad contours of early modern mining and metallurgy's significance for the European world-economy. From here I turn to two successive approximations of the geographical expansion of two crucial metallurgical sectors. The first is ironmaking, the indispensable material foundation of practically all significant economic activity in the era, a voracious consumer of forest resources, and in general, undercapitalized relative to other mining sectors. Copper and silver – the two ores were interlaced in varying proportions throughout Central Europe – constitute the second crucial sector. While early modern bullion flows from the New World into Europe would gain widespread notoriety in twentieth century historiography, indeed enjoying a resurgence with the arrival of the New World History (e.g. Frank, 1998), the commodity frontiers of Peru and later New Spain were prefigured by Central Europe's mining complexes a century before Potosí's discovery (1545). European silver's economic import was no less decisive, launching the price revolution decades before the arrival of significant bullion shipments from the New World.

In the final section, I examine the movements of regional crisis within these two sectors as they developed in the first half of the sixteenth century. While mining and metallurgy did not disappear from the region, Central Europe would no longer occupy a commanding position within the wider frame of the European economy. The crises which led to the displacement of Central European metals were rooted in the *political ecology* of these commodity regimes on a regional scale, as well as the political economy of the emergent world capitalist system – that is by intra-European contradictions no less than extra-European bullion imports. These crises were not so much energy crises, narrowly conceived, although this is a rough approximation. They were, rather, crises of regional-scale production complexes in which the production of nature was central to at first

[112] To borrow a phrase from Chandler (1977).

rising, thence declining, profitability relative to emergent competitors on the frontier. Thus would the silver centers of Freiberg and Joachimsthal give way to Potosí, the copperworks of Neusohl give way to Falun, the Upper Palatinate's iron smelters to England and Sweden.

Mining & the Great Expansion: Or, Capitalism as Mode of Extraction

The great expansion that began in the 1450s pivoted on by a revival of mining and metallurgy. From the middle of the fifteenth century, an extraordinary metallurgical expansion began that encompassed a broader Central European zone, comprising parts of the present-day Czech and Slovak Republics, southern Poland, Hungary, and central and southern Germany. Its dureé would correspond tidily with Braudel "first" sixteenth century (1450-1550). Home to abundant argentiferous (silver-rich) copper ores, this Central European zone offered no less plentiful iron, lead, zinc, tin, and salt,[113] along with the forest resources to render this mineral wealth usable.

In itself the revival was not unusual. Some four centuries earlier, the great expansion of the Middle Ages had occasioned a significant mining efflorescence.[114] But after 1450, it quickly became apparent that something was different. Part of this was technological. New techniques allowed the profitable smelting of argentiferous copper ores common in Central Europe, and new systems of water drainage were devised to allow for subsurface exploitation (Nef, 1964: 51; Braunstein, 1983).[115] In ironmaking, new blast furnaces enabled smelters to produce between five and ten times as much iron as heretofore. In the main, however, the technology was not so much, as it was new recently diffused. The crux of the matter was that the "new" technology was expensive, and so long as the depressionary conditions of the early fourteenth century persisted, most production continued to be organized along artisanal lines.

The pace of expansion was stunning. Iron production in the mid-fourteenth century stood at 25,000 tons (Sprandel, 1969: 311). Silver output had peaked around 1300 and declined sharply after mid-century. After the Black Death, throughout northwestern Europe there occurred a radical demonetization as silver coinage declined between two-thirds and 95 percent by century's end. Meanwhile, Central Europe's mines were devastated by war and declining profitability (Miskimmin, 1975: 113-114; 139-141; Patterson, 1972: 230).[116] Iron and silver both would expand at breakneck speed in the century after 1450. Europe's ironworks manufactured 60,000 tons in 1500 and 125,000

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[113] And to lesser degree gold in Silesia.

[114] Agrarian economies, capitalist or no, all depend on significant metallurgical inputs. Iron was crucial and indeed would become more so in the ensuing centuries.

[115] A new technique – the *saigerprozess* – allowed the profitable smelting of argentiferous (silver-rich) copper ores, plentiful in Central Europe (Nef, 1964: 51). The new smelters (*saigerhütten*) were gigantic structures, some 100 meters long and typically 1500 feet square (Agricola, 1556: Book IX). Here was Marx's large-scale industry long before it achieved its "classic form" in late eighteenth century England (1977: 876). The *saigerhütten* did not appear overnight, for they were costly – two-thirds more expensive than medieval smelters (Wright, 1996: 190).

[116] It is worth noting that silver coins were not indestructible and need to be replaced. Simply to maintain a given volume of silver coin in circulation, the 4-5 percent lost annually through "the melting pot, losses at sea, and ordinary wear and tear in hand-to-hand circulation" must be replaced (Kindleberger, 1998: 1; also Patterson, 1972).

by 1540 (Kriedte, 1983: 56; Nef, 1950: 35). Silver output grew even faster, and with it copper production (for the silver was embedded in copper ores), and the lead needed to smelt both. In 1450, no mine in Europe produced more than 10,000 marks, about 5,000 lbs, of silver in a single year. Eight years later, eight mines annually produced more than 50,000 marks (Nef, 1941). Boomtowns emerged around strikes such Schneeberg, whose production was reckoned in the hundreds of marks in the 1450s, but reached thirty one *thousand* marks two decades later; Schwaz's substantial output of 14,000 marks in 1470 tripled by 1485 (Vilar, 1976: 72). Across Central Europe, the region's output expanded fivefold between 1460 and 1530s, reaching an astounding level not exceeded until the nineteenth century (Nef, 1964: 42; also Kellenbenz, 1977: 201).

The accelerated movement of time implied and indeed necessitated the accelerated movement across space. The pace of growth magnified the extraction of ecological wealth far beyond the sustainable capacities of medieval hinterlands. Thus began, as early as the mid-fifteenth century, the "urbanization of countryside" (Marx, 1973: 479). For this remarkable metallurgical boom was by no means evenly diffused across Europe. Growth concentrated geographically in Central Europe, further magnifying the ecological tensions of rapid expansion. And this reinforced the urbanization bias of the transition to capitalism more broadly (de Vries, 1996; Molenda, 1976b). No less than half of Europe's iron production and three-quarters of its silver output during the first sixteenth century was located in Central Europe. The very pace of expansion inscribed in the silver and metallurgical commodity frontiers, *internal to Europe*, meant not only that an expanded hinterland would be impressed into the army of capital. The very entrainment of such agro-extractive spaces entailed the continual enlargement of those spaces. (And the abandonment of others, which nevertheless remained in the orbit of capital as a "reserve army of places," to borrow Walker's salutary phrase [1978].) As local hinterlands were exhausted – this was always some combination of social dislocation and opposition intertwined with ecological overdraft – new zones would be identified, incorporated, and in time exhausted too.

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This metallurgical revolution was driven neither by new technology nor the expansion of demand in the abstract. Commercial expansion and technological innovation tells us little directly about the transformation of productive organization. The crucial ingredient was capital, not just to finance the new, more expensive equipment, but also to coordinate the circulation of commodities across far-flung spaces.

Although the long fourteenth century was one of economic crisis, as we have seen, it was a crisis that also facilitated the continued concentration of monetary capital in the hands of merchant-financiers. This happened most spectacularly in the Italian city-states; less spectacular (for the moment) were the Fuggers of Augsburg, the Nuremberg families and others in Central Europe. If the Italians have received better press,[117] it is by no means clear that their strategic importance was greater than the Germans. (Different to be sure, but greater? This remains to be seen.) It was no small matter that the great silver-copper strikes of the later fifteenth century coincided with the middle node of what Wallerstein once called Europe's "old dorsal spine" (1974) – the Upper German region

[117] Most recently, see Arrighi, 1994.

around Nuremberg and Ulm laying midway between the Italian and Flemish manufacturing centers (Ogilvie, 1996: 264). For these and other geographical reasons, the Fuggers, Welsers, and others would play a role in the rise of capitalism as central as that played by the Centurioni and other prominent families of fifteenth century Genoa. Metals in one, sugar in another. Both were indispensable movements in the extension of the commodity economy, each creating new corridors of bulky commodity exchange distinctive to the capitalist division of labor. It was, then, the *intersection* of market demand (for iron, for silver) and the demand for capital to fund the new larger productive units that accounts for the first cracks in edifice of artisanal hegemony within mining and metallurgy. And this intersection owed much to the geographical hinge role of Central Europe in the era's expansion. This tendency would be most evident in non-ferrous ores – above all copper and silver – but would not be entirely absent elsewhere.

Whether or not it is useful to think of the Fuggers and their ilk as "merchant capitalists" is open to debate. It is more certain that by 1450 southern Germany's capitalists were no longer merchants of the medieval variety. Drawing a contrast with rivals from the north, Strieder wryly observes: "The Hanseatic merchant had business*es*, the South German merchant had *a* business" (1935: 97 quoted in Brady, 1996: 271, emphasis added). The Augsburg-based Fuggers – some Nuremberg firms even earlier – were "true economic conglomerates, combining long-distance trade in goods, large manufacturing enterprises [in textiles especially], and mining operations with banking and the trade in offices and regalian rights" (Brady, 1996: 271). By 1510, the Fuggers alone outstripped the capital stock of the Medici Bank at its apex (1451) by five to one; by 1547 it would be ten to one (Rice, 1970: 41; Brady, 1996: 271; Koenigsberger and Mosse, 1968: 50-52; Stavrianos, 1966: 69). But the difference between the Medicis and the Fuggers was not simply one of capital stock. It was also profoundly geographical, and this was very much a sign of the times. For the Fuggers were not simply "economic conglomerates" but also transnational firms whose operations extended from Poland and Hungary, to Iberia and the Low Countries and into the emerging Atlantic system, even stretching in time to the India Ocean (MacCarthy, 1994: 20; Mathew, 1997).

The accumulation of monetary capital is obvious. More subtle, but no less important, was its articulation with the epochal reworking of material life. This was no one-way street. The accumulation of capital compelled far-reaching environmental transformations. In the same breath these transformations – and the oppositions they created – established the provisional limits of the European economy's productive base, and therefore the possibilities for sustaining accumulation over the long run.

These articulations may be sketched briefly, beginning with the price movements of the first sixteenth century, and tracing their connections with the reshaping of the town-country relations on a world-scale.

We might begin with the "Price Revolution." The historiographical debate in the twentieth century has turned on Hamilton's landmark contributions (1929, 1934).[118] As a consequence, much of the discussion focused on developments *after* the dawn of the sixteenth century. The geographical terms of the debate have shifted in recent years away

[118] The most recent wave of discussions on the role of silver in world history has turned on the relation between Europe and Asia (Pomeranz, 2000; Frank, 1998). For an incisive review of the debate on American silver up through 1970, see Wallerstein (1974: chapter two).

from Hamilton's focus on Spain and towards the flow of silver between Europe and Asia. But the temporal focus has changed little.

This presents something of a problem. Really massive volumes of American silver and gold did not arrive in Europe until 1530, while prices had begun to move upwards by 1450 (Hamilton, 1934: 42, 180; Vilar, 1976: 104; Braudel and Spooner, 1967). American silver imports would not exceed European production until the 1560s (Munro, 1994: 172). The Price Revolution, it is safe to say, did not spring forth from the mines of Potosí.

Braudel and Spooner called this earlier movement the "pre-revolution in prices" (1967: 401). It appears to have developed in three phases. An initial slow movement, averaging about one percent per annum across the second half of the fifteenth century, accelerated around 1480, and again with special force in the 1520s (Braudel and Spooner, 1967; Kosminsky, 1955: 18). The acceleration of the 1520s was prefigured, perhaps by as much as a decade, by developments the Low Countries, where Antwerp above all served as the switchboard of Europe's copper and silver trade (Munro, 2003b; Spufford, 2006; Braudel and Spooner, 1967: 401).

The European silver revolution of the fifteenth century could not have arrived at a better time. Central Europe's mines disgorged the silver needed to lubricate the arteries of accumulation in a European economy "desperately" short of "sound money" at the dawn of modernity (Yun, 1996: 119; also Day, 1978). At play in the conjuncture of the mid-fifteenth century was not only demographic revival. A rising population may or may not favor economic growth. Rather, the decisive variable was the "very severe monetary contraction" that characterized the decades between 1440 and 1470 (Munro, 2003b: 9). This overlaid the long-run effects of sustained demonetization during the fourteenth century crisis to produce a

> collective psychology of fear, based on the structural reality of a weakly-articulated economic system. The money of account [allowing, *inter alia*, for bills of exchange] might always collapse. It surely was in no man's hands, however wealthy, to control either singly or in collusion with others. Indeed, who knew, the whole monetary economy *might again* collapse? It had before. Bullion was a hedge. The money of payment might always be used as a commodity, provided only the two uses of money, as measurement of value and as means of payment, did not get too far apart. For this, the use of bullion was essential. And hence without it, Europe would have lacked the collective confidence to develop a capitalist system, wherein profit is based on various deferrals of realized value (Wallerstein, 1974: 46).[119]

[119] van der Wee (1963) underscores the point, linking this collective psychology with the accumulation of capital and technical innovation in the fifteenth and sixteenth centuries: "The *confidence of the ordinary man* in the great firms led to deposit banking become general: the Hochstetters, Fuggers, etc., frequently took advantage of this, while concentrating and mobilizing considerable dormant capital for commercial and financial purposes. On the other hand, concentration of capital furthered fifteenth century technical innovations in German mining also. Although its importance in this connection may have been overstressed… its stimulating influence is undeniable" (1963: 320-321, emphasis added). I write these words (December 2007) in a conjuncture of sharply rising gold prices, quite directly in response to fears of world economic stability precipitated by a faltering U.S. economy.

The point is decisive. The expansion of the first sixteenth century – the expansionary *conjoncture* of the long sixteenth century – was, if not generated by the expansion of sound money issuing from the mining boom, was a crucial force sustaining the century-long expansion. This for two reasons. First, because the mining expansion assuaged what Wallerstein calls the "collective psychology of fear." It is salutary to recall that bullionist fears of monetary instability persisted well into the twentieth century. Business confidence in commodity exchange depended upon confidence in bills of exchange.

The second reason is surely related, and this concerns the secular decline in the rate of interest. It was *European* silver, and to a lesser extent African gold (Vilar, 1976), that provided the crucial material basis for the extraordinary growth of commodity exchange from the late fifteenth century (Day, 1978: 47; Goldstone, 1984). Indeed the sharp uptick in the velocity of exchange within northwestern Europe figures prominently in the geographical reorientation of silver flows towards Antwerp and away from Venice and Danzig (Munro, 2003b: 11).[120] In this context of an expanding bullion supple and the rising velocity of exchange, the price of money declined correspondingly. The interest rate in Antwerp may have fallen by as much as half between 1480 and 1520; Italy's fell too but by much less, something on the order of 20 percent (Homer and Sylla, 1996: 142; also Koenigsberger and Mosse, 1968: 50). Blanchard sees "interest rates falling to a new all-time low… throughout western Europe" between 1505 and 1526 on the strength of "successive [mining] booms" from the 1460s (2001: 110; also Munro, 1994: 172-175). Together, the declining turnover time of capital and the declining rate of interest rendered sufficiently profitable the invasion of urban capital into that murky and heretofore unprofitable terrain of "material life." The consequences can hardly be exaggerated. On the strength of this first modern silver boom,

> the financial and commercial systems utilized by the international merchant community were transformed. The great mining boom since its inception had attracted investment funding from the south German merchant banking houses. As the returns from these investments were realized *these houses were able, with their newfound wealth, to fund with increasing ease the ever growing fixed and variable requirements of their industrial enterprises*; underwrite the burgeoning volume of their exchange dealings; finance their growing involvement in international trade; and even satisfy the voracious appetite of the Habsburgs for loans. In relation to the funding of commercial activity, the silver obtained from the mines, having been turned into coins at local mints, was available for exchange operations on local money markets. This either allowed merchants in distant centers to take up funds for commercial activity secure in the knowledge that their bills on these markets would be met when they fell due, or made abundant funding available to those proffering bills to finance their trade. In such circumstances money markets where commercial credit could be funded at relatively low interest rates drew trade towards them and effected a realignment of commercial activity in

[120] Although Danzig would later re-emerge as an important sink for American silver (see Chapter Four), and for the moment remained important for other reasons – especially in the cereal and copper trades (Kriedte, 1983: 33.)

> accordance with… central European mining activity" (Blanchard, 2001: 110-111).

This was the context for the Antwerp's emergence as the switchboard of the European economy in the first sixteenth century. Antwerp's ascent was in the first instance closely bound to its role as the clearinghouse for Central Europe's silver and copper trade. This would allow it to become, if not the organizing center of world accumulation, at least the crossroads through which a wide range of productive activities would find their market. Its "industrial hinterland" encompassed not only textile manufactures but also sugar refining, shipbuilding, glass- and brick-making, and the Leigeois ironworks (Spufford, 2006; also van der Wee, 1963; Koenigsberger and Mosse, 1968: 48-52). Flemish capital was, moreover, implicated in Madeira's fifteenth century sugar revolution (see Chapter Five), which found Flemings among the island's planter elites. Antwerp, furthermore, was not only the destination of Central Europe's silver and copper but also the major entrepôt for German firms (Harreld, 2005). The Fuggers could hardly have realized their gigantic investments in silver and copper without Antwerp and its connections to African and Asian markets.

European silver, then, was decisive in the construction of a new trans-Atlantic and globalizing division of labor between town and country. Central Europe's silver mining boom alongside American bullion more than tripled Europe's reserves between 1503 and 1660, and increased the total stock of silver by a stunning 50 percent (Braudel and Spooner, 1967: 445; Elliot, 1966: 180; Parker, 1974: 527-528). Besides its profoundly destructive environmental impacts at the point of production (about which more presently), this massive influx of bullion had two major effects in sustaining a transition to a *capitalist* division of labor – the first on emergent peripheries, the second on emergent core zones.

In the first place, American silver monetized the European world-economy sufficiently that the new peripheries in eastern Europe and the New World could not easily withdraw into regional autarchy. In Poland, "the influx of precious metal… caused the price of agricultural products to soar" relative to the rest of central and eastern Europe (de Maddalena, 1974: 308; also Anderson, 1974b: 285). While this might have benefited Eastern landlords, Western (especially German and Dutch) access to bullion flows and mastery of credit mechanisms served to create an uneven division of labor, transforming small initial differences into larger and more durable structures of inequality.[121] The crowning achievement of this Western strategy of uneven development was a "system of international debt peonage" that not only subordinated Polish landlords to the world market (Wallerstein, 1974: 121-122), but gave these landlords some incentive to stay in the game. Any significant demonetization of the world-economy would likely have removed or at any rate weakened that incentive. (We can say the same about American planters.)

When viewed from the perspective of the emergent core, the West's strategy of uneven development enabled by European and then American bullion was if anything more significant. It may be objected that the international grain trade — leaving aside the

[121] Access to American silver was a precondition of Dutch financial power in the Baltic. Precious metals financed some two-thirds of northwestern Europe's trade with Baltic in the sixteenth century (Munro, 1996: 171). See Chapter Four.

pressing question of what precisely was "international" and what was "local" in this tumultuous era — was not so important because it fed only 1-2 percent of Europe's population in the sixteenth century (Glamann, 1974; Braudel, 1981: 127). Is that a lot? Consider that only one out of ten Europeans, at most, lived in cities. (And this includes mostly cities of only regional importance.) Which cities were the major grain importers? Antwerp, Amsterdam, Lisbon, Genoa, and so forth. So what we have is the Baltic grain trade providing a significant share of the nutritional needs of urbanites in those very places where capital was being rapidly accumulated. Baltic grain gave capitalists a hedge against local famine, which, along with ensuing food riots in these major cities and agrarian unrest in their hinterlands, could very well have brought to an end the original accumulation of capital (Bogucka, 1978: 12; Tilly, 1975).

In concert with the generalized economic expansion after 1450, the new silver and gold at once served to lock the peripheral monocultural regimes — in eastern Europe (cereals, timber, stockraising), the Atlantic islands (sugar), the Americas (silver, sugar) — into the new division of labor, *and* to ensure the stability of the major urban centers through which virtually all of the world-economy's money capital flowed. (Then as now.) From this vantage point, we can see the creation of a new and deeply antagonistic relation between the city and the country — and also mutually reinforcing divisions *within* the countryside. Poland, for example, was locked into a low value added agricultural sector (grain), which allowed the Dutch to concentrate on high-value lines such as garden crops and dairy.[122] (Not to mention the Low Countries' concentration of high-profit activities such as transport, shipbuilding, and finance.)

Mining & the Conquest of the Forest, Part I: How Fast Do Trees Grow, Or, How Much Is Too Much?

Silver not only contributed to the economic recovery from the long fourteenth century crisis. Silver, and the revival it made possible, co-authored an epochal shift in nature-society relations. For the metallurgical boom was at the vanguard of an emergent rupture with the feudal mode of environmental transformation. In no other major sector of the European economy, save sugar, was the political ecology of capitalism so evident, so early. Once again, environmental devastation by itself tells us little. It is hardly an invention of the modern world. Metallurgy's monstrous record of environmental wreckage dates back to antiquity (Hughes, 2001: 63-66). While Europe's fifteenth century silver boom resembled premodern extractive cycles in certain respects, the pace of environmental transformation within regions, and the speed at which regions ascended and declined, was radically different. This was in evidence within the Central European mining zone between 1450 and 1540, although its world-historical import cannot be determined from this vantage point alone. Rather, Central Europe's metallurgical expansion attains its world-historical significance only when our angle of vision broadens to include the breakneck expansion of European power across the Atlantic. The European

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[122] If the amount of grain exported from eastern Europe in the mid-sixteenth century "was small in proportion to total consumption,… it relieved pressure at vital points, notably where the Low Countries industry and Andalusian [Spanish] viniculture were producing for European markets *on a scale that could only be maintained by importing food for their own people*" (Davis, 1973: 19, emphasis added; Hoffmann, 2001).

mining boom figures, then, as *at once* precondition *and* first moment of the metallurgical commodity frontier. The globalizing historical geography of European developments would only be revealed over the course of the *second* sixteenth century, with the re-centering of iron, copper, and silver production on the world-economy's Scandinavian and American frontiers.

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We will discuss the crises of Central European metallurgy in due course. For the moment, we begin with iron. It was, in Braudel words, "a poor relation" (1981: 373). Unglamorous as it was necessary, iron was a foundational element of everyday life, and its production a crucial index of economic growth. Its fuel-intensive character made iron, in equal measure, a crucial index of environmental transformation. Iron output is therefore an ecohistorical benchmark against which we might weigh the impact of silver and copper output. It was a benchmark in two senses. It was, first, the least voracious consumer of fuel per unit of output. And it was the most voracious consumer of fuel terms of aggregate production. It was as a consequence nearly always a key player in the competition for forest resources anywhere that iron was produced. The fact that Central Europe produced half the world-economy's iron and three-quarters of its silver (and a comparable share of its copper, lead, and tin) was, then, no trifling matter of geological serendipity.

Outside of peasant agriculture, there was no sector in the European economy that demanded more from the forests than iron. On this there is wide agreement. But if there is agreement on the iron industry's toll on the forests, it has been difficult to grasp the immensity of the devastation and its economic import.

We do not lack for indications of the forest stress in Central Europe's mining regions. Indeed, John Nef would advance his classic formulation of energy crises in seventeenth century England on the basis of the Central European experience (1932, 1934, 1964; also Clow and Clow, 1957). We do, however, seem to lack the wealth of primary sources that one would wish for. There is no early sixteenth century German analogue to the Englishman John Evelyn's mid-seventeenth century warnings on deforestation (Evelyn, 1664; but see Lehmann, 1699).

The problem may be stated simply. Metal production was pivotal to the production of commodities (as raw material, especially iron) and pivotal to the circulation of commodities (as medium of exchange, especially silver). Metal production was hugely energy intensive.[123] Given the epochal shift in the tempo of expansion within the commodity sector after 1450, metallurgy's demands on European forests increased faster than the capacity of forests to meet them. And given the necessary unevenness of this commodity-centered expansion – in great measure because of the location of ores, river systems, and fuelwood – the pressure on European forests was radically uneven. Quantification remains sorely lacking outside the domain of price history (e.g. Allen, 2003). In recent years, Nef's energy-crisis thesis has been revisited, and in various turns affirmed (Malanima, 2006), denied (Allen, 2003), and moderated (Williams, 2003; Warde, 2006b). Williams captures the middle-ground position well, emphasizing the

[123] And in the category of metal production, we must also include the energy-intensive manufacture of glass, salt, and potash.

> exaggeration and alarm at the extent and perceived immediacy of timber shortages put out by special-interest groups… Generally speaking, shortages appeared in the economic core[s],… but the scarcity was probably more local and limited than widespread (2003: 169; also Warde, 2003, 2006b).[124]

Williams is surely correct in one sense, but wasn't scarcity around the "economic cores" precisely the issue? Scarcity in the peripheries was hardly a matter of concern for Amsterdam's financial sector. Rising energy costs arising from the depletion of the peat necessary to power the city's sugar refineries was a different matter altogether. The very terms of the energy crisis debate have – "general" relative to "local" scarcity – may well obscure more than they illuminate the pivotal geographical tendencies of early modern capitalism. For in the era of the "Great Frontier" relative differences were all that mattered. (Is it so different today?) Local scarcities did not build towards local devastation – although there were exceptions – and they did not build towards general scarcity, except over the long-run and then in decidedly non-Malthusian fashion. *Rather, local scarcities undercut regional competitiveness and in so doing created the conditions for the relocation of metal production to new zones, and therefore the geographical expansion of the system as a whole.*

The successive and discontinuous relocation of metal production in early modern capitalism is hardly a novel finding. But were these waves of relocation and geographical expansion meaningfully connected to ecological contradictions? One way to make this connection would be through price history. Data on rising prices might be correlated with evidence of environmental transformation, and reasonable connections inferred. The problem is that we don't have adequate price series for mining towns and regions between 1450 and 1600.[125] Which means that some other means must be found to connect two movements. On the one hand, we encounter multiple occasional references concerning the "steady deforestation" – even "radical deforestation" – by smelters (Kellenbenz, 1976: 100; Nováček, 2001: 309). On the other hand, we find a smattering of equally scattered references to fuelwood consumption. Connecting the dots is a hazardous exercise, one that involves a judicious measure of quantification and qualification. Put spatially, we might call this, in respective turns, historical geometry and historical geography. We have already introduced the broader historical-geographical tensions of this first modern metals frontier.

We may begin from the standpoint of historical geometry.

The crux of the issue is found in this set of questions. We begin from the premise that metallurgical production was indeed central to the European economy, that it was

[124] A similar line of argument, for colonial Brazil, is offered by Miller (2000) and Barickman (1998), as we shall see in Chapter Six.

[125] A point that Allen does not address as directly as he might. Seeking to discredit the "generalized crisis" thesis of Nef, and more recently Sieferle, Allen contends there was no generalized timber crisis because his sample of price data reveal no secular tendency towards rising fuel prices. Allen's price series derived from major European cities across the Continent – from London to Valencia to Gdansk, Vienna, and Florence (2003). There is also Wiebe's data on the price revolution and on wood prices specifically, written in the late nineteenth century (1895: esp. 375-376 for England); Wiebe is widely cited and today generally regarded as suggesting some basic tendencies whose implications are unclear.

unevenly concentrated within Central Europe, and that its expansion commenced shortly after 1450. First, what was the geographical extent of forest exploitation and deforestation? And second, did the incorporation of the forests and their subsequent transformation precipitate some form of energy crisis? If so, when and where? And finally, How much is a lot? That is, how much (and how fast) is too much (and too fast)?

Let's begin with a suggestive collage of estimates for the fuel consumption of various metallurgical sectors. Westermann's estimates (Table 2.1) provide one place to begin. As we shall see, the hierarchy of fuel consumption is more accurate than the quantitative estimates themselves. My revisions to Westermann's figures are included for iron and silver, the two principal metallurgical sectors, whose fuel consumption will be addressed in some detail in what follows.

Table 2.1 Metallurgy and Fuelwood Consumption, by Weight

Product	Finished Product	Wood Required (Westermann)	Wood required (Moore)
Salt (refined by boiling)	1	15	15
Pig or Cast Iron	1	15	30
Wrought or Bar Iron	1	30	90
Copper	1	200	250
Silver	1	300	10,321
Potash	1	2000	2000
Glass	1	2400	2400

Source: Westermann, 1996: 928; also Sieferle, 2001: 109.

Some of these figures correspond with actually existing historical geography better than others. They nevertheless convey the metal producers' impressive appetite for wood fuel. Just how much wood, then, might be consumed in a given regional metal complex? A few examples, easily multiplied, will suffice. Kellenbenz puts Freiberg's silver production at 60,000 m^3 annually in the early sixteenth century (1974: 257). Reichanhall's salt works devoured between 84,000 and 210,000 m^3/year between 1520 and 1630 and those in Styria and Salzkammergut 150,000 m^3/year in the 1520s (Schmithuesen, 2005: 11; Sieferle, 2001: 62). As late as the 1580s, at time "when production had already fallen off," the tin districts of Schlaggenwald and Schonfeld each consumed nearly 76,000 m^3/year (Kellenbenz, 1974: 257). By the middle of the seventeenth century, Falun's copper output rested on the capacity of central Sweden's forest to supply *no less* than 600,000 m^3/year (Lindeström, 2002).

This much has been apparent for the past century.[126] Metal output required forest input. But how much input, and how significant was it in *driving commodity-centered frontiers of exploitation?* This involves some measure of technical discussion.

First, how much biomass could be found on a given unit of forest, say a hectare?

[126] Werner Sombart, in *Der Modern Kapitalismus*, made the argument for fuel-scarcity in German lands nearly a century ago (1921, vol 2, ii: 1145-1148).

Second, since trees obviously regenerate, what was the "natural increment" of the woodlands in question? (This is important given various traditions of coppicing in Europe, whereby a plot of forest would be subdivided into a rotation to allow for regeneration.)

Third, how much fuelwood could be extracted from a given hectare of forest?

Finally, based on production estimates, how great was fuel consumption?

We can explore the answers to these questions in their respective turns.

First, what was the *potential* fuelwood harvest for one hectare of Central European forest? Any answer requires an audacious movement of abstraction. Forest productivity varies enormously by region, species, climate, elevation, and soil. Moreover, timber is not created equal and most industries – say charcoal making and shipbuilding – favored particular species. (Oak in this instance.[127]) Nevertheless, we can make reliable estimates. Looking at early modern Europe, Michael Williams thinks 250 m^3/ha is a reasonable figure for a hectare of "fairly dense woodland" (2003: 532). It is not clear if this estimate represents standing timber volume or its harvestable increment – that is, the volume of wood that could be cut and then moved from forest to factory. My guess is that most Central European forests by the mid-fifteenth century were somewhat denser than Williams' estimate, but not by much. Stocking rates were surely helped by the 150-year interregnum of the long fourteenth century crisis. Alongside a shrinking population and systemwide decommodification, the contraction of fuel-intensive economic activities across the board during these crisis years gave forests time to regenerate. Recent forestry literature suggests a density closer to 300 m^3/ha for "old growth" timberlands. Although an imperfect analogue to the hardwoods (beech especially) of fifteenth century Central Europe, old growth Douglas fir stands in the American Pacific Northwest today offer a harvestable potential of 293 m^3/ha (Prudham, 2004: 61).[128] For coastal British Columbia, estimates fall in the same range, between 275 and 325 m^3/ha (British Columbia Ministry of Forests, n.d.). European foresters have arrived at similar ballpark figure, identifying an upper limit of 287 m^3/ha (Nabuurs, et al., 2007: 396).[129]

The second key variable in biological productivity is what foresters call the Mean Annual Increment, which we will call for simplicity's sake the natural increment (Perry, 1994). The natural increment is naturally at the center of debates over sustainable yield, ongoing now since the beginning of the twentieth century (*inter alia*, Langston, 1994). How much can a given hectare of forest produce? Again we are confronted with multiple

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[127] Although Scots Pine was the most widely distributed tree. Its softwood status notwithstanding, Scots Pine (known as Scotch Fir in the late nineteenth century) apparently made for quality charcoal and shipbuilding timbers as well (Croumbie, 1890).

[128] My calculation. These are from National Forests in the Pacific Northwest. The potential yield of these forests stands in contrast to the U.S. average of 67 m^3/ha (calculated from Prudham, 2004: 62). The inference that the National Forest timberlands are old growth is from Hermann and Lavender's reckoning of 174 m^3/ha for "naturally regenerated" coastal Douglas fir, after fifty years (1999: 58).

[129] The Republic of Georgia has arrived at a similar average of 300 m^3/ha (Republic of Georgia, n.d.). Other European reports indicate a stocking rate (under managed conditions) of 300-450 m^3/ha for 130 year old oak and beech outside Vienna (Lewis, et al., 2004). The high-end figures, we should note, occur under highly managed conditions, should not be regarded as typical.

variables that confound any attempt at rigorous quantification. Perhaps the biggest problem that we face in calculating average growth across large geographical space is that old growth stands grow very slowly, but are more useful for certain sectors (like shipbuilding), while younger stands (often grown in quasi-managed coppices) grow faster, but must achieve a certain critical mass to become useful for purposes beyond simple firewood.

Forest productivity estimates are therefore crucial to our understanding of early capitalism's environmental history. In a sense, everything comes down to this. The debate over energy crises in early modern Europe is all about forest productivity. And rightly so, since virtually everything in early modern economic life came back to the forest, or rather than relation between the forest, pasture, and arable land. Sixteenth century capitalism was no more conceivable without the forest than is twenty-first century capitalism without oil. Fortunately, in contrast to oil scarcity debates today, we have some means of gauging forest-energy supply as well as demand. Unfortunately, the debates over deforestation in early modern Europe have barely tapped the forestry literature, and as a consequence there has been a marked tendency to overestimate productivity.

Among the curiosities of this debate is a broad consensus on very high levels of forest productivity. Sieferle (2001), who thinks a forest crisis was in the works by the middle of the eighteenth century, posits average forest productivity at 5 m^3/ha for early modern Europe. Hammersley (1973), who doubts that eighteenth century England experienced a meaningful energy crisis in its charcoal iron industry, posits a productivity 7 m^3/ha! If true, such productivity unquestionably would have satisfied all but the very largest iron smelters and forges.[130]

Both Hammersley's and Sieferle's figures refer to coppicing, called *haubergwirtschaft* in the German tradition (Hoppe, 2005; Ogilvie, 1996: 278). Coppicing practices were like everything else quite varied, the basic idea running something like this. Coppiced forests were typically divided into somewhere between 20 and 30 parcels and set in rotation.[131] These parcels were clear cut, the trees left to regenerate from stumps (see Albion, 1926; Westoby, 1989; Smout, MacDonald, and Watson 2005). It sounds simpler than it was. Coppicing, Sieferle reminds us, was no easy task (2001: 54). Among other challenges, tree growth had be staggered such that there was neither too little shade nor too much. Wind damage was a constant threat. Not surprisingly, then, there was centuries-long process of experimentation to increase productivity, beginning in fourteenth century (Westermann, 1996: 939-940; Fernow, 1911). The resulting wood was

[130] Calculated from Hammersley's estimate of 100 cubic feet of annual growth per acre (1973: 606).

[131] In England, the standard coppice rotation moved through 20 parcels (Flinn, 1958). In the mining regions of early modern Germany, Hauhs and Lange think the standard was 25-30 years (2001: 88), which indicates a somewhat slower rate of growth than in England – all the more so because modern forestry really begins in Germany, as early as the fourteenth century in a very broad sense (Fernow, 1911). But forest productivity in Germany may have been even lower. John Croumbie Brown (1890: 34-35), the English-speaking world's leading authority on forestry in the late nineteenth century, indicates that the standard "cycle of rotation" was at least twice as long as what Hauhs and Lange (2001) suggest. In a passage that specifically mentions both the rotation cycle and charcoal production, Brown puts the standard rotation cycle in mid-nineteenth Germany at somewhere between 60 and 120 years (1890: 34-35)! It also appears that aggregate productivity for French and English forests was slightly higher than it was for Germany (Brown, 1883, 1884, also see below).

useful in the main only for firewood and sometimes charcoal. Construction timber demanded at least 80 years, usually closer to 120 (Hauhs and Lange, 2001: 88). Shipbuilding timber needed somewhat longer, especially the always-insufficient mast timber (Albion, 1926; Brown, 1890).

It is doubtful if any coppiced stands reached the productivity levels suggested by Sieferle and Hammersley, especially before the eighteenth century. Tree plantations today manage a worldwide average of 6.6 m^3/ha annually (L. Brown, 2001: Chapter Eight). There are significant variations. Canada, with a high proportion of boreal forests in its northern reaches, averages just 4 m^3/ha annually on its plantations. Under highly managed conditions that are to coppicing what modern feedlots are to stockraising, a quantum leap in productivity has been achieved in recent decades. In the American South and Pacific Northwest tree plantations average 10-15 m^3/ha, in New Zealand between 18 and 25 m^3/ha, and in Brazil, between 14 and 20 m^3/ha (Dekker-Robinson and Libby, 1998: 476; L. Brown, 2001: ch. 8; Avery, 2000; McDougal, 1986; Victor and Ausubel, 2001: 52; Sedjo, 1980: 704; Sedjo, 1989: 13).[132] Europe's productivity, inflected heavily by managed forests, stood at 5.8 m^3/ha annually in 2000 (Nabuurs, et al., 2007: 397).

While coppicing in a very loose sense of the term has existed since the fourteenth century (Fernow, 1911), the practice did not widely diffuse until the seventeenth and eighteenth centuries. Some means of indexing the productivity of "found" rather than "planted" forests therefore seems to be in order. Among forests of the "found" variety, productivity today lies somewhere between 1-2 m^3/ha annually – between 2 and 3 m^3/ha in temperate and tropical zones, closer to 1 m^3/ha (or lower[133]) in boreal zones (Victor and Ausubel, 2001: 51; Hermann and Lavender, 1999: 58). Again there are significant variations. At the high end of the spectrum for "naturally regenerated"[134] forest are the coastal Douglas firs of the American Pacific Northwest, with a natural increment of 3.48 m^3/ha over the first 50 years of growth (calculated from Hermann and Lavender, 1999: 58).[135] These are softwoods, and conifers tend to grow faster than the hardwoods prized by smelters, shipbuilders, and potash manufacturers in early modern Europe.

So where does this leave us for the period in question? My guess is that for early modern Europe, average annual growth likely oscillated around 2 m^3/ha. It was slightly lower in Scandinavia and in the Mediterranean,[136] modestly higher on the Atlantic coast. For southern Norway, Fernow at the end of the nineteenth century estimated the natural increment at 1.47 m^3/ha, falling to under 1 m^3/ha as one moved north (calculated from Fernow, 1911: 307). Fernow's estimates for much-warmer France at the end of the nineteenth century optimistically put annual growth at 2.8 m^3/ha (1911: 206) – although

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[132] Avery (2000) reports on genetically modified (and chemical-intensive) yellow pine that produces 50 m^3/ha/year in Brazil.

[133] Siberian forests, for example, produced just .28 m^3/ha/year in the late twentieth century (Dekker-Robinson and Libby, 1998: 474). A century ago, Fernow put northern Russian forest yield (natural increment) at 6-8 cubic feet/acre or .42 m^3/ha (at 6 cubic feet/acre) (Fernow, 1911: 257). Norway's northern forests enjoyed a natural increment of "not over 12 cubic feet" (.84 cubic meters/ha); its "southern districts… *nearly* 21 cubic feet [per acre]" (Fernow, 1911: 307, emphasis added).

[134] From Hermann and Lavender, 1999: 58.

[135] Smith et al. (1997: 35), looking at the Pacific Northwest as a whole (including plantations), put average growth for the region at 4.82 m^3/ha (my calculation). Prudham arrives at a much higher estimate (2004: 3), an astounding 120 cubic feet/acre, or 8.38 m^3/ha.

[136] "In all probability yields around the Mediterranean were significantly lower than those that could be achieved in northern Europe" (Warde, 2006b: 37).

both northern and western European estimates belong to a period significantly warmer than the cool temperatures of early modern Europe (Fagan, 2000).

Williams sees coppiced growth "*approaching* 3 m^3/year" in seventeenth century England (2003: 190, emphasis added), which may be optimistic since coppices frequently were slower-growing hardwoods. Indeed, Lindsay, in his study of charcoal iron smelting in the Scottish highlands of the later *eighteenth* century, finds that annual growth was no greater than 2.05 m^3/ha in coppices (1975: 288).[137] I am tempted to say that these figures are more-or-less in the same ballpark, that the difference is one rather more of quantity than of quality. But I am not so sure. Especially before coal-fired iron was generalized – this did not happen before the nineteenth century – there was a world of difference between an economy's capacity to extract forty, sixty, or eighty cubic meters of wood from a coppice. (And coppices were not generalized until the eighteenth century, and unevenly even then.)

Central Europe, famed for its dense forests, seems to have been characterized by lower productivity relative to Western Europe. It is therefore surprising that Sieferle, an advocate of the energy crisis perspective, estimates forest growth at 5 m^3/ha in the German lands (Sieferle, 1990: 14; 2001: 122). Westermann, looking closely at the German-language literature on early modern mining *and* forestry, thinks 2 m^3/ha is about right (1996: 935). Warde is prepared to go higher, but concedes that 3 m^3/ha is a "generous estimate" for German forests in this era (2006a: 315; 267-268). At the end of the nineteenth century, Mulhall estimated annual productivity[138] for managed woodlands in Germany at 2.8 m^3/ha and in Prussia at 2.1 m^3/ha (1899: 299).[139] The Canadian forestry expert Fernow, writing at the same time as Mulhall, offers an upward revision, but only for those German forests under "conservative" or "careful management" (1907: 183, 4). These woodlands yielded an average of 3.6 m^3/ha (calculated from Fernow, 1907: 23; 1911: 24).[140] Of course, the productivity gains of these "carefully managed" forests must be weighed against the profound ecological degradation that often ensued from this management – it was not for nothing that the word *Waldsterben* (forest death) entered the German vocabulary in the nineteenth century (J. Scott, 1998: 20; also Westermann, 1996: 931).

Why should this matter? Above all because of the frictions of distance in early modern Europe. Fuel supplies were not drawn from aggregate forests. These had to be drawn from a clearly delimited radius, not more than 10 kilometers in general, somewhat more by river. Part of this had to do with the economics of bulk transport. Sieferle states this well: "for each kilometre the price of wood will increase by forty percent if transported overland, ten percent over water, and three percent over sea (Sieferle, 2001: 59). In other words, the price of wood doubled for every three kilometers overland, and

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[137] Calculated from his estimate a yield of 16.63 m3/acre (41.07 m3/ha) for a twenty-year coppice. My re-calculation of Lindsay's numbers (1975: 288), suggests a slightly lower figure, of 37.5 m3/ha or an annual increment of 1.8 m^3/ha.

[138] Calculations from Mulhall (1899: 299), who reports on annual yields from German forests at 40 cubic feet/acre and 30 cubic feet/acre for Prussian forests. One acre = 2.47 hectares. One cord = 128 cubic feet or 3.62 m^3. One cubic meter = 35.4 cubic feet.

[139] This accords with Williams estimate for eighteenth century coppices. Williams see coppices growing at rates "*approaching* 3 m^3/year" (2003: 190, emphasis added). Also Fernow's guesstimate for late nineteenth century France, at 2.8 m^3/ha (1911: 206).

[140] Fernow provides two different estimates: 53 cubic feet/acre (1907), 50 cubic feet/acre (1911).

for every 13 kilometers by river or canal (Bairoch, 1993: 60). The problems for charcoal were magnified further by its friability. Hammersley puts the limit at eight kilometers overland for seventeenth century England (1973: 606). Beyond this limit, charcoal simply crumbled.[141] To some extent, the geographical bottleneck could be overcome by dispersing charcoal pits, smelters, and forges, which did indeed transpire. But colliers could not move at will; they needed roads, and therefore the overarching tendency was rapid exploitation of proximate forest resources within a fairly circumscribed radius. The difference between a range of 2-3 and 5-6 m^3/ha is considerable. An English iron smelter and forge producing 400 tons of bar iron – such as we might find the Forest of Weald in seventeenth century – would have consumed by 45,000 m^3 annually. At a rather optimistic average forest productivity of 2.5 m^3/ha, the forge in question would have engaged the annual increment of nearly 18,000 hectares. Abstractly, this could be easily in reach of smelter surrounded by thick forests, and in the absence of other demands on the forest. (Of course, it also depended on plentiful, and therefore cheap, labor power, which could hardly be assumed even in seventeenth century England![142]) But other demands were always present, from peasants, and from other commodity sectors. In Germany by 1525 no less than England in the early eighteenth century, peasant "communities [found] themselves pushed into background once and for all" by the "provincial princes' [realization of] decisive administrative power… over the forests" (Westermann, 1996: 927; Thompson, 1976). Decisive power perhaps; but contested strongly and continuously nevertheless.

Our third question concerns the harvest. It is hard to know just how much fuelwood could be extracted from a given hectare. Sieferle believes that fully one-quarter of volume was lost in transporting logs by water, and river transport was easier on log timber than overland haulage by oxen or horse. Access to water, either rivers or canals, was crucial to any significant mining operation in early modern Europe (Ure, 1844: 206).[143] By the mid-nineteenth century, losses in river transport were still considerable – Wilson thinks 10 percent in the northeastern U.S. – although at times wastage could go much higher (J. Wilson, 2005). Rotting was major problem since cut timber could not always be transported immediately. This had as much to do with political economy as unfavorable environmental conditions. If the market was unfavorable or workers did not get paid, fellings might be left on the ground. Indeed, this was a frequent occurrence (e.g. Goodman, 1998). Heavy rains or early thaws might impede transit overland or by river. Very large trees were impossible to haul, and therefore were left standing unless sufficient labor power was available to disassemble. In this respect, the reality of higher stocking rates in the aftermath of the long fourteenth century crisis was something of a mixed blessing. Large trees were great for construction but difficult to extract. Often

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[141] Charcoal "was," Smout and his colleagues observe, "an immensely cumbersome article to move *any distance*, especially as its friability could so easily turn it to valueless dust" (Smout, MacDonald, and Watson, 2005: 182).

[142] Engaging the forest crisis debate over seventeenth century England, Flinn (1958, 1959) wishes to argue that the forest scarcity problem was not a problem at all, and if anything, the problem was one of the rising cost of labor! Unless one can imagine a scenario in which the price of labor would never enter into the calculus, this restatement of the problem helpfully clarifies the modality of forest crisis. Rising labor costs in the extraction of energy resources is part of the fabric of energy crises, not exogenous to them. Resources are only resources when nature is mixed with human labor power.

[143] Although small-scale iron production could survive at some remove from waterways.

enough, there was greater urgency for coaling timber of middling size to feed the smelters. What Wilson finds for the mid-nineteenth century U.S. is perhaps relevant to the timber frontier conditions of late fifteenth century Germany: following harvest, *half* the trees in the timber frontier around Maine's Penobscot River watershed were left standing (Wilson, 2005: 96; also MacCleery, 1996: 58).[144] Even when big trees could be moved, these had to be processed subsequently either for charcoal (and broken up by axe) or for construction (and milled). Both activities involved considerable, on-the-spot bulk reduction. Sawmilled timber in mid-nineteenth century Finland, at a time when contemporaries were fully aware of a looming forest crisis and moving to address it, witnessed rates of wastage at about 25 percent (Kuusela, 1996: 5).[145] (And this at a time when sawmill technology had advanced considerably over that of the sixteenth century.) Breaking up wood by axe, for charcoal manufacture, was characterized by even higher rates of volume deterioration.

For these reasons, I am sceptical that extractive expeditions in sixteenth century Germany could yield on average more than 150 m^3/ha. And this is really a best-case scenario, for fuelwood only. For construction timber, the effective yield would have been lower. Assuming densely stocked timber stands (say, 300 m^3/ha), logging for construction timber yielded not more than 30 percent of existing stock (100 m^3/ha), *in the nineteenth century* (J. Wilson, 2005; Kuusela, 1996). For shipbuilding timber, at best the average yield was surely lower, certainly not more than 25 percent and most likely 20 percent (60-75 m^3/ha).[146] (And this figure corresponds to a much longer rotation cycle, minimally fifty percent longer than the century or so demanded for construction timber generally.) Coppiced stands would have yielded much less, about one-third of "natural" forest stands.[147] Assuming a 2.5 m^3/ha annual increment, a twenty-year rotation would yield just 50 m^3/ha, which means over two hectares of coppiced woodlands were cleared to make a single ton of bar iron in the sixteenth century. In 1540, Europe's forges produced 125,000 tons of bar iron (Braudel, 1981: 381; Nef, 1950: 35). One indicator of its toll on the forests, the world-economy's iron output would scarcely grow at all over the next century (Nef, 1950: 79-81).

The estimate of potential yield is in some ways less important than the difficulties we've just indicated. For what becomes clear is the challenge of cutting, transporting, and then processing wood so that it becomes directly usable. The bulk of the problem, from the standpoint of capital, was the deterioration of timber volume in transit. So this in

[144] MacCleery puts the waste of the early twentieth century US timber complex like this: "Large quantities of wood were left behind after logging, sawmills were inefficient, use of wood in buildings was based on custom rather than sound engineering, and huge volumes of wood were lost to rot and deterioration" (1996: 58). Much of this applies rather easily to sixteenth century European conditions as well.

[145] Assuming that one-sixth of "cutting waste and mortality" (30 percent in 1850) was tree mortality (Kuusela, 1996: 5): "Around 1850 there was a shortage of all timber assortments and fuel wood in the south-eastern part of the country and in the regions of the western seaboard; construction timber and sawlogs were in short supply throughout southern Finland" (Kuusela, 1996: 6). Whereupon the timber frontier moved north, replicating the pattern established in the seventeenth and eighteenth centuries in Sweden (Hildebrandt, 1992).

[146] The best-case scenario for the extraction of shipbuilding oak timbers is 97.24 m^3/ha (see Chapter Four). But this yield was achieved in eighteenth-century England by virtue of well-o

[147] The ratio finds support in Kellenbenz's rough estimate of French iron production in the sixteenth century, where 500 foundries "used up some 8,000 hectares of *tall* forest, or 25,000 hectares of coppice, every year" (1976: 100).

itself would have been incentive to find timber supplies as close to the colliers and carpenters as possible. But let's not forget that logging in itself was hugely labor intensive and extraordinarily dangerous. (If mechanization has reduced the former, logging today remains among the world's most dangerous occupations.) Which means that the small logging teams were anxious to fell the most accessible, *and most manageable*, trees. Moreover, the geographical range of motion for logging was quite circumscribed. Before steam power arrived in the logging business – and this didn't *begin* to happen until the 1880s – loggers seldom ventured beyond one mile from roads or preferably rivers (Robbins, 1997; White, 1980). Two miles may be regarded as a theoretical maximum. Fuelwood extraction could perhaps reach farther, but not by much, and tethered in the strongest possible fashion to rivers, or to roads sufficient for carting. Forest exploitation was, then, selective. Deforestation was always relative. The image of the clear-cut is mesmerizing, but should not distract us from always-partial character of early modern deforestation.

Now we can turn to the demands of the mining, metallurgy, and the social forces they set in motion.

Mining and the Conquest of the Forest, Part II
The 'Battle for Wood' and the Political Economy of Deforestation

So far we have established some parameters for supply. But what of demand? To answer our fourth question – How much fuel did the mining and metallurgical industries consume? – we turn from the technics of historical geometry to the historical geography of Central Europe's mining and metals boom.

The recovery from the long fourteenth century crisis commenced in 1450. The metals boom was crucial to the revival of economic growth. Iron and silver above all. Iron, like shipbuilding, was a crucial sector in the production of the means of production (Marx's Department I.) Little could be produced in fifteenth century Europe without iron. Agriculture, shipbuilding, not to mention the tools of war, all depended on iron inputs. Indeed shipbuilding, which was probably the leading sector in the production of the means of means of production, required truly massive iron inputs. For the era's very largest ships, the Portuguese Indiamen, these 2,000-ton ships required *five hundred tons* of iron for "nails and other necessary metalwork" (Braudel, 1972: 303). Of course, most ships were not more than 20 percent as large, but the consumption of iron is suggestive.[148] Silver was the lifeblood of the emergent capitalist order, which could not function without a reliable physical store of value (as we've seen) to lubricate the rapidly growing circulation of commodities, not least of all the very tangible fictions of land, labor, and

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[148] "The remarkable development of commercial shipbuilding… added largely to the demand for [iron]. Even a wooden vessel could not be constructed and launched without nails to hold the planks together, wire for the masts, and heavy keels of lead and metal sheets to sheath the hulls in order to gain speed and to prevent the ravages of worms. Each of these large ships had two or three bulky iron anchors, equipped with iron chains" (Nef, 1950: 88). For agrarian-led iron consumption, especially in the wake of the English agricultural revolution, Bairoch (1973: 491) indicates that a stunning fifteen percent of English iron consumption in 1760 was devoted to *horseshoeing*! (This not counting iron ploughs and other farming implements!!)

money. Put simply, iron was indispensable to commodity production, silver indispensable to the circulation and accumulation of capital.

There were other metals, of course. At the heart of the political ecology of the Central European metals boom was the "battle for wood" (Westermann, 1996: 931). Mining and metallurgy did not exist on a geometric plane. The metallurgical expansion was the vanguard of capitalist revolution within Central Europe. The upshot was on the one hand a new form of very messy competition, Westermann's battle for wood, and not wood alone. This was a battle waged not just between smelters and forges for fuelwood, labor power, and other indispensable factors of production. It was also a struggle for profitability on much wider front. As capital moved into mining and metal production, at times slowly and at other times with lightning-fast audacity, production units were increasingly entrained within the competitive logic of capitalism as a whole. Profitability could and did falter. And capital could and did withdraw, often to the chagrin of the local sovereigns (Long, 1990; Vlachovic, 1963). Nor was the battle for wood limited to the sphere of metal production. Mining booms and the metallurgical upsurge altered the geographical distribution of population. Boomtowns sprang up overnight – fifteen new towns in the Erzgebirge between 1470 and 1520[149] – and these demanded not just gigantic volumes of wood for construction and fuelwood, but gigantic volumes of wood *fast*, rapidly outstripping the regenerative capacities of local forests. The battle for wood served only to intensify pressures on local forests. Many of these new towns were founded "very close to each other because of the rivalry for mining revenues between the neighboring territorial rulers" (Kellenbenz, 1976: 109). The battle for wood was then a struggle not simply among rival enterprises, or between production and socio-biological reproduction, but also between the commodity sector and peasant society – and to make matters all the more complex, the commodity and peasant sectors were interwoven in the most fundamental ways. Nevertheless, the distinction stands. The mines, forges, and smelters could not simply extract forest resources at will; they confronted a society organized around a much different relationship to nature. (A matter to which we will return later in this chapter.)

We begin once again with iron. Iron's fuel requirements typically constitute the benchmark against which non-ferrous metal production is measured (Westermann, 1996; Sieferle 2001). If the sugar plantation was the leading agent of deforestation in the New World, the iron smelter and forge was its functional analogue within Europe. European iron production increased rapidly after 1450. That year production stood in the range of 25,000 tons (Sprandel, 1969: 311). By 1500, Europe's ironworks manufactured 60,000 tons a year, 150,000 tons by 1540 (Kriedte, 1983: 56; Braudel, 1981: 381). Half this production was in Germany, in a regional belt overlapping other metallurgical sectors, including silver (Kellenbenz, et al., 1977: 203; Cameron, 1993: 118; see maps in Williams, 2003: 189; and Lynch, 2002). What Table 2.2 suggests is the central role played by German iron production in the systemwide expansion of first sixteenth century. Central European iron output rose at least fourfold between 1460 and 1540 (Nef, 1964: 44). After this point, production growth stagnated, and indeed faltered by the early seventeenth century in crucial iron zones such as the Upper Palatinate. That this timing was closely coordinated with the stagnation and crisis of the silver and copper sectors in

[149] On mining boomtowns see Molenda (1976b) and Kellenbenz (1976: 109).

Central Europe is a matter of no small import.[150] In other words, iron was caught up in the same *ecological* contradictions, no less than economic contradictions, as silver and copper. We will have the opportunity to explore the crises that took shape out of these contradictions towards the end of the chapter.

Table 2.2 Iron Output in the European World-Economy, 1460-1790

Date	Iron production	Annual rate of increase[151]
1460	25,000 tons[152]	
1500	60,000 tons[153]	6.00 percent, 1460-1500
1525	100,000 tons[154]	6.68 percent, 1500-1525
1540	125,000 tons[155]	8.3 percent, 1525-1540 6.25 percent, 1460-1540
1600	125,000 tons[156]	No growth, 1540-1600
1700	162,500 tons[157]	1.3 percent, 1600-1700 0.8 percent, 1540-1700
1750	205,000 tons[158]	2.5 percent, 1700-1750

[150] Thus while Tom Scott (2002b: 111) rightly emphasizes that the predominance of "medium-sized firms" German iron production insulated it from the devastating shockwaves of the crisis of the 1550s – in contrast to the "oligopolists" that dominated silver and copper – it seems that the difference was one between steep declines in output for silver and copper, and the onset of stagnation for iron. The picture that Kellenbenz and his colleagues paint is one in which all the major iron producing regions in Germany either grew very slowly, stagnated, or declined sharply (the Upper Palatinate in this last instance) between 1500 and 1750. The expansion of output was achieved by the emergence of new productions zones, the very same frontier pattern within the German lands as that which characterized the world-economy as a whole during this period (Kellenbenz, et al., 1977: 203).

[151] Simple rate of increase.

[152] Sprandel, 1969.

[153] Cameron (1993: 118).

[154] Hale (1985: 216); Kellenbenz (1976: 108) puts the range at 66000-110,000 tons in the first quarter of the sixteenth century.

[155] The midway point of Nef's range of European iron production of 100,000-150,000 tons in 1540 (1950: 35, 422).

[156] Goodman and Honeyman (1988: 172).

[157] The midway point of Heckscher's range for European iron production of 145,000-180,000 in 1700 (1932: 134). Van Zanden and Horlings (1999: 31) provide an essentially similar figure, of 165,000 tons in 1700. Ponting sees 200,000 tons (1991: 326), and Braudel 180,000 tons (1981: 381), produced at the onset of the seventeenth century. Bairoch (1973: 488) opts for a much lower figure, of 110,000 tons of pig iron produced in early eighteenth century Europe. Bairoch's estimate is much too low. For this reason I have not included it as a reasonable estimate. Kriedte (1983: 36) sees bar iron production at 70,000 tons annually at the "beginning of the sixteenth century," doubling by 1600.

[158] Composite of de Vries' (1976: 108) range of 145-180,000 tons in 1750 (also Sprandel, 1969). Mulhall (1898: 332) puts European output (including the United states) at 157,00 tons in 1740 (pig iron, in Mulhall's estimate). Braudel gives a very high estimate, of 250,000 tons in 1750 (1981: 381).

1790	450,000 tons[159]	5.5 percent, 1750-1790

How much forested land was engaged by this production? Answering this question involves three sets of variables: 1) the kind of iron produced; 2) the efficiency of charcoal manufacture; and 3) the fuel-efficiency of iron manufacture, measured by charcoal consumption per unit of iron. Leaving aside steel, production of which was modest, there were two types of iron manufactured in early modern Europe. Pig iron, also called cast iron, was the most basic product. It took the least energy and was the crudest form of processed iron. Pig iron could not be forged directly or hammered, even while hot (Gordon, 1996: 10, Smil, 1994: 150). It could be cast for some purposes, say the manufacture of cookware or cannons (of poor quality), but beyond this, pig was usable for very little.

Pig iron existed primary as raw material for bar iron, which is also called wrought iron. Bar iron could be used for the full range of industrial products upon which the sixteenth century world-economy rested. The conversion from pig iron to wrought and bar iron was characterized by significant losses; it was a reduction process. At its most efficient, in eighteenth century England, pig iron was converted to bar iron at 77 percent efficiency, or 20 cwt. of bar iron for every 26 cwt. of pig (Hammersley, 1973: 603-605). But it would be a mistake to generalize this conversion to an earlier period. In the 1540s, efficiency was much lower than a century later, in the range of 33-40 cwt. for every 20 cwt. of bar iron (50-60 percent conversion) (Hammersley, 1973: 604).

The technical issue is important. If iron production estimates abstract pig iron lost (as slag) in the conversion to bar iron – as much as 50 percent in the period 1450-1540 – the resulting figures of fuel consumption would dramatically understate the reality. The difficulty in formulating an estimate inclusive of conversion losses is the paucity of references to the differential output of iron in sixteenth and seventeenth century continental Europe. For Germany, however, Keißling sees “iron bars” produced in the Upper Palatinate to the tune of “almost 8,500 tonnes” in 1475 (1996: 164). This suggests that Kellenbenz’s estimate of 10,000 tons for the region 1500 refers to *bar* iron production (Kellenbenz, et al., 1977: 203). Given a conversion rate of 50 percent, which seems reasonable – not until the 1540s in England do we find records of higher efficiency (Hammersley, 1973: 604) – this would put the region’s pig iron production at 17,000 tons in 1475. If this loss of 8,500 tons of pig iron was omitted from the production estimate, we would *understate* forest exploitation by more than 205,000 *tons* (205,445), or more than a quarter-million cubic meters (256,000), the annual increment of about 128,000 hectares of forest.[160]

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[159] Composite of Goodman and Honeyman (1988: 172); Braudel (1981: 381).

[160] Here I have taken Hammersley’s estimate of 800 cubic feet of *solid* wood to make one ton of pig iron in England between the 1540s and 1760s. I have calculated the weight of one cubic foot of solid wood from Hammersley’s conversion of cord wood to solid wood of 75 percent (96 cubic feet of solid wood equals 128 cubic feet of cordwood.) This is a somehwat dubious mathematical move on Hammersley’s part, since the standard solid wood cord in the U.S. today is 79 cubic feet (Martin, 1989), or 61.7 percent.

The next step is decisive. Just how much does a cubic meter of wood weigh? Here and throughout this study, I’ve opted for a standard cord (not solid wood) volume-to-weight conversion of 5800 lbs, or 1602.2 lbs/ m^3. This is the standard figure for a cord of wood consisting of mixed hardwoods and softwoods. The figure for softwoods is 5350 lbs., and these were usually *not* preferred by charcoalers (Smout, MacDonald, and Watson. 2005: 84); the figure for hardwoods only is 6400 lbs (from State of South Carolina, 1999). The higher figure, of 6400 lbs/cord, is precisely the measure used in New Brunswick’s nineteenth century colonial timber trade (calculated from Wynn, 1981: 40). Schmithuesen (2005: 12) relies on an estimate of

How much fuelwood did the smelters and forges consume? The diffusion of the blast furnace figures prominently here. Iron's rapid expansion was enabled by the diffusion of the blast furnace; it was sometimes called the indirect process because its product (pig iron) required subsequent refining. The blast furnace used water-powered bellows to intensify heat in a tall chamber reaching 7-8 meters high (Kellenbenz, 1974: 206). The higher temperatures achieved by the new furnaces enabled the smelting of low-grade ores, and therefore widened by a considerable margin the geographical frontier for iron.

Originating in the lower Rhine valley during the fourteenth century,[161] the blast furnace took off in Germany by the 1450s, in Sweden by the 1520s and England by the 1540s (Braudel, 1981: 378-379; T. Scott, 1996: 22; Nef, 1934: 11; Smil, 1994: 150; Hildebrandt, 1992; Söderberg, 2007: 131-132).[162] In contrast to the medieval bloomery, the typical blast furnace handled an output ten times greater – 100-200 tons of pig iron around 1500, rising to as much as 500 tons by 1700. This compared to the bloomery's twenty, or at most thirty tons (Crossley, 1966: 273; Nef, 1934: 11-12; Braudel, 1981: 378-379).[163] But there was an ecological price to be paid. The very basis of the blast furnace's high productivity – the intensification of heat – pumped so much carbon into the metal that it was fairly useless without subsequent decarburization. For this reason, the bloomery was not so much technologically replaced as geographically displaced – losing its smelter functions and specializing in bar iron production, becoming in the process a forge or finery (Smith, Sisco, and Jousse, 1961; Braudel, 1981: 378-379).

1000 kilograms for a "stacked volume of 1.5 m^3," which comes to 5309.3 lbs per cord (128 cubic feet, or 3.62 m^3); this makes sense, given that Schmithuesen's frame of reference is early modern Germany, and accessible hardwoods were quickly logged out, and as a consequence softwood weight-to-volume ratios would be most common. The nineteenth century statistician, Mulhall (1898: 297), finds that approximately one cord (125 cubic feet) came to 5600 lbs or 2.5 *English* tons (2240 lbs, 20 hundredweight of 112 lbs. each). This means a standard cord weighed, in Mulhall's view, 5734.4 lbs. Lindsay, looking at eighteenth century Scottish production, puts a 3.62 m^3 cord at 5858 lbs., or 1618.13 lbs/m^3. Both Lindsay's and Mulhall's estimates are essentially the same as mine. Some bias has been introduced throughout this study by reducing all "tons" to standard U.S. tons (2,000 lbs.), rather than English or metric tons. On balance, this has introduced a conservative bias in the calculations, in favor of minimizing the impact of capital accumulation on the environment.

Finally, my estimate of forest exploitation derives from the presumption of a mean annual increment of 2 m^3/ha.

[161] Braunstein dates the origins of the blast furnace, also called the indirect process, to the thirteenth century (1983: 578). The Chinese, however, had been making pig iron for many centuries (Mokyr, 1990: 48).

[162] The geographical shifts correspond to the rapid movement of this iron commodity frontier.

[163] The comparison between blast furnace and bloomery is to some degree misplaced. The bloomery did not production pig iron, whose carbon content ranged between 1.5 and 5 percent, but rather bar iron, with a carbon content that "seldom exceeded .8 percent" (quotation from Leever, 2003: 33; for carbon content, see Smil, 1994: 150). Hence the bloomery's fuel-to-iron ratios are not directly comparable, since the bloomery produced bar iron in one step and blast furnaces produced only pig. Smil is therefore somewhat off the mark in stressing the rising fuel efficiency of the blast furnace. He puts the charcoal fuel to metal ratio of the bloomery at between 8:1 and 20:1, which is probably slightly more efficient in energy (but not in labor) than the two-step process of blast furnace and forge/finery.

The technological shift expressed the underlying, albeit uneasy and uneven, transition from craft to capitalist production. Writing about England, but with clear relevance to Germany a century earlier (the timing is not insignificant), "between 1540 and 1640, the process of iron-making took on a new and highly capitalistic form… [The new blast] furnaces were vast structures compared with the earlier forges [bloomeries]. They often rose to a height of thirty feet and were usually more than twenty feet square at the bottom, with walls five or six feet thick of brick and stone necessary to withstand the great heat necessary to obtain molten iron" (Nef, 1934: 11).

Bloomeries persisted for some time throughout Europe, wherever fuel was scarce, or markets poor (Braunstein, 1983: 578). More productive in terms of labor, there is little question that the new furnaces were "inordinately extravagant of fuel" (Pounds, 1990: 199; also Blanchard, 1978: 106; Margot, 1998: 12-13). The die was cast. Labor productivity, not energy efficiency, would be privileged.

Just how extravagant remains open to debate. Estimates vary by type of iron, charcoal manufacture, and of course by time and place. Warde's estimates are probably most dependable for Central Europe in the fifteenth and sixteenth centuries (2003, 2006a, 2006b). In his view, a ton of wrought iron took something on the order of 50-100 cubic meters of wood (Warde, 2006a: 298). If we take the average of Warde's estimate (75 m^3/ton), this yields an iron-to-fuelwood ratio of 1:60 (by weight), assuming we are dealing with fuelwood volume measured in stacked rather than solid wood. Kellenbenz's widely cited figures (1974: 257)[164] are much lower: 4 m^3 for every ton of pig iron and 9 m^3 for every ton of wrought iron. Assuming this refers to stacked wood, this translates to a weight ratio of 1 ton of iron for every 3.2 tons of wood, 1:7.2 for wrought iron.[165] Warde calls these estimates "mistaken" and "far too low" (2006a: 299).

There is no question that Warde is correct – these levels of efficiency were unknown before the end of the nineteenth century, when charcoal had long since been displaced by coal in iron manufacture (Rostoker and Bronson, 1990). But Kellenbenz was no slouch. Surely among the postwar era's leading economic historians, he spent much of his life looking at the metals and mining industries in early modern Europe, and Germany in particular. My guess is that Warde's dismissal might be premature, correct rather more in the letter than the spirit of things. Stacked up against other estimates for fuel-to-pig iron production ratios, it is almost certain that Kellenbenz's volume estimates refer not to wood at all, but rather to *charcoal* – 3.2 tons of charcoal (or about 32 tons of wood) for every ton of pig iron.[166] This seems about right. Quite independently of Kellenbenz, Hoppe (2005) proposes an iron-to-charcoal ratio of 1:3.5 for the seventeenth century Siegerland, which had by 1650 emerged as Germany's major iron producer.

Charcoal offered two great advantages. It fired as hotly as "good bituminous coal" and 50 percent hotter than air-dried wood (Smil, 1994: 116). And it burned much more cleanly, free of the sulfur and phosphorous that forestalled the use of coal in iron manufacture until the early eighteenth century (Smil, 1994: 116; Nef, 1950). (Coal would however be deployed earlier in saltmaking and brewing.) Charcoal manufacture engaged the forests at a ferocious clip after 1450. Hammersley puts the wood-to-charcoal conversion rate at 10 percent for seventeenth century England, and it was no better in late nineteenth century America (calculated from Hammersley, 1973: 605; and Gordon, 1996:

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[164] For instance, Williams 2003.

[165] If we assumed that these figures referred to solid wood, then the ratio would be 1 ton of pig iron for every 5.1 tons of solid wood, 1:11.7 for wrought iron.

[166] At a late stage in the research, I discovered that this is almost exactly the ratio that Kellenbenz offers (albeit indirectly!) in *The Rise of the European Economy* (1976). Here he notes that the Upper Palatinate's 10,000 tons of pig iron required 400,000 m^3 of timber in 1464. This weight-to-volume ratio 1 ton:40 cubic meters, translates to a weight-to-weight ratio of 1:32. (Assuming a 1602.2 lbs/m3 assumption; if hardwoods were used exclusively or predominantly – rather that mixed hard and softwoods – the ratio would be much higher.)

36-37).[167] By the mid-seventeenth century, after a century of expansion characterized by rising energy efficiency,[168] English pig iron production still demanded 24 tons of wood for every ton of metal.[169] But this may be overly optimistic – just as we saw earlier that Hammersley's estimate of forest productivity was much too high, here it looks as though the estimates of fuel consumption are much too low. Smil suggests a figure for 1720 England of eight tons of *charcoal* for every ton of pig, more than three times Hammersley's proposed ratio (Smil, 1994: 156). A century later in North America, charcoal iron would be scarcely more efficient, taking about 2 tons of charcoal for every ton of pig (Williams, 1982: 18). My sense is that Kellenbenz's ratio for charcoal is essentially correct – we shall say 30 tons of wood (three tons charcoal) for every ton of pig iron – and a helpful baseline from which to proceed. Ogilvie puts the figure at 2.5 tons of charcoal for every ton of pig for sixteenth century Germany (1996: 277), but this seems more reasonable for Germany in the *seventeenth* century, and probably not generalized even then (Hoppe, 2005).

The real question of iron's fuel consumption turned on the conversion of pig into bar iron. In the eighteenth century, the European pig iron-to-charcoal ratio was 1:3 (Rostoker and Bronson, 1990: 141). There was improvement in the nineteenth century, in some places to as low as 1:1.8 but with considerable regional variation. Figures as a high as 1:4.5 persisted (Rostoker and Bronson, 1990: 141), a ratio that seems reasonable for the fifteenth and sixteenth centuries. But the fuelwood consumption of bar iron was not simply the added ratio of pig and bar. It also included the amount of pig left as slag. And this amount was considerable. The English experience suggests a range of 40-50 percent left as slag in the 1540s and 1550s. Not until 1568 would the slag proportion fall to one-third (Crossley, 1966; Hammersley, 1973: 604). Thrupp thinks one-third was typical for Germany in the late fifteenth century (1972: 257). But this is surely a case of reading backward from the English experience a century later. Even then we are dealing with best-practice conversion rates there were not generalized until the *seventeenth* century. Nevertheless, let us grant Thrupp's guesswork as a very conservative benchmark. If so, then the production of 10 tons of bar iron involved some 90 tons of woodfuel (about 112 m^3), more than doubling Westermann's estimate (1996: 928). And even with this doubling, the higher estimate still understates consumption.[170] This is summarized in Table 2.3.

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[167] Smil identifies a much higher conversion rate for the early modern era: "Typical charcoal yields… were only between 15 and 25 percent of the air-dried wood" (1994: 117). Hammersley's (1973) and Gordon's (1996) studies, engaged with the details of iron manufacture in specific times and spaces, seem rather more trustworthy. Even the high end of Smil's conversion ratio (15 percent) for charcoal was barely reached by Swedish colliers in 1880 (Gordon, 1996: 36-37).
[168] A "load" is equal to a "about a ton" (Perlin, 1989: 219; also Smout, MacDonald, and Watson (2005: 275). If so, Crossley's data suggest a charcoal-to-pig iron ratio in the range of 5:1 or 6:1 (1966: 275, 280).
[169] Calculated from Hammersley's figures (1973: 605-606).
[170] Warde's high figure of 100 m^3/wood for every ton of iron (bar iron, presumably) translates to 1:80 if the wood was mixed hard and softwoods, or 1:88 if the wood was hardwood (2006a). Nef (1932: 194), in the classic English-language formulation of early modern timber crisis, estimated that 200 cubic yards of woodfuel was necessary to produce a single ton of bar iron, which yields a metal-to-weight ratio of 1:123!

Table 2.3 Iron-to-Fuelwood Ratios in Central Europe, 1450-1540

	Ratio	Iron Produced	Cumulative
Pig Iron	1:30	15 tons	450
Bar Iron (without slag)	1:45	10 tons	450
Bar Iron (with one-third slag)	1:90	10 tons	900

This translates to a gigantic volume of forest swallowed up by the iron smelters in a very short period of time. If output stood at 30,000 tons annually in 1500, Central Europe's iron sector consumed 2.7 *million* tons of woodfuel. One should note that this is an *annual* figure. There are three main ways to consider, albeit abstract, the spatial dimensions of this demand. In terms of mean annual increment, this was 1.7 million hectares.[171] From the standpoint of a highly efficient coppicing system (in Germany called *haubergwirtschaft*), it comes to 614 square kilometers each year.[172] If "natural" stands were cut, then the zone of exploitation extended 22,500 hectares.

While the latter two angles of vision correspond to *actual* forest exploitation strategies, the first is purely heuristic. Heuristic in an important – should we say epochal? – sense. By 1540 Central Europe's iron output was twice as large, perhaps larger (Kriedte, 1983: 56; Braudel, 1981: 381). If production in Central Europe moved from about 20,000 tons to about 65,000 tons between 1450 and 1540, the zone of exploitation extended from 1.13 million hectares to 3.68 million hectares of natural increment. This was every bit as important as Europe's overseas expansion. Indeed, it was amongst the material conditions of this expansion.

Capital's assault on the forests was every bit as epochal in the geographical expansion of Europe as the voyages of Columbus and da Gama. What differed, relative to the American theatre, was the intensity of the battle for wood, between multiple economic sectors, and between these and the peasant economy. The limits to expansion within Central Europe were much more tightly drawn than they were in the New World. And yet the two moments were tightly intertwined, not least because iron was only the tip of the iceberg. The other crucial mining sectors of Central Europe were copper and silver. Without iron, ships could not be built. Without copper and above all silver, Europe could not trade, at first with Africa, and then with South and East Asia.

[171] Assuming 2 m^3/ha at 1602.2 lbs per cubic meter of wood. This comes to 56.7 hectares of annual increment for every ton of bar iron.

[172] Assuming a twenty year rotation (and therefore 12,280 km2 in constant rotation) and very high annual productivity of 2.75 m^3/ha. In this case each parcel in the rotation would produce 44 tons once every two decades. Let us bear in mind that such coppices were quite rare in German lands before the seventeenth century

'The wildness is taken from the forest by the metalworks': Making Silver, Accumulating Capital[173]

We may take silver's production's fuel consumption as a second benchmark, since data for copper mining centers are lacking. We may recall from Table 2.1 that Westermann's estimate identifies a quantum leap in the fuel requirements of silver relative to iron. Silver output was measures in thousands of kilograms; iron's in tons. We would therefore suppose the former's impact on surrounding forests to be relatively small, however pronounced in a few locales. But this does not seem to be the case, although certainly the iron industry's pressures on forests were more diffused. Joachimsthal in Bohemia (the present day Czech Republic) is a case in point. Europe's preeminent silver mining center in the 1520s, Joachimsthal produced no less than 326 tons of silver between 1516 and 1600. This "required a forest of 42,000-52,000 hectares" which would have yielded between 5.05 million and 6.25 million tons of woodfuel (Westermann, 1996: 935, my calculations).[174] Westermann underlines that this was the *smelter* requirement. Additional consumption should be set for "pit and tunnel construction," as well as housing and heating. These requirements contributed an additional 50 percent to the Joachimsthal's annual timber consumption.

The ratio that emerges is almost unbelievable. Not 1:300 as the estimates in Table 2.1 suggest, but 1:15,482 if we take Westermann's low estimate of 42,000 hectares of forest.[175] (If we presumed a rate of extraction higher than 150 m^3/ha, the ratio would be much higher.) Now, the ratio must be revised downwards, because as we know, in Joachimsthal no less than Potosí a few decades later, not all silver mined and smelted entered the official statistics. The "real output is likely to have been much higher" (Majer, 1994: 95). Let us say, then, that output was 50 percent greater, or 489 tons of silver during the sixteenth century. This revises the silver-to-fuelwood ratio to a mere 1:10,321, again taking Westermann's lowest spatial estimate of deforestation.

Although the data for silver mining centers' fuel consumption is sparse, we can crosscheck this against Freiberg's consumption. Westermann's reckoning for Joachimsthal translates to fuel consumption at between 60,000 and 74,400 m^3 annually, averaged over the last 84 years of the sixteenth century (1996).[176] This is large but not larger than the consumption of saltworks or other mining centers. Kellenbenz puts Freiberg's annual consumption at 60,000 cubic meters in the early sixteenth century (1974: 257), at a time when its silver mines produced 9,000 marks/year (2.25 tons) (Nef, 1941: 579). This gives us a silver-to-woodfuel ratio of 1:19,266 for the official production figures; if we inflate these figures once again by fifty percent, we still get a ratio of 1:12,818 – that is, about twenty five percent greater than the estimates for

[173] The phrase is from Lehmann (1699: 14), from his report on the Saxon Erzgebirge in the later seventeenth century.
[174] Assuming 150 m^3/ha harvest and 1602.2 lbs/ m^3. A higher rate of forest extraction would generate a higher rate of fuel consumption, and therefore I have opted for a more cautious estimate.
[175] Calculated from 5.047 million tons of woodfuel and 326 tons of silver.
[176] My calculation. From the range cited above, calculated with more precise figures of 5.047 million and 6.249 million tons of woodfuel.

Joachimsthal! Nor would the figures shift for Freiberg if we look at Thomasius's figures for the 1556, at a time when silver production "was more than twice as great" relative to 1526-35 (Nef, 1941: 579). Thomasius records charcoal shipments derived from 40,000 m^3 *over just three months* of 1556 (1994: 117). The ratio holds up well. Taking account of seasonal fluctuations, we can safely say that Freiberg was consuming about 120,000 m^3, twice as much as three decades prior, and producing twice as much silver. No wonder that a century later, the surrounding forests were "so hewn, that hardly a quarter of it is yet standing. His most serene Highness the Prince of Saxony often purchases from the Bohemian border Counts large pieces of wood by river for his *Saigerhütten* and smelting ovens at Freiberg" (Lehmann, 1699: 92).

Joachimsthal's rapid rise would be followed by an equally rapid decline. (A story to which we will return presently). Nearly two-thirds of Joachimsthal's silver would be produced in its first thirty years, about 203 tons minted. (Let us say 304 tons to account for unregistered production.) Taking our lowest estimate of 1:12,818, this translates to an annual consumption during the boom years of 1516-45 (production peaked in the mid-1530s) of more than 162,000 m^3 annually, complemented by an additional 86,000 m^3 annually for construction and heating purposes. This would have been sufficient to push back the forests at a rate of 1653 hectares of forest annually. This was certainly a sufficient rate of deforestation to create significant problems within three decades, by which time some of the forest would have begun to regenerate. But such newer, quasi-coppiced forests would have yielded less than a third less timber than the original stands. There was a clear logic of declining returns at work.

It was, then, no surprise that the mining expansion devoured central Europe's forests. By the sixteenth century there was "a general deforestation in Europe, which surpassed that of the thirteenth" (Appuhn, 2000: 865).[177] What took some six centuries for feudal Europe to effect (Darby, 1956), the emergent capitalist order achieved in just over a century. To the consequences of this achievement for Central European mining and metallurgy, we can now turn.

1557, Or, the 1929 of the Long Sixteenth Century: Mining & the First Great Crisis of the Capitalist World-Economy

The systemwide expansion launched in the 1450s came crashing down a century later. The curtain had come down on the first sixteenth century. The turning point, if any such world-historical shift can be reduced to a single year, was the crisis of 1557. The first sixteenth century now gave way to a second. Philip II's decision to reschedule his debt, converting short-run obligations to long-run bonds through the mechanism of the *juro*, initiated the crisis. France followed suit in short order, declaring bankruptcy the same year. Portugal would so in 1560. The bankruptcies (and these were not the only ones) precipitated a crisis in Antwerp's money market and thence capitalism's "first big international bank crash." It was a blow from which Antwerp would "never fully

[177] For Germany, see Blickle, 1981: 37-39, 73-74; for Czech and Polish zones, see Czetwertynski-Sytnik, et al. (2000: 274); for Scotland, see Smout, MacDonald, and Watson (1995); for Venice, see Appuhn (2000); for Spain, see Goodman (1998).

recover" (Koenigsberger and Mosse, 1968: 51; Braudel, 1984: 153; Scammell, 1989: 227; Wallerstein, 1974: 183-184).

Central Europe, where capitalism had advanced into material life most spectacularly, was hit hardest. The Fuggers, most famously, were devastated by Philip's bankruptcy. By 1600, "most of the southern German firms were bankrupt" (Koenigsberger and Mosse, 1968: 53). Seventy "great Augsburg firms" went bust between 1556 and 1584 (Kellenbenz, 1976: 80). Taylor underscores the severity of the crisis: "no trading community in modern Europe has ever experienced such a profound and lasting disaster as did the German middle class just at the moment when their financial power was at its greatest" (2001 [1946]: 7). But the roots of the problem did not lay in commerce alone, as Taylor suggests. From the vantage point of the world-economy, the problem was not the German firms' centrality in the circuits of finance capital but rather their engagement in the commodity-centered enclosure of material life. Put differently, the problem for the southern German firms was not too much focus on trade, but too little. They were at once merchant capitalists of a sort, and at the same time they were insufficiently mercantile (and excessively industrial) in substance.[178]

Two facts are salient here. First, as we shall see, the accumulation crisis hit first not in finance, but in production. Capital had commenced a "dramatic" withdrawal (and innovations slackened as a result) from Central European mining and metallurgy in the decades preceding the 1557 crisis (Bartels, 1996; Braudel, 1982: 323). In 1545, the Fuggers withdrew from Neusohl in Slovakia (Vlachovic, 1963). In 1552, two of the Tyrol's largest mining firms, "plagued by the overextension of credit and the high costs of deeper mines, went bankrupt. Creditors from Augsburg were pulling back. In 1553, the Augsburg firm of Baumgartner, the most important investor next to the Fuggers, gave up its Schwaz [silver] mining interests" (Long, 1991: 351).

Second, the real masters of the financial universe were not the Fuggers at all, but rather the Genoese diaspora. They alone retained sufficient flexibility to scale the heights of "grand capitalism" in wake of the crises of the later sixteenth century (Braudel). It did not hurt that Genoese capital, insofar as it engaged production, was wrapped up in sugar rather than silver. In any event, by 1557 the worm had turned. The Age of the Fuggers had given way to the Age of the Genoese (Ehrenberg, 1963; Braudel, 1984: 157).

Within Central Europe, signs of crisis had been evident for some time. By any measure, the geographical center of gravity in mining and metallurgy began to shift, a movement accelerating by the middle of the sixteenth century. There was a clear movement of Central European decline and a subsequent extension and recentering of

[178] Kellenbenz cautions against overstating the crisis, but in doing so merely reinforces the argument for the 1550s as a decisive turning point in the historical geography of capitalism. "That there was a serious crisis is certain, and perhaps an important phrase of early capitalism did end at this time. But a revived system of putting-out enabled new forces to take over, and perhaps all that vanished was nothing more than the first glamour of capital wealth" (Kellenbenz, 1976: 81). There is of course no question that proto-industrial economic organization persisted and indeed, even flourished after the crisis of the 1550s. But the efflorescence of the putting out system was a sign of relative weakness rather than relative strength in the European world-economy at this point. Small may be beautiful, but the elixir of accumulation it is surely not. The geography of accumulation had begun to shift in the most decisive fashion from the continental to the coastal, and from small-scale to large-scale. This would become quite evident in the rising scale of production inscribed in the movement of the silver and copper commodity frontiers to Potosí and Falun, and the sugar commodity frontier from Madeira and São Tomé, to Brazil, all in the later sixteenth century.

production to the frontier – for iron and copper in the direction of Sweden, for silver to the Americas. European silver production declined by three-quarters between 1526 and 1618 (Kriedte, 1983: 37). Iron production in the Upper Palatinate declined by three-quarters between the mid-sixteenth century and the eve of war in 1618 (DuPlessis, 1997: 104). Neusohl's copper production dropped from a peak of nearly 2,000 tons in 1510 to less than 300 tons in 1620 (Kriedte, 1983: 37). (Schwaz and Mansfeld copper output registered similar declines.) Meanwhile, new production zones began to emerge.

The crisis in question was above all a crisis of profitability and therefore one of accumulation. All sorts of problems are perfectly surmountable so long as one can realize above-average returns. And modern crises of profitability are, ultimately, about the articulations of world-scale accumulation regimes and regional production complexes, which are in the same moment also regional ecological regimes. These articulations form the fault-lines of modern environmental history. All crises are ecological, even if the precise content of the specific contradictions was enormously varied.

What was driving the crisis of Central European metals? The conventional story line for European silver is well established. American silver simply pushed out the European competition (e.g. Taylor, 2001: 7). In this scheme of things, Central Europe's ores were tapped, Potosí's richer, and there ends the mystery. There is of course a rather large nugget of truth in this explanation. Potosí's veins *were* extraordinarily rich (as we shall see), and Central Europe's fields had been exploited heavily by the 1540s. (Of course, declining ore quality is in itself a weak indicator, since it is but one of many conditions of profitability.) Central Europe's decline was surely reinforced by Potosí's ascent. *But it was not precipitated by it.* Central Europe's output peaked between 1526 and 1535 at 88 tons annually (Nef, 1941), declining thereafter.[179] Central Europe's decline as a copper and silver producer – recall that the two ores were found together throughout the region – started *before* the rise of Potosí, and *before* the great financial crisis of 1557 that inaugurated the long stagnation of the second sixteenth century (c. 1557-1648).

The crisis of Central European mining and metallurgy was, as crises always are, multidimensional. Some forces were more global than local, others more "social" than "ecological." The point I would underline is that these moments can only be grasped as a single process through which the political economy and political ecology of crisis unfold as a differentiated unity. Our angle of vision is the former, but in so doing I give no effort to creating durable lines between the two.

The 1557 financial crisis may have sealed the fate of this first metallurgical frontier, but it did not create the conditions of crisis. These must be found in the unstable mix of relations between an emergent capitalist production regime and the non-capitalist socio-ecological formations it engaged and challenged. Braudel in my view provides the best starting point for this kind of approach to metallurgical crisis in early capitalism:

> Europe, because of her very expansion, was acting as if she had decided to delegate the trouble of handling of the mining and metallurgy industries to dependent regions on her periphery. In the heart of Europe, not only were falling yields limiting profits, but the 'fiery furnaces' were destroying

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[179] Munro (2003b: 43) dates the peak slightly later, during 1536-40, which is in any event still before the arrival of American silver on a large scale. This fits with Braudel's characterization of 1540-1570 as a period of "intercyclical recession" (1984: 336).

> forestland, and the price of wood and [charcoal] was becoming prohibitive, so that the blast furnaces could only operate part of the time, thus immobilizing fixed capital to no purpose. Meanwhile wages were going up. Small wonder then that the European economy as a whole applied to Sweden for iron and copper; to Norway for copper; before long to distant Russia for iron; to America for gold and silver (1982: 325).

Braudel's picture of rising costs, immobilized capital, and falling profits may be fleshed out in successive stages. Where this picture really breaks new ground is in its recognition of ecology. Bartels for Germany (1996) and Vlachovic for Slovakia (1963) agree that the period after 1557 was characterized by rising costs of production. Central European mining was not simply the victim of American bullion. It faltered under the weight of its own contradictions.

Nowhere is the evidence as strong as we would like it to be. But this is simply amongst the occupational hazards of early modern economic history. Surely at the top of the list are rising fuel prices. The evidence is slim, but nevertheless suggestive. In Cipolla's view, "from 1470 onward, in all of central Europe, the price of wood was rising, slowly at first, *then rapidly*" (1976: 229; also Kellenbenz, 1976: 100) – a movement he attributes to relative deforestation rather more than price inflation. Schmithuesen, highlighting the battle for wood in German lands, finds that

> during the fifteenth and sixteenth centuries, the cities and pre-industrial [sic] entrepreneurs were already having to face the fact that the available increase in wood supply from the forests… would not adequately cover the growing demand for firewood and construction timber, for salt production, and for the metallurgical factories. There was an *unprecedented increase in demand and hence, in prices*, in the regional and international trade in logs and sawn timber, *which progressively had repercussions in many parts of Central Europe* (2005: 14, emphasis added).

Allen (2003), who is generally sceptical of the energy crisis thesis, offers some suggestive price data for Strasbourg, outside the metallurgical zone but within its economic orbit. The "real price of energy," Allen contends, increased about 25 percent between for Strasbourg in the first half of the sixteenth century (2003: 479). This may not seem much in itself, but the increase becomes significant in comparative perspective. Of the ten cities examined, only Gdansk registered a higher rate of increase – and this also for reasons not unrelated to ecological transformation. Meanwhile, Antwerp, Amsterdam, and London registered a *decline* in the price of energy (Allen, 2003: 479).

That fuel supply was an important issue from the earliest moments of the metallurgical boom seems quite clear. In the late 1450s, Nuremberg – not coincidentally the site of modern "forest sowing" and a longstanding metalworking center – had been compelled to relocate its copper smelters some two hundred kilometers northward, following the virtual shutdown of the industry in the wake of fuel supply difficulties (Wellmer and Becker-Platen, 2002: 725; von Stromer, 1970: 214; Powers, 1999: 265; Ortloff, 1999: 60). Thus it was not only forest legislation that registered the shrinking sylvan buffer, but the spread of commodification. From end of the fifteenth century in central and southern Germany, excessive

> timber felling… [produced a situation where] purchases of building timber, timber for fuel, and charcoal *could frequently not be met from local forests. Even in relatively forested regions of south Germany*, specific timber and plank markets appear at the level of the medium-sized towns… Both the medium-sized and of course the large towns proceeded in the sixteenth century to buy up whole parcels of forest from noble and monastic seigneurs, even some distance away, to cut and market timbers (Keißling, 1996: 166-167, emphasis added).

These purchases did not always occur in an atmosphere of liberty. During the peak years of Saxony's mining boom, around 1530, "the Elector… decided on the purchase of large woodlands from the gentry, *mostly against their wishes*, in order to possess the supply of usable timber" for the mining centers such as Freiberg (Thomasius, 1994: 114).

Thus did timber and even fuelwood become objects of, if not *long*-distance trade, then certainly *middle*-distance commerce. Which is another way of saying that the fuelwood frontier was in constant motion. Saxony, home to Freiberg among many other mining centers, is an important representative of this frontier movement. "Many chroniclers report that in the fifteenth and sixteenth centuries, in the neighborhood of the mining centres of Freiberg, Annaberg and Schneeberg scarcely any woodland survived" (Thomasius, 1994: 114). As nearby woodlands were exhausted, the frontier movement persisted, leading "to felling in more and more distant, but still wood-rich districts" (Thomasius, 1994: 114). And yet even the best roads in sixteenth century Germany were quite poor: "it was impossible to move large loads over long stretches" (Sieglerschmidt, 1996: 31). Roads were also crucial for gaining access to the woodlands themselves (Lehmann, 1699: 128). Even for roads of passable quality it was "ruinous to transport [fuelwood] more than thirty kilometers" (Braudel, 1981: 364). Construction timber might bear longer journeys – perhaps twice as distant (Thomasius, 1994: 114) – but these generally required access to river transport, which cut costs by 75 percent (Sieferle, 2001: 59). Even river transport, however, seems to have been insufficient. "The woodlands opened up by… waterways were overused and devastated" through the Saxon Erzgebirge during the sixteenth century (Thomasius, 1994: 114). Canals, sometimes as long as 30 kilometers, were built, which certainly extended the fuel catchment zone, but at enormous expense (Westermann, 1996; Thomasius, 1994: 121-122). And such expenses could be met only because of Saxony's primacy within the Central European silver complex – fully half of European silver flowed from Saxon mines between the 1470s and the 1530s (Scott, 2002b: 106). The ecological contradictions were as inescapable as they were enduring. Fully a century and a half later, in Lehmann's searing words,

> The wildness [had been] taken from the forest by the metalworks, which have hence lighted the larger portion of the forests through wood hacking and [char]coal burning, that one may at last in this formerly monstrous forest suffer a depletion of wood… In some mountain towns [in the Saxon

> Erzgebirge] once built within thick forests, [there is] left standing but a single stalk as a token (1699: 155, 176).

We have in the main treated metallurgy's relation to the forest as a fuel-consuming sector. But this is only part of the story. Construction timber was also demanded, and this was a crucial dimension of the competition for forest resources. There were two key sources of this demand. Although iron's demand for construction timber was reasonably low, copper and silver's was not. Among the inescapable geographical distinctions between premodern and modern mining was the latter's plunge into the earth. (Iron would move in this direction too, albeit much more slowly.) A whole series of technological innovations to drain water from the ever-deeper mineshafts was the starting point of the silver-copper boom (Braunstein, 1983). And this entailed a massive subterranean construction boom. By the 1470s Schneeberg's silver mines (in Saxony) had reached 200 meters; by 1482, this had doubled (Kellenbenz, 1974: 199-200). Joachimsthal's mines reached nearly 400 meters after just four years (Majer, 1994: 95). Westermann explains the construction challenge:

> All the main and side tunnels as well as their ends that went through brittle rock, had to be reinforced with wood constructions. To do this, piles were driven at an angle to the lateral pressure of the rock; ceiling beams were set on top to hold back the pressure of the mountain along the mine ridge; lengthwise flooring kept the entire wood construction from sinking; posts made sure that the rock could not fall down between the piles and ceiling beams. Through the tunnels that had thus been made secure, the ore and stones mined on the spot could be transported to the mine shaft in small lorries or carts on tracks. The shafts themselves were supported by wood constructions and equipped with various slide, ladder and liftsystems as well as pumping systems, all made of wood. For all these systems, special wood in various dimensions and qualities was needed. [A clear parallel here with shipbuilding!] The wood used in mine construction had to be strong and healthy. The trunks had to be peeled, absolutely not chopped, so that they would not rot quickly due to the high moisture underground. The total amount of wood required starts to become clear, however, if we realize that all the wood used for this kind of construction only held for a limited period of time and so need to be replaced, every six years on the average (1996: 930).

Looking at the early sixteenth century Bohemian Erzgebirge, Kvet explicitly links rising mine depth to escalating "demands on wood," prompting Crown regulation in 1525 to protect supplies (1994: 101). But it was not merely the static construction demands of mineshaft maintenance coupled with the exhaustion of proximate timber supplies. For the construction demands were anything but static. The subterranean frontier had to be continually extended. And this drew upon not only the timber resources but also upon the geometrically rising demands to move water from the mine depths. In some places, it was possible to use to hydraulic power to do this. In most cases, however, animals did the work, and more animals meant renewed pressure to extend arable land, which was often carved out from the forest. In 1569 Freiberg, for instance, 2,100 horses were at work draining water from the flooded mines, and they were fed with hay from no fewer than 12,600 acres (Cathro, 2006; Wilkinson, 1973: 123).

Everywhere that demand for construction timber and demand for charcoal overlapped, there was a vigorous battle for wood. There was widespread awareness of the difference between "timber forest, where no firewood [was] to be cut," and "leaf forest" (Fernow, 1911: 40), but practices of forest exploitation seem to have honored the distinction only in exceptional circumstances. Few states in early modern Europe were capable of effectively enclosing timber stands against the incursions of the iron smelters, as we shall see in the case of seventeenth century Castile (Chapter Four). Wood was harvested for charcoal and firewood first – not only because these were low-profit lines and could not bear the cost of transport (unlike construction timber), but also because the charcoal itself could not be shipped over long distances without significant degradation.

That fuel and timber prices did not rise faster has everything to do with initiatives "from above" to enclose the forest commons. It bears emphasizing the fuel costs were on the order of 70 percent of any smelter or foundry's budget (Wright, 1996: 194). By the later fifteenth century, the German states began to actively regulate forest access for their own revenue-maximizing interests, above all favoring fuel-intensive commodity sectors (Kellenbenz, 1974: 257; Waring, 1987: 239). Westermann sees a secular trend towards expanding forest enclosures, to the benefit of the princes and to the detriment of the peasantry, between 1450 and 1525 (1996: 927). These enclosures typically assumed the form of forest legislation, which ranks amongst the surest indicators of forest stress (but not *necessarily* crisis). For these measures registered the very process they sought to regulate, forest exploitation. Such legislation in its broadest sense was not new to early modern Europe. Antecedents may be found during the waning years of the late medieval expansion (Birrell, 1993). But the proliferation of forest legislation in the sixteenth century across the Continent, and its acceleration thereafter, indicates a sea change in the relation between European society and its sylvan substrate.

In Germany forest legislation was issued earlier and in more concentrated form than elsewhere. By the end of the fifteenth century, we find "various provisions which are unquestionably dictated by the fear of a scarcity of timber" (Fernow, 1911: 40). Pasturing was outlawed in newly cleared forest; sheep were identified as a special barrier to forest regeneration (Sieglerschmidt, 1996: 16; Fernow, 1991: 40). Fernow sees a tight cluster of forest regulations enacted by "most of the German States" between 1515 and 1590 (1911: 52). These

> had the force of general law exercising police functions over private forest property… The objects in view with this legislation were entirely of a material kind: the conservation of resources…. [I]t was [principally] to secure a conservative use of the princely as well as private forests, since devastation of the latter would require the former to be drawn on extravagantly; *it was to stave off a timber famine, and in certain localities to assure particularly the mining industry of their wood supplies* (Fernow, 1911: 52, emphasis added; also Keißling, 1996: 166).

The drive to enclose the forest commons was driven on the one hand by the demands of the smelters, and the urban industries they supplied. On the other hand, enclosures were also precipitated the tensions emerging between peasant society and the commodity sector. Here demography figures prominently. The demographic expansion began in Germany, feebly by 1470, and in earnest by 1500 (Helleiner, 1967: 15, 26; Pfister, 1996: 39-41; Scott, 2002b: 119). Seccombe finds the two movements related: "restricted access to woodlands, treated formerly as commons, eliminated a vital means of supplementing subsistence for the swelling ranks of the land-poor, thus stimulating" semi-proletarianization and proto-industrialization, and in so doing partially unhinging family formation from access to land (1992: 160). It was, then, less an abstract Malthusian moment than the unstable concert of feudal and proto-industrial demographic orders. Indeed, the demographic push seems have to been strongest in those regions enjoying sustained manufacturing and extractive expansions between 1500 and 1550. (In Saxony for instance.) Growth would slow appreciably as economic expansion gave way to stagnation in the second sixteenth century (Rosener, 1996: 70).

It is in any case quite clear that the demographic expansion after 1470 was leading to geographical expansion by 1500. In part this marked the "resumption of the [medieval] German movement eastwards" (Helleiner, 1967: 25). But there was also a clear internal movement of converting forest to arable land. The author of the *Zimmerische Chronik* (1550), reports that

> In our time the population of Swabia, *as in all other lands*, has so markedly increased and multiplied that the lands have been more cultivated than at any other time in human memory, so that there is no corner, even in the most remote forest and in the highest mountains, that remains uncleared and unpopulated (quoted in Pfister, 1996: 41, emphasis added).

By 1560, "the land available [within the Empire] had run out," generating an early modern incarnation of the late medieval crisis, characterized by widening poverty and "ecological exhaustion" (Pfister, 1996: 41). Hence, precisely at the moment when the metallurgical sector faced unprecedented crisis, the cornerstone of its profitability, cheap fuel, was being removed by the demographic push – which was itself conditioned by metallurgy's great expansion.

As if to go from bad to worse, the "Little Ice Age" returned with a vengeance at the very moment when this agro-demographic movement seems to have reached its limits. The period 1450-1550 seems to have been relatively warmer and drier than the centuries immediately before and after (Pfister, 1996: 42). The turn towards colder weather was not destiny. The Dutch and English agricultural revolutions raised yields significantly despite this unfavorable climatic turn (Overton, 1996; Brenner, 2001). Germany would not host such an agricultural revolution, and this would intensify the underlying dynamic. Not only would yields begin to fall after 1550 (Pfister, 1996: 42). Falling yields, all things being equal, had to be recouped through the extension of arable, and this could only be accomplished a large scale (so long as population continued to grew, which it would continue to do until 1618) by pushing back the forest. Yields were also maintained by extracting nutrients from the forests, through the common practice of "raking"

(Schmithuesen, 2005: 8). Peasants would collect leaves and needles “as a substitute for fertilizer,” producing a whole series of “negative effects on stand development” (Schmithuesen, 2005: 8; also Perry, 1994: 489). Finally, we have just seen that sheep were targeted by forest legislation, which registered the pasturage functions of these sylvan commons. When forest exploitation accelerated, as it did around mining centers, the upshot was a feedback loop of overexploitation. Forests were cut down, and sheep and goats consumed the fragile shoots that otherwise would have matured. The “once thick and enormous woods” of the Saxon Erzgebirge had been “abandoned” for this reason: “one cannot deny that the goat herds do great damage, when they eat up the newly emerging wood and young saplings and the year’s growth” (Lehmann, 1699: 177-178; also Sieglerschmidt, 1996: 15-16).

The upshot was the socially-driven reconfiguration of forests across vast swathes of Central Europe (Westermann, 1996: 936-937). Schmithuesen, echoing the findings of a substantial literature, emphasizes that the political ecology of early modern forest exploitation is “still noticeable today” throughout Central Europe’s “mosaic of… natural forest communities... alternat[ing] with largely man-made forests (2005: 13, 2; also Sieglerschmidt, 1996: 12-16; Thomasius, 1994).

It may be objected that many of the non-ferrous mining centers were in mountainous zones somewhat removed from established population centers, which is true enough. Nevertheless, the same dynamic we’ve just seen for Germany as a whole seems to have held for the new mining towns as well:

> [Their] need for foodstuffs… led to more extensive [forest] clearances over [progressively] wider areas. At first these clearances were concentrated in the vicinity of the new mining districts and new mining towns (Schneeberg 1477, Grunthal 1491, Annaberg 1497, Schmiedeberg 1501, Brand 1515, Joachimsthal 1515 [1516], Schlettau 1515, Johnstadt 1517, Marienberg 1521, Scheibenberg 1522, Oberwiesenthal 1526, Gottesgab [close to Joachimsthal] 1532) *but soon extended into further areas of the Erzgebirge* (Thomasius, 1994: 113, emphasis added).

While some peasants likely benefited from this movement, most did not.[180] The 70,000 people who lived in the mining centers of southern Saxony and the Erzgebirge by 1500 – a number rising sharply over the next three decades – depended on extra-regional imports for two-thirds of their daily bread.[181] Massive grain imports from 60-80 kilometers to the south (around Leipzig) sustained the mining expansion, and this demand favored larger producers over small (Scott, 2002b: 120). And though there were factors beyond the mining boom and the long bust that followed, the long-run tendency in Saxony was towards the *de facto* dispossession of the peasantry. Between 1550 and 1750, the peasantry declined from just under half to just under one-quarter of the population,

[180] Nor did it benefit the vast majority of the miners. “Almost all of them depended for their food supply on the large employers: the *Trucksystem*, an extra means of exploiting the workers,” provided them, at prices favoring the merchant, with grain, flour, fat, clothes and other *Pfennwert* (cheap goods). *This trade provoked frequent protests among the miners*” (Braudel, 1982: 325, emphasis added).

[181] The same held true for the Tyrol even earlier, where the “boom in mining” and the ensuing, “substantial rise in population in the first half of the fifteenth century made [the region]… dependent on grain imports” (Keißling, 1996: 152). For Neusohl’s dependence on food imports, see Hildebrandt (1997: 287).

while the ranks of the cottagers grew from 4.6 percent to 30.4 percent (Kriedte, 1983: 55). Were not these long waves of the metallurgical cycle and dispossession interdependent?

The broader tendency among the peasantry was resistance, in small and large ways both, to the enclosures of the forest commons. Forests were, in Westoby's apt phrase, "the poor man's overcoat," crucial to survival (1989: 56; also Birrell, 1993). Forest enclosures intensified the contradictions of the peasant demographic regime and set in motion increasingly serious resistance. This took the form of a series of agrarian revolts beginning in earnest by 1476, culminating in the German Peasants' War of 1525 (Brady and Middlefort, 1981). Access to forest commons loomed large in the revolt's famed "Twelve Articles" (reproduced in Blickle, 1981: 198-199).

The timing is important, for the Peasant War coincided with the very apex of Central European mining boom. The contrast with the situation a century previous was sharp indeed. In 1450, "there were still extensive forests, so there were few conflicts between peasants and forest overlords… By 1525 the situation was *entirely changed*" (Blickle, 1981:73, emphasis added). Not forest scarcity in the abstract, but forest enclosures and access to the commons were central to the concerns of the movement. The radical cleric Thomas Munzer in 1524 decried these enclosures through which "every creature should be transformed into property – the fishes in the water, the birds of the air, the plants of the earth: the creatures too should become free" (quoted in Marx, 1843 [1972]: 49).

Moreover, forest enclosures overlaid legal codes in mining regions. In silver-flush Saxony, one such code "gave miners the right to prospect, lay out roads, fell trees, and divert streams onto peasant farmland wherever ore was suspected beneath the surface" (Waring, 1987: 239). In 1537, peasants in the neighborhood of the Schneeberg silver mines complained to Elector Johann Frederich that miners had "needlessly" dug up their fields and in so doing "ruin our properties for us with the paths to each and every shaft, and there they put up earthworks and huts and bring in wood for wagons, buildings and fire and all the other things bring in there, riding through our grain and grass" (quoted in Karrant-Nunn, 1989: 317).

A different source of opposition emerged from within the extractive complex itself. While it would be unwise to see anything approaching a modern extractive proletariat in the mining boomtowns of the era, there were strong moves in this direction. Karrant-Nunn thinks the category of "preproletariat" rather more prudent (1993), although I wonder if it might not be most fruitful to refer to a proletarianization process that unfolded unevenly, partially, and with periodic reversals.[182] The center of gravity was shifting away from artisanal modes of production, towards a transitional form of modern enterprise. (In this sense, German silver mining and Madeira's sugar cultivation may be viewed as halfway houses enabling rapid commodification in this era of transition.)

In the pits themselves, production units were small: rarely more than 8-10 workers in a single mine, although some employed six times as many. Nevertheless, the geographical concentration of workers was enough to suggest the modernity of the situation – in 1515, 10,000 were found working the 274 pits at Falkenstein in the Schwaz region (Kellenbenz, 1974: 200-201). Between 1496 and 1525, there were thirteen "major

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[182] Braudel evinces an uncharacteristically Marxist emphasis on this point: "As these powerful mining interests were set up, can we not see *emerging* a genuine working-class proletariat, a labor force in its plainest form?" (1982: 325).

strikes and riots" of silver miners in Annaberg, Freiberg, Joachimsthal, Marienberg, and Schneeberg (Karrant-Nunn, 1989: 321; also 1993). Lynch records strikes at Innsbruck in the Schwaz and at Gossensass as well. The miners' list of grievances was quite modern. Karrant-Nunn (1989, 1993) shows how their demands were quite distinct from those of the peasants, despite overlap between the two classes. These demands included relief from "extortionate prices for food charged by 'company stores," the length of shifts, an extension of the number of paid holidays, and complaints about the "slow payment of wages" (Lynch, 2002: 34-35; Braudel, 1982: 325). All of which entailed a secular trend of rising wages, even when the mineworkers did not win the immediate struggles. In the absence of significant measures to increase labor productivity and coupled with mounting resistance, then, the rising wage bill effected a further squeeze on profitability (Blickle, 1981: 120-122; Kellenbenz, 1974: 255; Kreidte, 1983: 38-39; Lynch, 2002: 34-35; Nef, 1964: 49; Waring, 1987).

Within the silver sector, the trajectory of Joachimsthal/Jachymov is perhaps most suggestive. Located on the Czech-Bohemian side of the Erzgebirge, it was the era's last great mining center and also its greatest – the town's name would give us the word "dollar." Here, the pace of capitalist advance and thence retreat was strikingly revealed.[183] Founded in 1516, there were no fewer than six major episodes of labor unrest over the ensuing nine years, culminating in what Majer calls a "general strike" of 3,000 miners in 1525 (1994: 93; also Karrant-Nunn, 1989: 321).

More significant than labor unrest was deforestation. Given an absolute minimum of 10,300 tons of woodfuel to produce just one ton of silver, this is not surprising. But the smelters' causal relation to deforestation was one of *primus inter pares*, not absolute primacy. Growing from practically nothing in 1516, Joachimsthal by 1535 "had reached the size of Prague… with its 18,000 inhabitants" (Westermann, 1996: 934). The town's "construction boom" coupled with fuelwood demands to strip the surrounding area of wood. Covered by "heavy forests" in 1516, by the 1540s, "the forest land reaching up to the Bohemia-Saxon border had been fully cleared and *remained bare*" (Westermann, 1996: 934; Majer, 1994: 93, emphasis added). In the 1530s, following the extraordinary expansion of the 1520s (Nef, 1941), the state imposed "fees… [on any] wood [from local forests] that was not used directly for mining purposes" (Westermann, 1996: 934). The extent of deforestation is inadvertently suggested by Westermann, who reports that the legislation of the mid-1530s reserved "all forests within a 10 kilometre radius of the town… for mining needs (= 2,930 hectares)" (ibid). Now, a 10 kilometer radius covers an awful lot of ground, some 314 square kilometers, or more than 31,000 hectares. As recently as 1516, "heavy forests… covered the slopes and valleys" (ibid). Even assuming that just one-third of this territory was forested at the onset of the silver boom (10,000 hectares), this translates to more than 7,000 hectares of deforestation in a very short period, not more than twenty years. Surely this was rapid enough to contribute to

[183] There is surely an important connection to be made between the environmental history of workers' health, broader landscape transformations, and workers' movements in making of capitalism. I can do no more than hint at it here. In a moment of macabre serendipity, in the history of sixteenth century Joachimsthal, we find the symbol of the dollar interlaced with the modern world's first cases of lethal exposure to uranium ores (Mould, 2001; Agricola, 1556: 6; Weisberger, 1994: 1). (This in addition to the predictable forms of silicosis: "The greatest trouble they [the miners] have is by dust, which spoils their *Lungs* and *Stomachs,* and frets their *Skins*" [Brown, 1685: 170].) The roots of "transuranic capitalism" (Krupar, 2007) are revealed in the transition to capitalism!

Joachimsthal's "deep crisis" by the 1540s (Majer, 1994: 96). Annual silver production would fall from 53,000 marks between 1526 and 1534, to less than 9,000 marks in the decade after 1565 (Nef, 1941: 588). Despite sustained decline, the smelters' footprint on the surrounding countryside was still evident eighty years later. In Gabriel Richardson's travelogue of the German lands, we are treated to a constant refrain that remarks upon the "thicke woods" in *every* major region *except* for that surrounding Joachimsthal, where the "woods [were] in part cut downe" (Richardson, 1627: 22).[184]

Nor was the crisis confined to German lands. In the Slovakian-Hungarian copper zone surrounding Neusohl,[185] the crisis played out with striking synchroneity to the German movement. The cost-cutting began with labor power and proceeded onwards to the production process and its fuel demands. By 1540, the Fuggers' "rationalisation measures," in response to faltering profitability, provoked "fierce resistance… both from the town of Neusohl and the workers themselves" (Kellenbenz, 1974: 255). A decade that began with "fierce resistance" from society, closed with mounting ecological challenges. "Such was [Neusohl's] consumption of wood for fuel that the works were likened to Mt. Etna because of the clouds of smoke that billowed from its furnaces" (Lynch, 2002: 23). By the end of the 1540s, the forests surrounding the town were "completely denuded" (Shröcke, 1994: 134).[186] Barely more than a decade later, "about 1560, the [copper] foundries of [nearby] State Hory and Harmenec were compelled to reduce drastically their activities or to close altogether because of a shortage of wood" (Cipolla, 1976: 230).

By the 1560s, the crisis of Slovakian copper mining was in full swing (Vlachovic, 1963). New, much larger and more efficient smelters were built in Neusohl, but this seems to have done little to revive profitability as copper prices moved south during the 1560s and 1570s (Kellenbenz, 1974: 208, 254; 1976: 116; Vlachovic, 1963). That copper smelting was hugely demanding of wood fuel is not in doubt; the process of refinement was an extended one. "The Copper-Ore taken out of the Mine," Edward Brown reported in the 1660s, "is burned and melted fourteen times before that it becomes fit for use" (1677: 66). It is difficult to credit deforestation as the main culprit here, but it would imprudent to dismiss it is as a strategic factor.

The movement of deepening crisis in Neusohl would be registered by the Crown's appointment in 1564 of "two forestry experts… [whose job was to ensure] that the stocks of timber in the forests were used economically and at the same time protected" (Kellenbenz, 1974: 256). The volume of wood consumed is astounding, yet quite probably an underestimate. The 1564 report, Kellenbenz tells us, indicates that "57,000 cubic meters of wood were floated down the River Gran to the collecting points at Neusohl, where the smelting works consumed 24,000 loads of charcoal a year" (1974: 256). Producing 560 tons annually in the 1560s (Kellenbenz, 1974: 208), these imports would have supplied no more 40 percent of smelter demands.[187] (Which means aggregate

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[184] On the sylvan abundance of German lands, see Richardson, 1627: 2, 4, 12, 14, 19).

[185] Ruled by Hungary in the sixteenth century.

[186] Such was the pattern prevailing also in the Sudetes, to the east of the Erzgebirge. Barzdajn (2004: 45) refers to "excessive exploitation and deforestation" that was "*most intense* in the sixteenth and seventeenth centuries." Potyralski uses almost the same language for the region, characterizing the process that began in the early sixteenth century as one of "the devastation of the forests" (2004: 39).

[187] 57,000 cubic meters of woodfuel for 560 tons of copper translates to a metal-to-fuelwood ratio of 1:80. Even Westermann's cautious estimates (see Table 2.1) puts the metal-to-fuelwood ratio for copper at 1:200; it was as we've seen higher for silver (1:300 at a minimum), which was also produced at Neusohl, albeit in

transport costs were high and almost surely rising, and this would have undermined the conditions for a revival of profitability.) Nor should we forget, Kellenbenz reminds us, "an additional need for mine timber" (1974: 256). A century later, in the 1660s, Brown found little timber within ten miles of Neusohl. The town's smelters were supplied from lands farther down the Gran, where, in contrast to the mining town, the "Country is very full of wood" (Brown, 1677: 66).

In the other key metallurgical sector, iron, the limits of expansion were reached in the Upper Palatinate – Central Europe's pivotal iron producer – by the early sixteenth century. Much less capitalized, and more dispersed geographically than silver and copper, the secular trend nevertheless holds. As we have seen, the Upper Palatinate's iron production declined by three-quarters between 1550 and 1618 (DuPlessis, 1997: 104). Westermann thinks the ecological overdraft of the Upper Palatinate's iron industry was no less than 50,000 hectares over the course of the sixteenth century (1996: 938) – but this estimate is based on an excessively optimistic view of ironmaking's energy efficiency. The actual extent of deforestation would have been, *at a minimum*, three times higher. Without making overly much of precise figures, Westermann's estimate translates to a metal-to-fuelwood ratio of 1:27, which is much too low. Low estimates notwithstanding, Westermann implicates a three-fold pattern of "wood scarcity" in the region's crisis, characterized by: 1) felling nearby forests before reaching maturity; 2) the "usually unsuccessful" enactment of forest legislation; and 3) widespread closure of foundries owing to a "precarious wood supply" (1996: 938-939).

Two major geographical shifts in the iron sector warrant our attention -- one within Germany, the second at the scale of the European economy. The first was the shift in the center of *German* iron production from the Upper Palatinate to the Siegerland on the Rhine by 1650. The Siegerland's great innovation was the diffusion on a large-scale of the *haubergwirtschaft* – called coppicing by the English – premised on the equally large-scale displacement of deciduous trees "with faster growing conifers to replace fuel supplies more rapidly" (Ogilvie, 1996: 278; also Hoppe, 2005). Indeed, the transition to capitalism seems to have been accompanied throughout Germany's mining zones by a transition from hardwood beech to "pioneer" conifers such as birch (Hettwer, Deicke, and Ruppert, 2003: 278; Thomasius, 1994: 117). The Siegerland was also importing charcoal (by river) from nearby Sauerland in Westphalia (Ogilvie, 1996: 278). Importantly, the

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much more modest amounts). Over four tons of silver were produced at Neusohl each year between 1541 and 1546 (8140 lbs), when output was just barely more than half that of the boom years 1504-14 (Vlachovic, 1963: 70). My guesstimate runs as follows. The two key operative assumptions are these. First, if a "load" of charcoal in Kellenbenz's hands corresponds to a standard English "load" of wood, then a load of charcoal amounts to 50 cubic feet (Mulhall, 1898: 596). Lindeström (2002) thinks a cubic meter of charcoal weighed in at about half that of a cubic meter of wood (808.1 lbs/ m^3 rather than 1602.2 lbs/ m^3). If so, then 24,000 loads of charcoal comes to 13,696 tons of charcoal, derived from 136,960 tons of wood (approximately 171,000 m^3). From the standpoint of 560 tons of copper produced in the 1560s, this yields a copper-to-fuel ratio of 1:245. *It is, however, possible that these are two separate figures entirely*, that the 24,000 loads of charcoal were for the copper smelters and foundries; the 57,000 m^3 of woodfuel, for silver. For Kellenbenz's report of 57,000 cubic meters of wood almost exactly corresponds with the lowest silver-to-woodfuel ratio we reached, above. For 8140 lbs (4.07 tons) would have required, at our lowest possible ratio (1:10,321), some 52,436 m^3 of woodfuel. This certainly falls within a reasonable margin of error. A production site as large and strategically as significant as Neusohl would certainly have consumed in the ballpark of 230,000 m^3 annually; this would have put the town in the top rank of metallurgical fuel consumers. But it would not be off the charts.

Siegerland was then exporting pig iron for subsequent reworking into wrought iron and then higher-value commodities north to Mark and Berg in the Rhineland (Scott, 1996: 22; Ogilvie, 1996: 272, 278).

And yet, for all the forest productivity advances of the *haubergwirtschaft*, Siegerland would not be, as the Upper Palatinate had been, the central iron producer for the world-economy. Coppicing was a second-best option. Even at a high level of productivity, a 20 to 30-year coppice would not yield much more than one-third to one-quarter the timber of older forest stands (Kellenbenz, 1976: 100). Much better was the open frontier.

Within Europe, Scandinavia was the obvious choice, and the only choice for low-profit lines in iron and copper. Norway emerged as the crucial shipbuilding timber frontier by the 1580s, at the very moment when deforestation had led to rising timber prices in Gdansk (Malowist, 1960). We will return to this part of the story in Chapter Four. But it was the emergence of Swedish iron and copper that made possible the development of, first Dutch, then British, world power. This is a long story that cannot be told here in full. But the recomposition of the world-economy's geography signified a decisive restructuring of capitalism in the wake of the 1557 crisis. Within a matter of decades, the town-country antagonism that had propelled the first sixteenth century's expansion gave way to another. The first sixteenth century had flowed through Antwerp. The second would be channeled by Amsterdam. A century before, Antwerp had displaced Bruges, knitting together the sugar and spice trades of the Atlantic and Indian Oceans with the proto-industrial expansion and metallurgical transformations of Central Europe. The second sixteenth would replace Antwerp and Saxony with Amsterdam and Potosi; Slovakian Neusohl would give way to Swedish Falun and its Great Copper Mountain (*Stora Kopparberg*); Madeiran sugar surrendered to the Bahian sugar mills; and Polish timber would be eclipsed by Norwegian wood.

The emergence of Sweden in the 1580s as the pivotal "swing producer" in iron and copper can scarcely be overemphasized. Let us concentrate on iron to illuminate the broader geographical shifts. The central fact is this. The European world-economy depended on low-cost iron, and iron production was stagnating even as accumulation revived after 1570. Where iron output grew 6.25 percent every year between 1460 and 1540, it would not grow at all between 1540 and 1600, and output growth between the mid-sixteenth century and the dawn of the eighteenth century was a scant 1.3 percent a year (see Table 2.2). Meanwhile, Sweden's exports of bar iron jumped at least sixfold – possibly eightfold – between 1600 and 1700 (Boethius, 1958; Braudel, 1981: 381; Cameron, 1993: 119; Heckscher, 1954: 93).[188] This iron was decisive to Dutch success, perhaps even more so to the subsequent rise of the English. England's output grew as well, but likely not by more than fifty percent over the course of the seventeenth century (van Zanden and Horlings, 1999: 31). England's economic history in this period is unthinkable without Swedish iron – the relationship was one of "absolute dependence" (Heckscher, 1954: 93; de Vries, 1976: 108-109). Moreover, without a continued stream of iron imports in the eighteenth century, from Sweden, and increasingly the Baltic and North America, England's geopolitical and economic position surely would have suffered. Not least in relation to its chief rival, France, where iron output grew fivefold

[188] Exports grew faster than output in Sweden's long seventeenth century. Iron production itself grew fivefold between 1600 and 1720 (Heckscher, 1954: 93).

between 1720 and 1789, fully two-and-a-half times the pace of English iron's expansion (Nef, 1950: 283).

Sweden's ascent had everything to do with its extraordinary sylvan wealth. "It was," Heckscher quietly observes (1932: 139), "the quantity [of charcoal] rather than the quality [of iron ore] to which [Sweden] owed her privileged position."[189] A historically low population density may rightly be held responsible for this, but such an explanation seems to put cart before horse. Climatic and pedological factors surely limited the demographic push, but more to the point was Sweden's distance from the commodity system. By the 1570s, Sweden was probably no more commercialized than most parts of New Spain or Peru (Anderson, 1974b: 179; Wallerstein, 1974: 312-313; Malowist, 1958, 1959).[190] Possibly less so. It was a near-perfect commodity frontier.

But this geographical shift, like those that would follow, was hardly the expression of the self-regulating market. The globalizing world market of the mid-sixteenth century would compel, but could not create, such a re-centering. This latter would require the state, to create, as in a "hothouse" (Marx), the conditions for renewed commodification and accumulation. It would require, in other words, an intensification of primitive accumulation strategies; a turn to what we might call *coercive-intensive accumulation*. What Braudel (1982: 325) draws to our attention in the long passage we encountered earlier in this chapter – namely, that after the 1550s, "Europe, because of her very expansion, was acting as if she had decided to delegate the trouble of handling of the mining and metallurgy industries to dependent regions on her periphery" – is that there was not one but *two* "Americas." The dependent regions on (or *of*?) the European periphery were to be found in Europe no less than in the New World. In the recentering of iron and copper production that Braudel illuminates, Dutch capital began pouring into Sweden by the later sixteenth century, accelerating sharply on the eve of the Thirty Years War (de Vries, 1976: 107-108; Evans, 2005; Boethius, 1958; Hildebrand, 1992). The role of the state was decisive. Swedish Absolutism was singularly effective in overseeing the production of ecological conditions sufficient for a rapid transition to *large*-scale production (Sunderberg, 1991, 1992; Hildebrand, 1992). Sweden, it is true, offered ecological advantages – abundant and accessible forests coupled with high-grade ores – that situated it favorably to German producers, who were already in serious decline (Boethius, 1958: 149; Heckscher, 1932; Kreidte, 1983).[191]

And yet for all its natural advantages, it was not ecology in itself but *political* ecology that proved decisive to Sweden's ferrous ascent. As early as the 1570s, the Swedish Crown began to enclose forest for metallurgical activity. By the early seventeenth century, the Crown established an agency empowered to coordinate a "forest rationing"

[189] The emphasis here in on charcoal as primary; Sweden's *osmund* iron was renowned for its high quality throughout Europe. In contrast to English iron, *osmund* contained minimal phosphorous, and therefore was highly prized for its malleability (Evans, Jackson, and Ryden, 2002).
[190] "The index of commercialization in agriculture was probably the lowest anywhere on the continent. A natural economy prevailed over the country, to such an extent that as late as the 1570s, a mere six per cent of royal revenues – taxes and rents – were paid in cash, while most state officials were equally remunerated in kind" (Anderson, 1974b: 179).
[191] Indeed Germany's mining outfits were going bust and large merchant-industrial houses such as the Augsburg-based Fuggers were directing their investments away from mining by the 1550s, at the very moment when the Iberian-Genoese "material expansion" was giving way to the "Age of the Genoese" (Long, 1991: 351; Arrighi, 1994).

system and the geographical dispersal of metallurgical production – say ore smelting from the production of bar iron – so as to limit fuelwood scarcities (Boethius, 1958: 152; Heckscher, 1934). This turned, we should say, on the effort to expel traditional slash-and-burn peasant agriculture from those forest zones closest to the mining centers (Emanuelsson & Segerstrom, 2002). The first such prohibition of swidden cultivation was announced in 1647 (Hamilton, 1997). These territorialist activities aimed directly at sustaining increasing commodity production. (Although this latter, to be sure, was implicated in the most direct fashion with Sweden's imperial ambitions, which themselves turned crucially on agro-ecological matters [Myrdal, 2007].) Expansion not conservation – or rather conservation *qua* enclosure as necessary for continued expansion; this was the whole point (Boethius, 1958: 152). On the basis of this unusually far-sighted ecological strategy of primitive accumulation, Swedish iron exports – a stunning *eighty percent* of production (Ryden, 1998: 390) – constituted a strategic reservoir of raw materials crucial to the expanded reproduction of first Dutch, and then English, territorial and capitalist power in the century after 1620. (It was this increment of iron output that allowed the fleets to stay afloat and the Caribbean sugar revolutions to proceed.)

And yet, even in Sweden deforestation quickly materialized. By the 1690s iron mills in the northeast confronted rising prices in wood and charcoal, setting in motion an upward spiral of conflicts with the surrounding peasantry and their forest commons (Graner, 2005). It bears more than a footnote to mention that by the 1750s growing "alarm" over the state of forest resources prompted the Swedish Crown to impose a ceiling on iron output (Pounds, 1990: 300). It was ineffective but this is precisely the point. Charcoal prices spiked in the 1760s, and remained high until century's end (Hildebrand, 1992; Isaacson, 1998). Here as elsewhere, there were layers within layers of the commodity frontier. The frontier movement that recentered European iron production in Scandinavia was also in play within Sweden, as the centers of iron production moved northwards (Hildebrand, 1992). By the close of the eighteenth century Sweden "saw signs of an ecological crisis caused by overuse of scarce land resources," especially forest products (Eliasson and Nilsson, 2002). This was broadly coincident with yet another phase of metallurgy's global expansion, this time in the direction of Russia and the United States (Evans, Jackson, and Ryden, 2002; Jones, 1987).

Conclusions

The crisis of Central European metallurgy was a crisis of its production regime, and above all, of its ecological regime. The forests receded and yet survived in new form. Conifers displaced hardwoods. And yet, the fate of the forest is and at the same time is not the point. What emerges in these snapshots of world-historical movement is the modern character of capital-nature contradictions and the crises that ensued. In the first place, longstanding tensions between economic activity (especially mining and metallurgy) and environmental sustainability were exploited in new fashion within Central Europe after 1450. The sometimes gradual, sometimes rapid removal of constraints on commodity production – registered perhaps most clearly by a wave of epoch-contributing if not epoch-making technical innovations – amplified the socio-ecological contradictions of an earlier era. On the one hand, new technological regimes combined with the accumulations of wealth that survived the long fourteenth century crisis. This allowed for a rising scale of production, perhaps not *always* a quantum leap in the century after 1450, but a qualitative leap nevertheless. On the other hand we find the rising scale of exchange. The emergence of a modern world market set in motion powerful sources of demand that lay outside Europe's old dorsal spine, above all the great commerce of the Atlantic and Indian Oceans; it was a trade impossible without European silver and copper.

The two movements, one in the sphere of production, the other in the sphere of circulation and exchange, constituted at once powerful ecological crisis tendencies and powerful ecological fix strategies. Central Europe's metallurgical regime was not simply a predatory regime, although this it surely was. It was extraordinarily productive and innovative. Plunder paired with productivity was the basis of the mining regime's capacity to extend ecological hinterlands radically faster and cheaper than its medieval forerunners – in fuelwood, construction timber, foodstuffs, stockraising, and all manner of other crucial inputs. In the Saxon Erzgebirge, for instance, virtually every stream larger than trickle carried timber to the mining towns; many of these streams were widened or otherwise managed for this very purpose (Thomasius, 1994). In time, and for any single production center never more than 50-75 years, this strategy entered a phrase of declining returns. It was not just that accessible sources of ecological wealth were relatively exhausted; the ecological *regime* itself became progressively exhausted, for reasons that turned on, say, fewer trees, but also for reasons that turned on the articulation of the regional productive complex with the world market and its geopolitics.

The crisis detonated by the bankruptcies of 1557 was, metaphorically and perhaps quite literally, not so much a crisis of the trees as it was a crisis of the forest. The scale of vision enters here with special force. The full flower of regional crisis was impossible to discern from the vantage point of the region in question. For the crisis of Central European metallurgy was in the same breath a crisis of capitalism as a whole, although I am doubtful that it signified a new phase of capitalism. Perhaps it is safer to say that a new configuration of early capitalism was taking shape, and the seeds of large-scale industry began to germinate at this time.

Ultimately, the full flower of crisis is impossible to see within the regional frame of Central Europe because early capitalism's crucial ecological fix strategy – the commodity frontier – moved *through* regions; it was not contained within them. Thus a big part of the evidence that I have adduced becomes convincing only in relation to the globalizing movements that followed, to the world-historical patterning of the commodity frontier. The crisis that began to unfold in the 1530s reached critical mass by the 1560s. As we have seen, this was the very moment when American silver imports exceeded Central European production. So the arrival of American silver was not inconsequential. But the Central European crisis was not a crisis of bullion supply, however important this factor surely was. The region's silver production did not rebound significantly when American shipments faltered towards the end of the 1560s, as Potosí's first mining boom exhausted itself, a story we will discuss presently.

CHAPTER THREE
'This lofty mountain of silver could conquer the whole world'
Potosí and the Political Ecology of Underdevelopment, 1545-1800

The discovery of Potosí in 1545 ranks amongst the signal events in modern world history. It was not simply that the Cerro Rico was an "unparalleled geological fluke" (Bakewell, 1988: 16). This it surely was. The Cerro Rico was the world's greatest silver deposit (Cunningham, et al., 1996: 374). But there was more to it than this. For this stroke of geological good fortune went even deeper. Potosí's rich veins, containing as much as 30-40 percent silver, were also free of significant copper and lead – in striking contrast to the European mines that we've just surveyed (Cunningham, et al., 1996; Ure, 1856: 626; Barba, 1640: 133). The geographical significance of the contrast would become apparent with the introduction of mercury amalgamation to the Andes in the 1570s. European ores did not only fall into a lower grade relative to Potosí, the relative purity of the Cerro Rico's veins would make amalgamation relatively easy. In contrast, the intrusions of copper and lead into already low-grade European ores rendered mercury-*silver* amalgamation impossible until the end of the eighteenth century (Teich, 1975).[192]

Potosí's dramatic ascent owed as much to Europe's expansionary political economy as it did to geology. When the Spanish stumbled upon the Cerro Rico, here was a moment of "Discovery" in its distinctively modern sense. The name itself, *Potosí*, like so many Spanish place-names in the Andes, derives from Quechua and indicates a longer history pre-Conquest geographical knowledge (Wilson and Petrov, 1999: 10; J.R. Mumford, 2004). Indeed the Spaniards' discovery of the Cerro Rico undoubtedly owed everything to the appropriation of local geographical knowledge.

It was an act of appropriation that rested upon the peculiar crisis-creating and crisis-fixing strategy of early modern capitalism, the commodity frontier. The crisis of Central European silver mining was the first precondition of Potosí, as geographical site rather than geological find. The great wave of European silver mining had already crested by the 1540s. The decline of Saxon and Bohemian silver mining was reinforced by the rise of Potosí; it was not a consequence of it. The crisis of Central Europe's mining complex was therefore an ecological crisis conceived relatively and relationally. *Relative*, not absolute, exhaustion was what really mattered, and this relative exhaustion at once precipitated, *and was precipitated by*, the contradictory relations of markets, states, and social classes in Central Europe and the world-economy. As we have just seen, the enclosures and ensuing degradation of land and labor that flowed from the commodifying impetus of the metallurgical vanguard set in motion rising production costs, partly ecological, partly social, always interwoven. In one zone after another, within 50-75 years, these reached a crescendo that signified the demise of any regional extractive regime as *central to world accumulation*. Clearly we are looking at relative rather than

[192] Mercury amalgamation in gold quartz mining had been known since the fourteenth century (Blanchard, 2005: 1157-1160).

"absolute" ecological crisis. Large-scale mining did not disappear in Central Europe; its centrality was merely displaced through global expansion.

From this standpoint, we may begin to move beyond environmental history's declensionist narratives.[193] For the point of the analysis is not simply to identify the scale, scope, and speed of, say, declining ore quality, soil exhaustion, or deforestation in one region after another. Rather, among the great emancipatory potentials of ecohistorical research is to develop a dialectical-feedback perspective that illuminates the relational political ecology between regional environmental transformation and world accumulation. In this sense, we would do well to revisit Genovese's cogent observation that "rise of capitalism requires a theory that includes the inability of the soil [along with the rest of nature!] to recover sufficient productivity to maintain a competitive position" (1967: 88; see also Engels in Marx, 1967, III: 725). It was precisely the inability of regional socio-ecological formations – such as Central Europe's extractive regime – to *regain* the competitive edge (once lost) that underpinned early capitalism's profound geographical restlessness. It is therefore the question of regional centrality in world accumulation that is of paramount importance. And it was this position of centrality that Central Europe relinquished in the mid-sixteenth century, giving way to Potosí. Potosí's vast silver mining complex would in turn be eclipsed by the ascent of New Spain in the late seventeenth century. (Sugar, too, would play out this pattern, as we shall see in Chapters Five and Six.)

The relocation of silver mining to the New World offered a near-perfect combination of highly favorable ecological and social conditions: fabulously rich ore deposits and accessible sources of cheap labor power. If Europe's mining complex faced formidable obstacles at home, in the New World it could play a decisive role in fundamentally reshaping the hemisphere's socio-ecological order. By 1600, Europe's silver production amounted to just ten percent of the American gold and silver arriving in Seville, and this latter was only a portion (albeit a large one) of New World bullion exports (Brading and Cross, 1972: 545).

At the core of this hemispheric reconstruction was city-building, the lynchpin of Spain's colonial strategy. This approach, "the direct opposite of the British gradualistic model, permitted Spain to conquer and control an entire continent in a few years with a very small occupying force." The Spanish colonial city was the vanguard of imperial advance. "From it the Spaniards moved out to a hostile environment to conquer, control, and indoctrinate the surrounding populations. Conquerors lived, by and large, in the city, while the conquered remained in the countryside" (Portes, 1977: 61; see also Hardo and Aranovich, 1970; J.R. Mumford, 2004).

On the mining frontier, this urban-imperial logic was carried to new heights. At once dominant and dominated, mining boomtowns ruled over the surrounding countryside, even as they were subordinated to broader imperial and economic structures. They were the organizing centers not only of underdevelopment in the economic sense, but of a profoundly unequal ecological exchange between American peripheries and European cores, enabling (and enabled by) a new, multi-layered and globalizing town-country antagonism. The mining frontier thereby created an increasingly serious rift in the

[193] See comments by Steinberg (2004) and McNeill (2003b) on environmental history's declensionism.

metabolism between the country and the city – what Foster calls a "metabolic rift"[194] – within Latin American regions, and at the scale of the world-economy (Foster, 1999; also Kautsky, 1988: 214-215; Moore, 2000a; 2003a). Nutrients flowed from country to city within the New World, and thence from urban centers in the periphery to the core. As relative exhaustion seized regional formations harnessed to the political ecology of the metabolic rift, successive waves of geographical expansion ensued. This is the world-historical moment of what Gadgil and Guha call "*sequential overexploitation*" (Gadgil and Guha, 1992: 121).[195] The competitive logic inscribed in the modern world market drives the exhaustion of local ecological wealth (including local sources of labor power), necessitating the geographical expansion of commodity relations, either through the progressive extension of city-hinterland relations within regions, or the outright relocation of production.

This is an important contrast with pre-Columbian (or pre-Pizarroan) dynamics. There is no need to argue that the Incans and their predecessors were "ecological angels," to borrow McNeill's well-turned phrase (2003b: 25). Yes, the Incas transformed their environments, often brutally, through "the forceful extraction of labor services…, the relocation of contumacious populations," and all manner of other unsavory measures (Godoy, 1985: 275; also Abbot and Wolfe, 2003; Browman, 1974; Crawford, Wishart, and Campbell, 1970; Lechtman, 1975). Deforestation, soil erosion, and ecological degradation are in some broad sense fundamental to the whole history of human civilization (e.g. Ponting, 1991). But continuities become meaningful only in the light of rupture and crisis. In this, the rise of capitalism and its epochal geographical conquests provides sunshine in abundance.

The European invasion implanted a new ecological regime that was interwoven with capitalist political economy, cultural imperialism, and European legal frameworks (to name but a few). This is the point missed by those environmental historians and historical geographers who have, for instance, moved to quickly to dismiss – to take what is arguably the pivotal text in the debate – Elinor Melville's work on soil erosion and colonial sheep raising in sixteenth century Mexico (1990, 1994).[196] It is undeniable that

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[194] Marx's theory of metabolic rift identifies the ecological contradictions embedded in the town-country antagonism that emerges during the transition to capitalism. From this standpoint, early capitalism burst asunder the largely sustainable nutrient cycling of earlier city-hinterland complexes. There emerged an "irreparable rift" in the metabolism of nature and society (Marx, 1981: 949). From the sixteenth century, a "metabolic rift" developed, whereby nutrients flowed out the countryside and into cities at increasing volume and pace. Nutrient cycling was increasingly disrupted, precipitating one after another "local" ecological crisis whose global impacts manifested in recurrent waves of geographical expansion, as capital sought out new supplies of land and labor. This formulation owes everything to John Bellamy Foster's formulation (1999, 2000). My extension of this perspective develops along two lines. First, the origins of the metabolic rift are found in the sixteenth century rather than (as Foster's account suggests) the Industrial Revolution. Second, there is not one but a succession of metabolic rifts in successive phases of world capitalist development (see Moore, 2000a).

[195] For a world-historical conception of sequential overexploitation, see my "Environmental Crises and the Metabolic Rift in World-Historical Perspective" (Moore, 2000a).

[196] Butzer has led the charge against the notion that imperialism is necessarily bad for the environment (1996; and Butzer and Helgren, 2005: esp. 82). The problem is that Butzer is comparing two regions (New Spain and the Mediterranean) that are similar in a certain and very broad geographical sense but in the process obliterates history: the medieval Mediterranean and early modern New Spain were two very distinct historical-geographical formations (see esp. Butzer, 1996). Among world environmental historians, Richards (2003: 334-376) is sympathetic to the critique of Melville.

the New World's indigenous empires rested upon a critical mass of population, and it is equally undeniable that certain forms of ecological stress followed. *But these ecological stresses must be situated historically, within their respective ecological regimes*. Aztecs and Incas alike stressed their environments, and at least partly in response they enacted the standard eco-geographical strategy of premodern empires, what I have called the *resource* frontier strategy.[197] It was, however, the chief means through which new zones were either absorbed directly into the imperial polity or subordinated through tribute relations. This was, however, first and foremost a relation of territorial power. Commerce was secondary. Not so with the *commodity* frontier strategy. And because this strategy turned in the first instance on the accumulation of *capitalist* power rather than territorial power, European colonial regimes confronted a qualitatively different "Nature" than that experienced by premodern tributary states.[198]

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Nowhere did the socio-ecological contradictions of this commodity frontier strategy appear more starkly than in Potosí, located in the Viceroyalty of Peru (present-day Bolivia). The New World accounted for 74 percent of the world's silver production in the sixteenth century (Barrett, 1990: 225). By far the largest producer, Potosí's output dwarfed that of Zacatecas (Mexico) by a factor of seven (Garner, 1988: 911; Brading and Cross, 1972: 571). Almost overnight, Potosí emerged as one of the European world-economy's largest cities — with 120,000 in 1573 it was bigger than Madrid, Rome, or Paris (Galeano, 1973: 31). In 1610, its 160,000 residents still topped Amsterdam (80,000), London (130,000), Sevilla and Venice (both 150,000) (Bakewell, 1988: 191; Kamen, 1971: 21). Together with the mercury mines of nearby Huancavelica,[199] Potosí's silver complex pioneered a rapid expansion of commodity production throughout the Viceroyalty of Peru and the nascent world capitalist system, with profound implications for the health of land and labor alike.

In the quarter-century following the 1545 discovery of silver on the Cerro Rico, the path from rock to pure silver was circuitous indeed. Mining and smelting remained largely under Indian control. Indians mined silver ore, much of which found its way into Spanish hands as tribute. These in-kind tributary payments were then sold back to the Indians, who smelted the ore in thousands of *guayras*,[200] small wind-ovens specially designed for the high altitude. "It was a pleasant site in those days to see eight, ten,

[197] See my Introduction to this study.

[198] Fisher suggests as much in his study of pre-Conquest environmental history in Mexico, centered upon the Lake Patzcuaro Basin, home to the Tarascan empire: "[W]e can actually identify specific land degradation mechanisms. For the Classic period, this included the construction of large settlements, rather than agricultural practice, whereas for the early conquest period the primary land degradation trigger was large-scale landscape abandonment" (2005: 93). Of course, large-scale landscape abandonment is a nice way of putting depopulation, which was driven forward not just by Afro-Eurasian diseases but also by the political ecology of European imperialism, of which Melville's (1994) ungulate (sheep) explosion was a crucial moment.

[199] Huancavelica and Potosí, declared Peru's viceroy in 1648, were "like two poles which support this kingdom [Peru] and that of Spain." Indeed, Huancavelica "had the distinction of being unique and irreplaceable, so that its preservation is matter of even greater concern [than that of Potosí]" (Quoted in Whitaker 1941: 3).

[200] Sometimes called *wayras* (Smale, 2005: 34) or *guairachinas* (Wilson and Petrov, 1999: 10).

twelve or fifteen thousand of these Fires burning all at the same time" (Vega, 1608: 347; also Espinosa, 1628: 623; Zárate, 1555: 100).[201] Subsequently, the Spaniards acquired the pure silver through the market, where their purchasing power was augmented by control over the highly lucrative coca leaf trade (Cobb, 1947: 117-199; Cole, 1985: 3-4; Stavig, 2000: 90; Stern, 1988: 850-851).[202] But transaction costs remained high, or too high at any rate for the Spaniards' tastes. "These Indian workemen are riche," Augustin de Zárate would comment at the height of the *guayra* silver boom in the mid-1550s, "for but he that hathe but foure or five thousands poyzes [*pesos*], is counted but poore" (Zárate, 1555: 100).

The arrangement worked so long as ores remained rich. In the first two decades after Spain's formal (if not at all turns *real*) enclosure of Potosí, the ores were rich indeed. In the earliest years, veins sometimes yielded ore with silver content as high as twenty five percent, in rare cases even fifty percent (Wilson and Petrov, 1999: 10; Ulloa, 1772: 64), although grades were highly variable and did not hold for *all* deposits.[203] Mixed with relatively soft chlorargyrite, the silver could be smelted in the *guayras* with relative ease. The chronicler Cieza de Leon described the process in the way:

> To extract the metal they make pottery forms in the size and manner of planters in Spain, they have in a number of places holes or ventilators. In these contraptions they place charcoal with the metal on top; sited on hills and highest where the wind blows with more force, they extract the silver, which is then purified and refined with small bellows or cane tubes through which they blow (1553: 335-336).

There is a crucial ecological observation here. *Charcoal* appears as the initial fuel for smelting. How much charcoal? This is uncertain. It was certainly radically less than what Central Europe's silver-copper ores demanded, in part because of the ores held more silver. The trend is however clear. Fuel demands escalated, and the most fertile ores were quickly tapped. As ore quality declined, more and more fuel was necessary to extract less and less silver. By 1618, there may have been as little as 52 ounces of silver per ton of rock (Wilson and Petrov, 1999: 12). Nor did it help matters that the rock itself became harder – rock that was not only more expensive to dig through, but more heat-resistant. Declining ore quality, then, set in motion an upward spiral of production costs. As proximate woodlands were decimated for charcoal production, the Indian smelters turned to *ichu* grass,[204] which once dried – it was a poor fuel during the rainy season (Pearce, 1999: 675) – made for an acceptable if inferior substitute.

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[201] Espinosa (1628: 623) puts the figure at 6,000 *guayras*.

[202] In 1566, three colonial coca planters argued in a letter to Philip II: "The cultivation and trade of coca is a most important enterprise and of the greatest significance… because by means of coca it is assured that the Indians will turn over the major portion of the plate [silver] which they mine each year. If they would receive no coca, however, they would keep most of the plate and hide in their *huacas*… The Spaniards would profit nothing from this turn of events… and Your Majesty would see how much of the fifth he now received would suffer" (quoted in Gagliano, 1963: 50). On the profitability of the coca trade, see McAlister (1984: 222-223); on the high price fetched by coca in Potosí, see Zárate (1555: 100).

[203] See Cobb's (1947: 124) qualification, mentioned below.

[204] Sometimes called *icho* (Whitaker, 1941: 92).

By the 1560s, smelting was no longer effective. By the end of the decade the yield on Potosí ore fell 98 percent from two decades earlier – from 100 hundred marks (approximately 20.3 kilograms) a quintal (approximately 500 pounds), to just two (Cobb, 1947: 124). Quite predictably, fuel costs began to rise, and silver output fell two-thirds between 1546 and 1571 (Bakewell, 1987: 239). As surface deposits were exhausted, mine work became more arduous and less remunerative for Indian workers, who increasingly decided that the game was not worth the candle. Thus did "Spanish mine owners [find] themselves confronted by a labor shortage that had very little do with the number of Indians living in their midst." By 1561, there were 20,000 Indians living in Potosí but just 300 working the mines, 94 percent fewer than a decade earlier (Cole, 1985: 4; also Ramirez, 1994: 101). "In short, the pillage/conquest economy established after 1532 had reached its limit" (Andrien, 2001: 49).

Spain's 'Global Strategic Vision'[205]
The Remaking of Trans-Atlantic Ecology

Potosí's socio-ecological crisis did not go unnoticed from above. Spain's imperial ambitions fed on American silver. "[I]t was the swelling flow of New World silver that made Philip [II] think he could conduct war both in the Mediterranean against the Turks and in the north against the Dutch" (McNeill, 1982: 109). Indeed Philip may have taken too seriously the motto he emblazoned upon Potosí's second coat of arms: "for the wise King this lofty mountain of silver could conquer the whole world" (quoted in Rudolph, 1936: 536). The contraction of silver production was a very serious matter indeed, all the more so as it was followed by: 1) "an enormous increase" in Spain's military outlays after 1566; and 2) an increasingly severe fiscal crisis within Castile,[206] which paid the lion's share of these imperial adventures. Philip II tripled taxes and thrice declared "bankruptcy" – in reality converting short-term into long-term debt by issuing the bonds known as *juros* – between 1557 and 1577 (Parker, 1974: 561, 568-569, DuPlessis, 1997: 50-53). Indeed, the very bankruptcy that precipitated the 1557 European crisis – visiting ferocious devaluation upon South German capital, as we have just seen (Chapter Two) – was made possible by the flood of American silver pouring in Sevilla in the early 1550s. Philip was no longer beholden to the Fuggers and could dispense with their services.

As if to go from bad to worse, Philip's financial woes were underpinned by an impending agro-ecological crunch at home that would deepen in the closing decades of the sixteenth century (DuPlessis, 1997: 50-53; Phillips, 1987; Wallerstein, 1980: 146). Although Spain's agrarian crisis of the second sixteenth century is well known, its political ecology has been underplayed. Da Silva cites a 1609 source that expresses growing concern. "The insatiable farmers were *exhausting the fields*," reports da Silva's source (quoted in da Silva, 1964: 244, emphasis added). This was almost certainly connected to the peasantry's escalating indebtedness; de Maddalena refers to a "heavy increase in the mortgages on peasant property" by the early seventeenth century (1974:

[205] This is Parker's phrase (1998: 8).
[206] Although I have referred to a Spanish Empire it bears noting that the relevant European unit was Castile and not Spain. As Kamen puts it, "the centre of expansion was not 'Spain,' which continued to be a moral concept rather than political entity, but the Crown of Castile" (1994: 469-470).

299). Between 1570 and 1630, "little by little, almost everywhere people [in Castile] became obsessively worried that the land could be exhausted" (da Silva, 1964: 244). Growing concern over the "decrease in yield" and the "search for new lands" were, da Silva argues, "*actually parallel*" (ibid, emphasis added; also Elliot, 1963: 115). The search for new lands led in short order – and apace with the monetization of the social economy – to renewed soil exhaustion and thence renewed movement onto new lands.

What is to me quite striking about da Silva's argument is the frontier movement of sequential overexploitation *within* Castile. From this standpoint, the crisis in Castile and the crisis in Potosí appear as differentiated moments in a singular (if multilayered) process. Two aspects of the trans-Atlantic relations can now come into view. First, the process of relative exhaustion and the search for previously untapped arable land within Castile was eased partly by grain imports. But grain imports were financed with the backing of American silver, and steady grain supplies demanded a steady silver inflow from across the Atlantic. In the other direction, new breadbasket regions emerged over the course of the sixteenth century. Among these was Sicily, whose shift from sugar to wheat mattered less than the expansion of monoculture, driving rapid forest clearance and precipitating major soil erosion problems by the seventeenth century.[207] Meanwhile, the old breadbasket regions of the Baltic were experiencing mounting exhaustion problems (Szcygielski, 1967), such that by the early seventeenth century Polish grain's competitiveness had been significantly eroded (Parker, 1979: 39-40; see Chapter Four).

Second, so long as the expansion of arable land sustained a rising population, the inhibiting impact on the Castilian "home market" was limited. But the expansion of arable was, it turned out, insufficient. For Braudel, "the reclaimed land often gave an inferior yield" (1972: 426); Weisser sees a "severe downturn" in yields in Toledo and Segovia between 1600 and 1640 (1982: 153, also 150-151). Even a seemingly modest decline in yields, say from 1:4 to 1:3.5, represented a dangerous contraction in agriculture's capacity to feed the extra-agricultural population (Parker, 1979: 39). Once population growth stagnated and a great reversal was set in motion – Braudel calls this Mediterranean-wide movement "an agricultural revolution in reverse" (1972: 427) – escalating tax burdens throttled the direct producers. There was, then, a decisive agro-ecological moment to the deindustrialization of Castile.

This is not to deny that American silver raised production costs for Castile, or that Dutch manufacturing prowess allowed its textiles to penetrate the Castilian market (Anderson, 1974b). The question is one of relative causal weight in which the political ecology of the situation remains salient. It is clear, however we might draw these lines, that Segovia's thriving textile industry (second only to Cordoba's) virtually collapsed in this period, its output falling three-quarters between 1570 and 1600 (Kriedte, 1983: 73). Was this not related to the agro-ecological retrogression and the escalation of tax burdens that ensued? Between 1559 and 1598 "the burden on the ordinary taxpayer in Castile increased by some 430 [percent], at a time when nominal wages had risen by only 80

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[207] In the sixteenth century, "the wheat monoculture using a simple two-course rotation which was practiced on most of the island was extended up the slopes of mountains and into forests. Olive orchards were sometimes burned to make room for more grain. In the seventeenth century the result – deforestation and soil erosion in the uplands, malarial marsh formation in the lowlands – reduced the island's peasantry to misery… [The island's agro-ecological regime denied] the island's interior both the capital need to increase output without mining the soil and the physical security needed to permit cultivators to live near their fields" (de Vries, 1976: 52).

percent" (Kamen, 1994: 486; also Weisser, 1982: 153). The collapse of the home market and stagnating agricultural productivity – already amongst the lowest in Europe (Kamen, 1994: 487) – meant that Philip II's geopolitical projects could be sustained only through reckless borrowing. Taxes on the peasantry could be ramped up, but only so far and no further. When Charles V abdicated in 1556, the Crown's "*juro* debt…, or annuity payments on loans made largely for the war effort," amounted to 68 percent of "normal Castilian revenue" (Kamen, 1994: 481). By the time of Philip's death in 1598, *juro* debt was eight times the Crown's annual revenue. Precisely who owned the debt? The Genoese above all, and it was Genoese capital that financed commodity production throughout Europe (Braudel, 1972: 501-502; 1984: 157-174, 208-209).

The creation of the public debt, as Marx notes, was a decisive moment of primitive accumulation (1977: 915).[208] This was not only because the *juros* accumulated by Genoese bankers were tradable, and this power granted the Italians unusual freedom after 1566 to export silver directly from the Peninsula. It was also because the Genoese had reoriented their "surplus capital" from the American trade towards the bond market, thereby opening the door for Dutch capital. The financial expansion launched by the Genoese in the aftermath of the 1557 crisis was, Arrighi rightly observes, a moment of stagnation *and* expansion of the material economy (1994). (The world-historical alchemy of *combined* and uneven development.) We might observe that this duality was carried forth by a geographical division, indeed one that would persist into the twentieth century. The rapid expansion of the productive economy in the north after 1557 rested upon the financial power of the Genoese in the south, whose surplus capital was now available not only to fund wars (as Arrighi emphasizes), but also the material expansion centered in northern Europe.

The rise of the Dutch was, then, intimately connected with the decline of the Spanish.[209] And it was this conflict that underpinned the implantation of an increasingly capitalist ecological regime in the Andes. Which brings us back to the trans-Atlantic environmental history of Castile and Peru. Castile's credit-worthiness turned on its revenues from the silver mining frontier. These revenues could be sustained only by a constant effort to intensify and expand the imperial division of labor – one that for all its premodern vestiges ultimately lived and died on the production of a handful of strategic commodities. (Silver above all.) And this was possible only through recurrent waves of environmental transformation driven by the competitive logic of a polycentric geopolitics and the modern world market.

If the ecological specificities differed between Castile and Peru, the tendencies towards what Sauer (1981) once called ecological "overdraft" and what Marx (1977) would call primitive accumulation were in full force: soil exhaustion and thence the restless search for new arable land, monetization, proletarianization (or more properly, semi-proletarianization), land concentration… Are these not the very issues at the heart of the Agrarian Question in the long twentieth century?

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[208] The *juros* were "the first widespread use of [state] bonds by an Absolute monarchy in Europe" (Anderson, 1974b: 71). As Anderson perceptively observes, these bonds were largely made possible by the Crown's hegemony over the Potosí mines.

[209] Here I agree and at the same time do not agree with Kamen (1994), when he writes that no serious scholar would entertain such a notion as the "decline of Spain." But the fact of the matter is that Spain's *global* power was on the wane, to be eclipsed at the commanding heights of geopolitics and the world-economy by the Dutch and then the British.

But let's not stop at such generalities. The argument that I'm making – and what environmental historians have yet to admit to the research agenda – is that environmental and economic changes in one region are dialectically bound to those in another. Crudely put, the political ecology of change in the metropolis is dialectically bound to the political ecology of change in the colonies. This town-country or metropolitan-colonial "feedback" moment of modern environmental history is one issue that remains largely untouched.[210] And so it is from this very perspective, not simply world-historical and regional but one that pivots simultaneously on the construction and contradictions of the town-country and metropolitan-colonial divisions of labor, that we trace the interrelations between Castilian and Peruvian environmental history at the end of the sixteenth century.

From Plunder to Production: The Political Ecology of Colonialism

To return to the story at hand, it was in this context of threefold crisis – within Peru, within Castile itself, and within the European dependencies (above all the Netherlands) – that the Crown convened a "special junta" in 1568 to address the emerging crisis, empowering a new Viceroy (Francisco de Toledo) to implement a sweeping reorganization of the Peruvian mining frontier (Assadourian, 1992: 56-58; J.R. Mumford, 2004; Stern, 1982: 82). Toledo's challenge? Find a cost-effective and therefore profitable solution to the problem of declining silver output. In the decade that followed, Potosí's revival depended upon two decisive innovations: 1) the replacement of smelting with an amalgamation process that used mercury to extract silver from the ore; and 2) the large-scale replacement of voluntary with forced labor through a system of rotating forced labor drafts, called the *mita*. The first presupposed the second. The perfection of an amalgamation process adapted to Andean conditions preceded by just a year Toledo's proclamation of a geographically expansive *mita* in 1572. Mercury amalgamation made possible the extraction of silver from low-grade ores. Its profitability, however, turned on the availability of a huge and tractable labor supply. Some three million Andeans would work in the mines before the abolition of the mita in 1819 (Ferry, 2000). Thus amalgamation and the *mita* were at the core of a series of socio-ecological transformations. These would be profoundly implicated in the commodification of land and labor throughout the region, and its deepening articulation with a globalizing capitalist system.

This era of accelerated social and environmental transformation unfolded at multiple scales. At the point of production, control passed from Indian to European hands. What had taken half a millennium in medieval Europe took less than fifty years in the Andes. The colonial transition replayed on an expanded scale the transition from small-scale artisanal mining to large-scale industrial extraction in Central Europe a century before (Lynch, 2002; Waring, 1987). Spanish mine owners (*azogueros*) were in the midst of "evolv[ing] from low-investment, low-risk [entrepreneurs] into industrial businessmen" (Cole, 1985: 18). The *guayras* were displaced, although not eliminated. Even at the height of Potosí's glory in the early seventeenth century, smelting by means of these

[210] Even by such a gifted student as Grove, who nevertheless points in the right direction (1995, 1998). For a spectacular instance of the geographical disconnect between metropolis and colony, see the Simmons' environmental history of Great Britain (2001)… which does not, for example, discuss Ireland, much less India, Kenya, or the West Indies!

small wind-ovens persisted (Espinosa, 1628: 623).[211] After 1571, in the place of the *guayras*, there were now huge stone tanks, capable of holding two and half tons of crushed ore (Bakewell, 1987: 214).

This restructuring of production was made possible by a thoroughgoing transformation of the surrounding social and physical environments. Here the Spaniards replicated on an incomparably grander scale the constructed waterscapes of central Europe's fifteenth century mining centers (Sieber and Glasebach, 2000; Lynch, 2002; Thomasius, 1994). Around the Cerro Rico, this entailed the construction more than thirty dams, whose interconnected reservoirs accumulated the rainfall during the brief and torrential wet season.[212] This amounted to "the greatest single concentration of hydraulic mill technology anywhere" in the European world-economy (Craig, 1993: 125). These reservoirs powered 140 *ingenios*, those great mills responsible for pulverizing the ores into fine powder, preparatory to amalgamation (Craig, 1993; Bakewell, 1987: 218).

Large-scale waterpower was indispensable to the second phase of Potosí's silver boom. Silver output skyrocketed nearly 600 percent between 1575 and 1590 (Bakewell, 1987: 242). In equal measure, the ambitious reshaping of the region's waterscapes generated ecological contradictions that would ultimately seal Potosí's fate. "Potosí was [consistently] plagued by disastrous floods," likely intensified by widespread deforestation (Brown and Craig, 1994: 305). Perhaps the decisive turning point was the collapse of the Caricari reservoir, the city's principal reservoir dam in 1626. Part of this was outright destruction. The 1626 flood was monstrous indeed. "It was so violent that one saw mountains of water coming down, higher than the tops of the tallest houses… [Indeed] it might have destroyed the whole town… [if not for] Divine mercy" (Espinosa, 1628: 634-635, 637).

The flood killed at least 350, possibly as many as 4,000, inhabitants. More important, from the standpoint of capital, was the destruction of all but six of Potosí's 132 mills, "79 of them irreparably" (Espinosa, 1628: 635-639; Rudolph, 1936: 537). If forest clearance had escalated flood risk over the preceding decades, changing climate, just as we saw in our discussion of feudalism's crisis (Chapter One), may have been the proverbial straw on the camel's back. The flood was preceded by a "long drought" that "had dried out" the exteriors of the dam, Espinosa observed (1628: 637). Moreover, it is not clear that a torrential downpour overwhelmed the levee; the rainy season lasted from June through August (Acosta, 1590: 219). The flood occurred in March.

From this disaster, "[t]he *ingenios* of Potosí never fully recovered" (Craig, 1993: 145). And yet, the flood was likely something more than a case of bad luck.[213] In the first instance, it seems likely that the reservoirs were maintained on the cheap. The construction of the first dams had been spearheaded by Toledo in 1573. While four mineowners "offered to build at their own expense a lake to impound the summer rains" (Rudolph, 1936: 531), the chief outlay was labor-power, and this was provided by the colonial state. Toledo "offered to assign 20,000 Indians for building the waterworks and a force to maintain them in perpetuity" (Rudolph, 1936: 531). This is a gigantic figure, 20,000 workers. If true, it represents a workforce fifty percent larger than the Potosí *mita* in the 1580s. So the start-up costs for this second phase of Potosí's expansion were borne

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[211] Epinosa visited Potosí c. 1616, at the very height of the boom.
[212] Five of these reservoirs were still in use during the late 1990s (Absi, 1997: 39).
[213] As Hanke (1956) would have it.

by the state. (How little the modern world has changed since!) But it is far from clear that these reservoirs were maintained. There is no mention of these workers in the literature.[214] Even if such workers were mobilized, they were likely put to work constructing more reservoirs rather than maintaining dams already built – for the dams were built not all at once, but over a half-century (1573-1621). Moreover, the very logic of extractive economies is the diminishing rate of return from declining ore quality, necessitating (as we shall see presently) more and more labor to maintain the same volume of silver ore – itself very much a treadmill of production. It was a cruel logic (Bunker, 1984, 1985). Even the same volume of output was insufficient, insofar as worldwide overproduction of silver depressed its purchasing power on the global market (Flynn and Giraldez, 2002).[215]

So the maintenance of infrastructure was likely to be a secondary concern relative to maintenance of output. Thus the likelihood was a drastic contraction of output rather than gradual decline over a century or more. And this was precisely the case. The reservoirs were quickly rebuilt. But there would be no return to the halcyon days of the early seventeenth century. Although the "more important of the *ingenios* were rebuilt," much of the capital devalued in the flood was not replaced (Rudolph, 1936: 536). Capital looked for, and found, other investment opportunities. Where? As in New Spain, the crisis of the silver mining economy – one of the hallmarks of the so-called "general crisis" of the seventeenth century – was a veritable boom for the home market of Peru (Assadourian, Bonilla, Mitre, and Platt 1980). The divisions of labor initiated during the first century of colonial invasion were now turned, albeit for too short a time, towards agro-pastoral and manufacturing activities connected with mining, but no longer fully subordinated to the silver frontier.

Amalgamation & the Persistence of the Fuel Question

Relative to smelting, mercury amalgamation was a "cold" rather than "hot" technology. But this distinction takes us only so far. Amalgamation certainly consumed less fuel than smelting. (How much less we will consider presently.) Yet, because amalgamation enabled such a large increase in output over so short a time, the consequence was *more*, not less deforestation. And more to the point, the geographical concentration of material throughput and population in the new Andean metallurgical

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[214] Above all in Cole's definitive study of the Potosí mita (1985).

[215] "Silver mining was checked because of the declining value of silver in terms of the goods it could buy. The price of silver was determined by royal decree until 1732, and then only slightly increased; indeed, while Spanish prices (in terms of silver) stabilized about 1600, Mexican prices were rising until a little before 1630. [And Peru's too? This seems likely – *JWM*.] The price of European goods in American was further increased after 1621 by the costs and risks of bring them across an ocean dominated by Dutch maritime power. These processes must sooner or later have made the purchasing power of silver so low that it was not worth continuing to produce it at constant or rising real costs… [T]he marginal American producers with the deepest mines, the most floodable workings, were being squeezed out; it was becoming difficult for the miners either to accumulate for themselves or to attract from outsiders the fresh capital that was need to push shafts to still greater depths and to construct adits and pumps to cope with the ever-worsening flood problems. Many of the Potosí mines [by 1635]… could no longer be worked profitably" (Davis, 1973: 160-161).

centers entrained the relentless drive to incorporate new zones into its commodity-centered division of labor.[216]

The native smelters by the 1560s, we have seen, "could not get at all the silver *except at too great effort and cost*" (Espinosa, 1628: 623, emphasis added). And if amalgamation emerges in the literature as a relatively cost-free technological windfall, an environmental history perspective suggests that this was only half true. A windfall perhaps, but certainly not cost-free. The quantum leap in the scale of production in the later sixteenth century generated a quantum leap in the consumption of human and extra-human nature. In the first place, the extraction of mercury itself demanded a considerable volume of charcoal, resulting in deforestation around the mercury mines at Almaden (Spain) and Huancavelica (Peru) (Parsons, 1962: 200-201; Brown, 2000: 467; Favre, 1975; Goldwate, 1972: 52).[217] Moreover, the mercury-silver amalgam required further heating to get at the pure silver. Espinosa's account is particularly illuminating. Each step in the process required fuel. Lower quality ores would be "first roasted in ovens [prior to]… its grinding in mills" (1628: 626). So widespread were these lower quality ores by 1616 that there were 200, maybe as many as 700,[218] such "furnaces maintained on the Potosí and Tarapaya ranges" (1628: 627). After roasting, these and higher quality ores would then be sent to the mills. Pulverizing the ore and placing it in a brine of mercury and salt, "they put the containers on furnaces and start the fires underneath in small ovens, so that the heat may cause the mercury to amalgamate more quickly with the silver" (ibid: 626).[219] Next the mercury-silver amalgam, which would materialize as "lumps" would be wrung out (by hand presumably) so as to "separate all the mercury they can from the silver" (ibid). These still-moist lumps would be placed into clay pots "shaped like sugar loaves, with"[220] – in the fashion of sugar refining – "an aperture at the end of the narrowest point." These pots were then "set… in ovens specially made for the purpose" (ibid: 626-627). "After the fire has severed the mercury from his friend the silver," silver bars are manufactured through still more application of heat (ibid: 627). And this was not the end of it. There was yet another step in the assaying process. Here the inspector "applied a very hot flame" to groups of bars in order to ascertain their purity (ibid: 628).[221]

Amalgamation, then, answered but could not abolish the Fuel Question. As we've seen, the shift from the "hot" technology of smelting to the "cold" process of mercury amalgamation did not eliminate the problem of fuel supply. On the one hand, a kilogram of silver could now be produced with considerably *less* wood (or its *ichu* equivalent) than previously. How much less? In late eighteenth century Europe, the "improved

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[216] *Pace* the Malthusian sensibility of the otherwise astute Dore (2000), who sees a reduction in population as synonymous with a reduction in environmental stress.

[217] By the early seventeenth century, wood scarcity led to the use of icho, a course grass, in mercury refining (Cobb, 1947: 62). Cobb (1947) puts the transition to icho grass in the early seventeenth century, suggesting that the costs of transporting wood or charcoal – recall the friability and fragility of charcoal in transport (Chapter Two) – had become too great.

[218] Espinosa's manuscript is apparently unclear on this point.

[219] Adequate heating reduced the time needed for amalgamation from twenty to eight days (Espinosa, 1628: 626).

[220] The metaphor of the sugar loaf appears recurrently throughout contemporary accounts, not only Espinosa's. See for starters Barba (1640) and Africanus (1600: 69).

[221] See also Frezier's first-hand account (1717: 156-161)

amalgamation process" pioneered by the Austrian metallurgist von Born[222] consumed just 15 percent of the wood (charcoal) demanded by the silver smelters (Born, 1791; Whitaker, 1941: 67; Teich, 1975: 326). This new amalgamation method, which enjoyed success in Idrija's mercury mines, reduced by half the fuel budgets of the older, Almaden-style furnaces (Whitaker, 1941: 69). So even if we give amalgamation a very generous measurement, the unit fuel saving of amalgamation relative to smelting was 70 percent. This may be *too* generous. *Ichu* was not interchangeable with charcoal. An inferior fuel source, it simply didn't burn as hotly. "Icho… will in *some respects* supply its place," Governor Antonio de Ulloa noted unenthusiastically in 1772 (1772: 64, emphasis added). Indeed this ecological reality prevented the timely transfer of Idrian technology to Huancavelica in the 1790s. As Whitaker observes:

> The fuel problem seems to have been an important factor in preventing the use of the most efficient Idrian type of furnace at Huancavelica. The only satisfactory fuel available in large quantities was a kind of brush, *icho*, when did fairly well for the small Huancavelica furnaces *but could not provide the much hotter fire required by the large Idrian furnaces*" (1941: 123, emphasis added).

Even so, an increase in fuel efficiency by 60-70 percent was surely significant. But rising fuel efficiency, as Jevons suggested more than a century ago (1865 [1906]: chapter 7), does not directly translate into reduced demand for raw materials. Indeed quite the contrary! Insofar as rising fuel efficiency is achieved through technological innovations within the competitive structures of the capitalist market, such efficiency translates axiomatically into rising demand for raw materials, and consequently rising material throughput and rising ecological stress:

> *It is a wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption…* If the quantity of fuel used in a blast-furnace, for instance, be diminished in comparison with the yield, the profits of the trade will increase, new capital will be attracted, the price of pig-iron will fall, but the demand for it increase; and eventually the greater number of furnaces will more than make up for the diminished consumption of each (Jevons, 1865: 140-142).

This is the "Jevons Paradox" (Giampetro and Mayumi, 1998; Clark and Foster, 2001; Clark and York, 2005). Although associated most closely with nineteenth century industrialization, this paradox was clearly in play during Peru's long seventeenth century. Upon introduction of the amalgamation process, output grew so fast that gains in fuel efficiency were offset by the more than seven-fold increase in silver production between 1572 (120,000 marks) and 1585 (860,000 marks) (Bakewell, 1988: 16-17). Assuming a sixty percent savings in fuel consumption per mark, this amounts roughly to a tripling of total fuel consumption.

Even this may understate the increase. For the transition to mercury amalgamation was never totalizing. The *guayras* did not disappear. The Indian-controlled production

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[222] Baron Ignaz von Born (1742-1791) (Teich, 1975: 309).

process had been displaced from its centrality in production. But it had not been eliminated by amalgamation. On top of this, some ores, especially those with a high lead content, were "not proper to be separated by Quicksilver" (Barba, 1640: 133). Thus the mines at nearby Andacaba, not more than 25 miles from Potosí, were barely profitable, Barba argued, because "there is not enough wood near the place to melt it down" (Barba, 1640: 133).

As Barba suggests, the consequences were economic as well as ecological. For the moment, we will focus on the direct consequences emerging from the point of production. Cobo argued in 1653 that mercury production was entirely dependent upon *ichu* – no wood was available (at a reasonable price) close enough to Huancavelica (1653: 150). A century later, in 1763, Governor Ulloa reported

> that the supply of *icho* in the immediate vicinity of Huancavelica had been exhausted, that it had to be brought from places as much as fifteen or twenty miles distant, *with a consequent increase in its cost*, and that at the same time the deterioration in the quality of the ore required an ever-increasing quantity of fuel to produce the same amount of mercury (Whitaker, 1941: 123, emphasis added).[223]

We find another intriguing piece of evidence on rising fuel costs in the distinction between two first-hand accounts of the silver production process. We find in Espinosa's 1616 report no mention of wood scarcity (1628). Frezier's account a century later is however quite different (1717). In the very midst of his description of the amalgamation process at Potosí, Frezier writes that "[t]here… [is] neither Wood nor Coals throughout the greater Part of Peru, but only that Plant they call Ycho," a second-rate fuel in his estimation (1717: 158). Two pages later, this time reporting on the persistence of *guayra* production, Frezier is again moved to comment on wood scarcity (once again in contrast to earlier contemporary reports): "having but little Wood, they heated their Furnaces with the Ycho above-mention'd" (1717: 160). And so it was that first timber, then icho, was attacked from all angles. No wonder the reports of fuel scarcity!

A 1603 source reports 1,000 Indians bringing firewood to Potosí. That many again were transporting wood for other purposes, and another thousand were transporting and making charcoal. While 3,000 workers engaged the wood and fuel trades, there were 4,600 working underground in the mines (Anonymous, 1603: 122). Here was an epochal reversal of the pre-Conquest geography of metallurgy and fuel. Prior to 1531, there is no archaeological evidence to suggest that fuel was carried to the smelters. Rather ore was transported smelters close to where fuel was available (Lechtman, 1975). This would have diffused metallurgy's demands on proximate environments. Not so with Potosí's mining complex. The wooden axles for the *ingenios* – twenty feet long and twenty inches square – were imported from Andean valleys far below, sometimes as distant as 200 miles away (Bakewell, 1987: 218; 1984: 24; Sauer, 1981: 50).

Local construction and fuel needs devoured the forests around Potosí: "Trees were consequently stripped quickly from areas around large mining centers, in some of which

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[223] Favre connects this process of escalating "pressure on the land" proximate to Huancavelica to social differentiation and rising "pauperization" within indigenous society (1975: 425). The broader social relations of indigenous society are outside the ken of Whitaker's analysis.

– the high Andes and the dry Mexican plateau – they can never have been plentiful. *Timber then had had to be brought in at great cost over great distances*" (Bakewell, 1987: 218, emphasis added). The timber hinterland was progressively enlarged, at each step exerting upward pressure on the cost of production. By 1714 Potosí, even as its population had declined from 160,000 to 70,000 and its mills declined from 120 to just 40, was drawing timber from the Paraguay mountains (Frezier 1717: 83, 145-146; Espinosa, 1628: 624).

At Potosí's zenith in 1600, then, it is no surprise that there was "growing scarcity and cost of fuel" (Bakewell, 1987: 214). This caused refiners to stop firing the stone tanks containing crushed ore and mercury and to use "only the sun's warmth" (Bakewell, 1987: 214). But it is far from clear that this happened across the board. As we've seen, Espinosa's account from 1616 indicates the persistence of firing the stone tanks that held the silver-mercury amalgam (1628). It is conceivable that some refiners stopped heating the tanks when profitability was high, but returned to the practice later, as overproduction took its course and exerted downward price pressure on the world silver market. For mineowners were chronically indebted (Braudel, 1982: 327), and it may have been that overproduction escalated so quickly that it became profitable (that is to say, necessary) to reduce turnover time by heating the amalgam tanks. (Amalgamation cut the time required by more than half, Espinosa indicates [1628: 626].) A significant reduction in turnover time would compensate for rising fuel costs. This would have been, in part, an expression also of rising labor costs owing to the longer distances involved in transportation, a tendency reinforced by the prolonged demographic collapse, about which we will learn more presently.[224] It was a temporary solution.

Yet the big question remains. Did deforestation, rendering fuel supplies ever more distant and therefore more costly, enter into the calculus of production and distribution decisions? Szaszdi provides some tantalizing evidence (1981: 200). With the introduction of the amalgamation process in 1571, a quintal of mercury sold for 180 pesos in Huancavelica. Prices ran about 10 percent higher at Potosí. "At such a price amalgamation could not have been profitable" (Szaszdi, 1981: 200). Yet by the end of the decade the price of mercury had fallen by more than 75 percent, to a "little over 40 pesos." The "important breakthrough," if we are to believe Szaszdi, "occurred… when Rodrigo Torres de Navarra started the use of the Andean grass called *icho* [sometimes called *ichu*] as fuel in the smelting process at Huancavelica, *which immediately reduced the price of mercury*" (1981: 200, emphasis added). The implication is clear. The relative scarcity of wood had rendered fuel so expensive that it threatened the introduction of the new amalgamation regime. Szaszdi's interpretation is supported by Luis Capoche's

[224] "Another source of higher costs, clearly apparent by the end of the century, was Indian labor… By 1600, [the mita], even though it was designed to provide Potosí with between four and five thousand active laborers at any particular moment in the year, was clearly falling short of supply all the manpower that was needed. The labor requirements of silver production had grown far above the ability of the Indian communities to meet as prescribed in the original *mitas* of the 1570s… So miners and refiners had turned to Indian wage labor to fill the gap, to such a degree that by 1600 slightly over half the Indian workforce producing silver in Potosí seems to have been contracted wage labor. This was a good solution to the problem of labor, in the sense that it seems to have prevented an *absolute* shortage of workers from arising…. But the solution was expensive" (Bakewell, 1988: 19, emphasis added).

observations (1585). By the early 1580s, possibly earlier,[225] Capoche reports on the "excessive price of wood, in relation to the cost of everything else" around Huancavelica, to which timber was brought in regularly from a distance of "twenty-five to thirty leagues" (1585: 117).

Moving from the point of production to the social division of labor, we can see two distinct and mutually reinforcing pressures. Potosí had bloated to 160,000 people in the first half of the seventeenth century (Hanke, 1956: 1). Beyond the demands of the immediate production process, there was the relentless cold – between May and August "you can hardly sprinkle your house before it freezes" (Espinosa, 1628: 632). Madrid, of roughly comparable size but with a more favorable climate, consumed some 12,500 tons of charcoal each year for heating and cooking in 1630 (de Vries, 1976: 164). And while the city's semi-proletariat may have used other fuel sources, various grasses and dung, it seems a safe estimate that fuel consumption outside the extractive sector must have been at least twice that of Madrid's. (We ought to be mindful, too, that this figure excludes the demand for construction timber!)

But it was neither demography nor climate that underpinned rising fuel consumption, although these were important variables. It was the wood-intensive character of European world-economy – "a civilization literally made of wood," Sale wryly observes (1990: 84; also Braudel, 1981: 362-367). The fuel demands of Peru's silver frontier magnified this tenfold. Even in much warmer breadbasket regions such as Cochabamba, whose farms supplied Potosí,[226] Spanish colonials consumed wood at a feverish pace. The contrast with their indigenous neighbors was striking. The Jesuit Bernabe Cobo was moved to observe that the Indians "use so little [wood] that a Spanish household burns more wood in a day than an Indian household does in a month" (1653: 236). The difference, Cobo argued, was to be found in the industrial accoutrements of European civilization. The Indians "barely had any other reason to use wood, in respect to that they did not have ovens for bread, nor lime and bricks nor the other things for which we consume so much firewood" (1653: 236). In contrast to the Europeans, "*they did not need to cut down the thick trees*" (1653: 236). Cobo might have added that Spanish town-building in general consumed vastly more wood for construction than indigenous settlements (Gade, 1999: 55).

Deforestation weighed particularly heavily on highly vulnerable mountain ecosystems, which suffer from high rates of soil erosion and enjoy only a "fragile stability, easily upset by unintentional human action" (J.R. McNeill, 1992: 352; also Dunaway, 1996: 358-359).[227] By 1603, the devastating ecological consequences of the Cerro Rico were readily visible:

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[225] Capoche's *Relaciones* was first published in 1585 but written from observations "at some indeterminate date before 1585" (Bakewell, 1984: 17), although at least several years after Toledo's reforms (c. 1572).

[226] One of the distinctive geographical qualities of the Andes is its proliferation of micro-climates, such that vastly different ecological zones coexist within relatively small regions (Stavig, 2000: 90). For instance, Tarapaya, which deFrance describes as a "suburb" of Potosí, was just 9 miles away from the Villa Imperial, but more than 2000 feet lower (deFrance, 2003: 107). The difference was "not inconsequential" (ibid), and offered a relatively warm retreat for Potosí's elites. See also Gade and Escobar (1982: 431-432): "The villages of Surimana and Totora [in Southern Peru] are less than two kilometers apart, but a trip between them takes an entire day." Espinosa observed that while "no crops or trees can grow, and there is no grass on the range… for six leagues around Potosí… [O]nce these six leagues are passed, there are valleys with marvelous climate, with vineyards and all kinds of Spanish fruit" (1628: 632).

[227] For special reference to the Andes, see Dollfus (1986: 18-20).

> Even though today, *because of all the work done on the mountain*, there is no sign that it had ever had a forest, when it was discovered it was fully covered with trees they call *quínoa*, whose wood they used to build the first houses of this settlement… On this mountain, there was also a great amount of hunting of *vicuñas*, *guanacos* and *viscachas*, animals very similar to the rabbits of Spain in their fur and meat, but with a long tail. There were also deer, and today not even weeds grow on the mountain, not even in the most fertile soils where trees could have grown. This is the most frightening, because now the mountain is covered with loose gravel, with little or no fertile land, crossed with sterile mineralized outcroppings (Anonymous, 1603: 114-115, emphasis added).[228]

Did this lead to serious erosion problems, and therefore undermine the socio-biological structures of the emergent Andean peasantry? (Which would in turn have undermined the reproduction of low-cost laborpower for the mines?) Our anonymous reporter from 1603 suggests so. Part of the answer to this question must wait until we move to the reorganization of human nature in the reworking of Peru's social economy. It is however clear that Iberian expansion in the New World everywhere led to the massive introduction of European livestock, and this broadly favored erosion, especially in mountain environments. Frezier, for instance, observed after nearly two centuries of conquest in Peru that the roads traveled by gigantic mule trains, "scarce ever [have] any Grass" (1717: 175). Silver mining centers, along with sugar zones, were the greatest consumers of Eurasian animals in the New World. And these animals, Ellenberg suggests, were implicated in widespread deforestation throughout the Andean highlands:

> Under natural conditions a large part of the Andean highlands would be covered with forests or woodlands… [T]he west Andean valleys… would be clothed in woodland if man had not interfered for hundreds or thousands of years. As in the more human and cooler altiplano, these woodlands were destroyed partly by cutting firewood and timber and by burning adjacent grassland areas during the dry season, but mainly by the browsing of indigenous as well as introduced animals… [With the introduction of Eurasian animals] *overgrazing and acceleration of soil erosion soon became severe problems*, simply as a result of intensifying and diversifying the impact on the land. Animal-trampling on the slopes became more dangerous, because llamas and alpacas have broader and softer feet than the sharp-hoofed sheep, goats, cattle, donkeys and horses which replaced them (Ellenberg, 1979: 407, 411, emphasis added; also Dickinson, 1969: 300; Crawford, Wishart, and Campbell, 1970: 175).

[228] Far from an isolated event, deforestation around Potosí signified a structural tendency of the new colonial order throughout the Viceroyalty of Peru: "[T]he presence of innumerable small-scale mines and some much larger operations suggests the area [Northern Potosí] may have begun to become barren of aborescent vegetation during this [the colonial] period" (Godoy, 1984: 368).

Ellenberg might have added that the erosion problems set in motion by large concentrations of Eurasian animals were leant critical mass by the changing climate. The Andes, in stark contrast to Europe after the late thirteenth century (Chapter One), experienced a "long dry period between 1160 and 1500." Subsequently, the Andes moved into sync with Europe's "Little Ice Age," with climate becoming much wetter between 1500 and 1720 (Thompson, Moseley-Thompson, Bolzan, and Koci, 1985).

As for Andean livestock, llamas especially were widely used to supply Potosí. In this respect there was continuity. Under Incan and Spanish hegemony alike, widespread llama herding was organized under local control – this a key difference between the mining frontiers of Peru and New Spain. The historical-geographical literature has tended to emphasize rising *human* population as more or less correspondent with rising *animal* population (e.g. Dickinson, 1969; Dore, 2000). But this obscures a significant unevenness between the two. A defining feature of European imperialism from the very beginning was the rapid expansion of Eurasian livestock. These animals multiplied out of all proportion to their human companions. This was, as Crosby suggests (1986), partly a matter of finding new environments with few natural enemies. It was also in part the inevitable accompaniment to the animal-intensive character of the European world-economy in long sixteenth century. Marx's astute if undeveloped observation that "every particular historical mode of production has its own special laws of population" applies to extra-human as well as human populations in the modern world (1977: 784).[229] It is also clear that the movements of human and non-human populations exhibited a combined and uneven character in the transition to capitalism in colonial Peru.

Large-scale mining was inconceivable without abundant livestock. Extractive centers relied on these mammals not only for food, but also for transportation, hides for sacks, pouches, ladders, ropes, shoes and clothing. Not to mention as organic motors for the *ingenios*, mine hoists, and other machinery – as sources of power, the stronger Eurasian animals were indispensable. Animal fats provided the oils to lubricate machinery, and for tallow to make candles. Underground mining was impossible without these (Espinosa, 1628: 625). Consumption of tallow in 1730s Zacatecas — considerably smaller than Potosí — was over 80 tons *a year* (Semo, 1993: 12; Crosby; 1972: 86; deFrance, 2003: 107; Sluyter, 1996: 172). And though he does not mention the volume of tallow, Espinosa was moved to characterize the 300,000 pesos spent annually on candles as "almost unbelievable" (1628: 625; also Cobb, 1947).

Moreover, while colonials could have chosen to eat llamas and alpacas, Iberian tastes favored those Eurasian animals with sharp hooves (deFrance, 2003: 117-122). The consequent inflow of *live* animals into Potosí was staggering. Our 1603 informant reports on 1,000 sheep entering Potosí weekly, another 2,000 llamas, and each year, 4,000 cattle for the slaughterhouses – suggesting many more cattle "equivalents" in terms of leather bags, rope, clothing and shoes, tallow, and so forth (Anonymous, 1603: 127; see also Espinosa, 1628: 517-518).

In Espinosa's account (1628), one can hardly skip a page without missing a reference to ranching in Peru. In one region nearby Potosí in 1610, he marveled at the fourteen ranches, with 1,600 cattle, 5,000 sheep, 12,000 goats, and 400 brood mares. "At present

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[229] Marx understood this very well indeed: "An abstract law of population exists only for plants and animals, and even then only in the absence of any historical intervention by man [*mensch* or humankind in the German original]" (1977: 784).

[1616] there are many more, for they breed well and multiply rapidly" (Epinosa, 1628: 530). In another region Espinosa observed an "annual increase of 18,000 head" in the cattle, sheep, and hog ranches (1628: 536).

Even these figure do not convey the immensity of Potosí's animal consumption. The *mita*, which we will discuss momentarily, put some 13,300 workers on the roads to Potosí every year. With their accompanying families, there were fifty to sixty thousand people heading to Potosí during the annual labor migrations. And this was not all. Around 40,000 llamas made possible these migrations, which in some cases traversed hundreds of miles, (Cobb, 1947: 80).

Nor were dietary tastes and the mita alone responsible for the livestock explosion. It was also the extractive consumption of animal labor power. Here we can consider, in Hribal's memorable turn of phrase, that "animals are part of the working class" (2003). Daily, some 8,000 llamas carried ore from the Cerro Rico to Potosí's *ingenios* (Espinosa, 1628: 625). From the early eighteenth century, Frezier comments on the mule trains heading towards Potosí that

> notwithstanding all this Precaution, such great Numbers of them die, that the Roads in Peru are not better known by the Tract of their Feet, than by the Skeletons of those that tire out of the Vales, where they can have nothing to subsist on, for there is scarce ever any Grass or Water; for which Reason they are obliged every Year to bring 80 or 100,000 Mules from Tucuman and Chili, to make good that continual Loss (Frezier, 1717: 175; also Cobb, 1949: 40 for the period 1545-1640).

High llama mortality stemmed partly from a challenging geography. Llamas, less hardy than expensive mules, often expired in the arid journey from the mercury entrepot at the port of Arica to Potosí (Cobb, 1949: 40). They also suffered when the sheepskin mercury bags burst, apparently a common occurrence (Cobb, 1949: 37, 40-41). Moreover, at least a partial transition from llama- to mule-trains was underway in the early seventeenth century. This would have been more costly but also a sure way of recouping one's investment in timely fashion. Was this related to escalating pressures to accelerate turnover time? Quite possibly. The organizers of these trains were merchants, who in contrast to the *azogueros* enjoyed no protections against wholesale foreclosure. Merchandise could be seized; productive capital could not. Mule trains cut transport time by a third or more relative to llamas, but "suffered badly from the speed and the lack of food on the journey" (Cobb, 1949: 41). Why was food lacking? Partly because maize was costly and heavy. And partly because "there was little pasture" (Cobb, 1949: 41). Pastures on the road to Potosí had been overgrazed. Could we expect anything else with a stunning 350,000 llamas supplying Potosí every year (Browman, 1974: 194)?

The upshot is that non-human populations were rapidly increasing and becoming, in a sense, "urbanized." That is, Peru's transition to capitalism necessarily entailed an unprecedented geographical concentration of human *and* non-human animals. What were the effects on forest and ground cover, and what were the implications for the emergent world capitalist system? This is still largely unexplored terrain.

If we are to believe Cobo's reckoning, a Spanish household in seventeenth century Peru consumed as much wood in a day as an Indian household in a month (1653), we have some metric from which to evaluate the rupture between the Incaic period and early modernity. Peru's Spanish population roughly tripled between 1600 and 1750, growing from 50,000 to 150,000 (McEvedy and Jones, 1978: 310; Spate, 2004: 179). Given the disproportionate numbers of Spanish-born men to women in Peru, however, the European population organized a much larger number of *households* relative to the Indian population. Moreover, since European colonials occupied strategic positions in the territorial and capitalist machineries of conquest, it seems reasonable to adjust Cobo's estimate. An alternative metric would take account of the wood consumption involved in urbanization, transportation, and extraction, above and beyond the immediate of household reproduction. An upward revision in this light would identify Spanish *per capita* wood consumption at sixty times that of the Indian population. (Even this is a conservative estimate.) The political ecology of modern colonialism meant that the 50,000 Spaniards in Peru by 1600 would make an "ecological footprint" equivalent to three *million* Indians.

A higher estimate would incorporate the impact of Eurasian animals. We have already reflected on the implications of the Eurasian animal invasion onto the slopes of the Andes. Their smaller and sharper hooves contributed to erosion problems in fragile mountain ecosystems. Quite apart from this, Eurasian animals simply multiplied faster than llamas and alpacas, in many cases at least twice as fast, and several times more when it came to pigs (Browman, 1974: 191). The two population dynamics meet up in deforestation. The first movement (Europeans) favored forest clearance, the second (Eurasian animals) militated against the regeneration of forest cover, along with whatever vegetation had managed to survive. In this era of early modernity – long before the introduction of fossil fuels – such long-run secular pressure on forest and vegetation cover would undermine the capacity of any region to sustain an extractive economy. The "Fuel Question," in this broad reckoning, was essentially unanswerable for Spanish Peru, *within* Peru. Constant geographical expansion was the only effective strategy, and this would not, *could not*, continue indefinitely.

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The environmental history of European expansion *within Europe* – and the ways that intra-European socio-ecological and geopolitical contradictions reinforced and propelled recurrent waves of imperial, commodity-centered expansion *outside Europe* – will be told in Chapter Four. What we will do in the second half of this chapter is invert the usual empirical focus of colonial environmental histories. If environmental history is customarily focused on the transformation of landscapes, the labor process and socio-biological reproduction seldom appears as pivotal to these transformations.[230] In what follows, we begin with the mobilization of bodies, and proceed to the mobilization of space.

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[230] But see most recently Peck's call to attend more closely to labor history in the writing of environmental history (2006). The earlier work of McEvoy (1995) is highly suggestive of how environmental history might take seriously the labor process and the body as accumulation strategy. The challenge remains: to situate the production process and the reproduction of labor power in world-historical perspective; to break out of the regional container of conventional environmental history.

Mobilizing Bodies: Potosí and the Human Nature of Underdevelopment

If Philip II was continually frustrated in his efforts to conquer the whole world, the conquest of Peru proceeded with unprecedented modernity and success. The decisive pivot was Potosí, but not simply because it produced silver. Rather the geographical concentration of silver ore in the Cerro Rico – in contrast to New Spain's polycentric mining frontier – enabled and encouraged a radically interventionist imperial policy. But such policies would have borne little fruit if not for the social and physical infrastructures of the Incas. The *mita* was the most conspicuous reinvention, as colonial practice transformed the premodern labor draft system into a dragnet of primitive accumulation. But the *mita* itself, it is perhaps too easily forgotten, was a spatial strategy that at once created and depended upon an impressive built environment of roads, bridges, and inns. It was these infrastructures, retooled and redirected after 1531 in the interests of capital accumulation and tribute extraction, that "allowed Spaniards to dominate Andean space to a degree not yet possible… in the tamer, more regular spaces of Iberia" (Mumford, 2004: 319). More regular? Or perhaps *less compliant*? For these Iberian spaces, like most of Europe, were home to the chronically anti-Absolutist strata of urban bourgeoisies and artisans, Muslims in Granada (until their expulsion), and multiple peasantries.[231] The inner logic of Spanish Absolutism would reveal itself most starkly in Peru, not the Peninsula.[232]

Ecological contradictions degraded bodies much as they denuded the landscape. In retrospect almost unbelievably, the Spaniards' preferred term for Indians was *naturales* (Stavig, 2000). The modern conquest of nature seemed to make no meaningful distinction between human and extra-human nature.

The course of events in Potosí captures what seems to be the basic socio-ecological pattern of metallurgical commodity frontiers in the early modern period.[233] In the early stages, high yielding ores translate into high wages and decent working conditions. But sooner or later ore quality declines. When this happens, profitability begins to hinge more and more on two things: 1) rising capital intensity, manifest not only in surface infrastructures but also deeper mines; and 2) driving down the wage bill for labor power. While technological and social innovations could temporarily check rising costs, they could not do so indefinitely.

The overwhelming preference for the ecological regime of early modern capitalism was the second option – the external ecological fix – although as we have seen, technological innovation was certainly operative. Drawing workers either from outside the commodity economy, or only loosely articulated with it, mineowners found

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[231] I do not mean to suggest that there was an absence of indigenous resistance to Spanish colonialism in the Andes. For the early decades of Spanish rule, see Henson (2002).

[232] Perry Anderson, unwisely treating "Spain" rather than the Empire as the relevant geographical unit in his study of Spanish Absolutism, admits as much: "the stubborn recalcitrance of Aragon was compensated [or made possible? – JWM] by the limitless compliance of Peru. The colonies, in other words, could act a structural substitute for the provinces, in a total polity where orthodox provinces were substituted by autarchic patrimonies" (1974b: 71)

[233] The resemblance to the sugar frontier is particularly striking. The capacities of the plantation system, linked to the trans-Atlantic slave trade, enabled sugar frontiers to bypass the trickle down effects of the initial boom (see Chapters Five and Six).

themselves in a favorable position not only to enjoy the fruits of cheap labor, but also to exploit these workers with little regard for their health (Tandeter, 1981: 104).[234] In itself, the death and bodily damage suffered by Indian mineworkers, much like slave mortality in the Middle Passage, posed no real *short-run* threat to profitability in the early modern world-economy. In certain respects, the "brutal relationship" of the Indian laborers known as *mitayos* and colonial entrepreneur was even more exploitative and dangerous than under slavery (Stern, 1982: 84).

The contrast with Incaic mining practices was especially sharp. Under the Incas, rest periods had been common, "the same Indians were not continuously in the mines… *and none of them died from overwork*" (Cieza de Leon, 1553a: 163 emphasis added). Under the Spanish, this changed radically. The problem was not simply that the colonial *mita* was exploitative, which it surely was. Rather, the very mode of organizing labor through coercive, but short-run, labor drafts intensified the exploitation of the *mitayo*, perhaps even beyond that of African slaves. In this sense, the colonial *mita* prefigured the labor regime of indentured servitude in seventeenth century British possessions (Williams, 1944). Tandeter puts his finger on the essence of this overexploitation tendency in the *mita*. The system "did not place any investment at risk… Immediate profitability was the overriding consideration of the entrepreneur in his relation with the forced laborers" (Tandeter, 1981:104). By the end of the sixteenth century, precisely at the moment when Potosí's silver revolution was in full flower, this tendency was amplified still further by the practice of hiring out *mitayos*. As we shall see, such overexploitation represented not only a shameful legacy of early European expansion, but also constituted a major force for geographical expansion, within Peru as well as outside it.

Potosí's renaissance was driven initially by the exploitation of tailings, ore that resisted the smelters. But these were exhausted by the end of the 1570s. The solution? Dig deeper. A rising proportion of *mitayos* was put to work in the increasingly deeper, and as consequence increasingly dangerous, mines. Work-related fatalities escalated sharply. "As the mines plunged deeper into the cerro, the work grew harder and accidents became more common. *Mitayos* were buried in cave-ins, suffered broken limbs in falls, and succumbed to respiratory diseases" (Cole, 1985: 23-24). These were part and parcel of the labor control problems that emerged apace with the mines' increasing scale and depth – problems, we might add, that if not entirely new nevertheless represented a qualitative shift in the direction of that "industrial pathology" associated with capitalist production from the era of manufacture onwards (Marx, 1977: 484).[235]

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[234] African slaves did work in Peru, although their numbers were limited relative to mitayos and *forasteros*, those de-racinated wage laborers (Anonymous, 1603).

[235] Marx comments rather perceptively on the political ecology of the body in the capitalist labor process: "Capital asks no questions about the length of life of labour-power. What interests us is purely and simply the maximum of labour-power that can be set in motion in a working day. It attains this objected by shortening the life of labour-power, *in the same way as a greedy farmer snatches more produce from the soil by robbing it of its fertility*.

By extending the working day, therefore, capitalist production, which is essentially the production of surplus-value, the absorption of surplus labour, not only produces a deteriorations of human labour-power by robbing it of its normal moral and physical conditions of development and activity, but also produces the premature exhaustion and death of this labour-power itself" (1977: 376, emphasis added).

One final note. It may be objected that Marx's comments on this subject are germane *only* to the period of large-scale industry. Not so, empirically as I show. Marx was also keenly aware that these contradictions of "industrial pathology" (1977: 484) were in play from the origins of capitalism. This is evident from his

Mineowners responded by disregarding colonial prohibitions and imposing fixed quotas.[236] This was early modernity's "stretch out," as the bosses dramatically extended the working day. In the 1570s, for instance, the colonial state forbade more than two trips a day for *apiris*, workers who carried the ore from the mine depths to the surface. By the 1580s they were carrying as many as two *dozen* loads of 25 kilograms upwards some 300 meters. Mine shafts often flooded, forcing *mitayos* to work "knee-deep in water," rendering them susceptible to disease. Rest periods — originally two weeks for each one worked — were increasingly disregarded (Cole, 1985: 23-25; Tandeter, 1981: 104-105; Cobb, 1947: 86-89). By 1600, "the proprietors decided they were losing time changing shifts, so they started keeping the workmen underground continuously from Monday evening to Saturday" (Rowe, 1957: 174). The mines, said mineowner Luis Capoche, had become a "harsh executioner of Indians, for each day it consumes and destroys them, and their lives are made miserable by the fear of death" (in Bakewell, 1984: 145).[237] Notwithstanding this increasingly brutal labor regime, ecology proved stubbornly resistant. Yields continued to decline. By the mid-1580s, "workers were taking out only half the amount formerly produced" (Cobb, 1947: 77).

For the workers on the surface who crushed the ore in the *ingenios*, conditions were no better. Inhaling dust, these workers began to suffer from silicosis, rendering them vulnerable to a wide range of respiratory diseases (Bakewell, 1984: 149). Once the ore was crushed into a fine powder, it was mixed with mercury in the unhealthiest manner imaginable. "Instead of a hook to stir," Frezier wrote in 1714, "an Indian stirs it with his feet, to dissolve it" (1717: 157). The inhospitable climate merely reinforced and rendered all the more deadly the assault on workers' immune systems (Newson, 1985: 55).

Nor did help matters that the standard work shift was 12 hours, day and night. This gave way to round-the-clock shifts during the rainy season, "when advantage had be taken of every hour of adequate water flow" to power the *ingenios* (Bakewell, 1984: 152). Here was a prefigurative moment of "industrial time"[238] – which we shall see again in our examination of the sugar commodity frontier (Chapters Five and Six). Shift work itself represented an important moment of ecological degradation as "industrial pathology," rendering workers highly vulnerable to disease and disability. "Shift work often goes against the rhythms governing many bodily functions… It has [a negative] impact on the metabolism (the bodily processing) of various chemicals and toxins to

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comments on the "entombment in the mines of the indigenous peoples of" the New World during the first era of primitive accumulation (1977: 195). But he goes further, in the heart of the discussions on manufacture and large-scale industry: "*Manufacture* [not as some might assume machine-o-facture]… is the first system to provide the materials and impetus for industrial pathology… [These contradictions are] *finally* completed by large-scale industry erected on the foundation of machinery" (1977: 484, 548-549, emphases added).

[236] Mineowners were in the same structural position as sugar planters and other commodity producers in the early modern world-economy: "Whatever the cause [of mining capital's insecurity], in Potosí as in other mining towns of the Andes and Mexico, the *mercaderes de plata* [silver merchants] tended to accumulation more wealth than the men directly occupied in mining silver ores [– I would say the men whose *capital* was directly occupied –] and turning it into metal" (Bakewell, 1988: 47; also Braudel, 1982: 327. For sugar, see Chapters Five and Six; for the broader argument for the European world-economy, see Braudel, 1982, 1983).

[237] Nor would this improve over the next century: "[T]he entrance, and Mine works [of Potosí] are so dangerous, that few that go in return again," observed Samuel Clarke in 1657 (Clarke, 1657: 150).

[238] See Thompson's groundbreaking essay on the subject (1967).

which individuals are exposed in the course of their work" (Freund and McGuire, 1999: 94; also Levins, 1996: 5-6).

These contradictions extended well beyond Potosí. Huancavelica was the mercurial pivot on which Peru's silver economy turned. Huancavelica's mercury mines — known far and wide as the *mina de la muerte* (mine of death) — were especially lethal. Mercury poisoning, ravaging kidneys and the central nervous system, complemented the standard occupational hazards. One estimate puts the life expectancy of the miners at Huancavelica at just six months (Goldwate, 1972: 47), although Brown indicates that recovery from metallic mercury contamination[239] was possible (2000). Here as elsewhere, workers suffered from silicosis and tuberculosis. Mercury-laced dust amplified the problem. "Workers remained at the mines through the week and had little opportunity to wash away the contaminating dust. This prolonged their contact with the mercury and increased its absorption by their bodies." Nor was this the end of it. Poisoned workers carried the toxins from the productive to the reproductive sphere. Returning home, they "polluted the living quarters and contaminated their wives and children" (Brown, 2000: 478).

Huancavelica's workers were caught up in the same inexorable logic we saw in Potosí. Between the 1570s and the 1630s, high-grade surface deposits were exhausted. The exhaustion of ores led in short order to the exhaustion of the workers, as mineowners ordered them to move ever deeper into the earth. Declining yields reduced some dangers but created new ones. There was less mercury in the dust, but drilling deeper pushed ambient temperature upwards. "Subterranean heat and poor ventilation within the galleries caused mercury to volatilize, converting "the atmosphere… into a true 'culture' of mercury intoxication" (Brown, 2000: 472). The workers had gone from the frying pan into the fire, and it was the profound danger of these fumes that most alarmed contemporaries (e.g. Acosta, 1590: 242). As yields declined, the city's mining guild began systematically to disregard the colonial state's regulations. Huancavelica's "naturally toxic conditions" were as a result correspondingly magnified by the guild's profit-maximizing orientation (Brown, 2000: 495). Small surprise, then, that the mercury mines became "an increasingly dangerous… By 1600 the environment at the mines had deteriorated to such an extent that conditions for the workers were horrific" (Brown, 2000: 470-471; Fox, 1962; Galeano, 1973: 50; Stern, 1982: 85). As many as *two-thirds* of Huancavelica's mineworkers died from their labor in the early seventeenth century (Brown, 2000: 492).

Nor was mercury toxicity limited to Huancavelica. Given the constant movement of Indian laborers in and out of mining centers, widespread mercury deployment undermined the biological conditions for reproduction. Mercury contamination, Brown speculates, may have

> hampered recovery from the post-Conquest Andean demographic collapse not only due to the deaths at the mines but also because mercury poisoning made survivors less given to procreation. Mercury contamination can also diminish female fertility, a consequence that would have affected wives of

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239 Metallic mercury can be flushed from the body with much greater ease that biomethylated mercury, such as that absorbed by eating contaminated fish.

> *mitayos* living in quicksilver-producing huts or helping at the refining ovens (2000: 488).

Brown's speculation finds some support in the demographic history of Almaden's mercury mines, where Gonzalez finds "little or no capacity for growth." *Pace* Brown, however, Gonzalez finds a "comparatively high birth rate," undermined by "an exceptionally elevated death rate" among the adult male mineworker population (1994).

The poisoning of bodies was complemented by the poisoning of land and water, and through biomethylation, back to bodies. The volume of mercury "lost" in Peruvian silver production was measured not in thousands but rather *hundreds of millions* of grams — some 300 tons *annually* between 1580 and 1640. Over half this volume evaporated or found its way into the oceans (Nriagu, 1994: 174).[240] Nevertheless a huge volume remained, and this represented a powerful toxic invasion of regional ecologies.[241] "One gram of mercury poured into eighty million liters of water would be cause for concern under [U.S.] human health standards for drinking water, enough to contaminate a typical mid-western lake" (Project Underground, n.d.). Sixteenth century sources indicate that "the most moderate loss of mercury is about a pound for every mark [8 oz.] of silver refined, *a loss that can never be recovered*" (Gomez de Cervantes, 1599: 151).

This was an early instance of capitalism's metabolic rift radically extended. Mercury not only disrupted the nutrient cycle; it poisoned it. Dumped into rivers, mercury poisoned the entire food chain — the fish, the animals who fed on them, and the humans who ate both. The bioaccumulation and consequent magnification of mercury toxicity through biomethylation — "concentrations of mercury in predatory fish can be a *million times* higher than in the surrounding water" (Stephens, 2001:20) — are not only highly durable over time. They are also highly "mobile, moving through the environment in the water and in the atmosphere, to locations quite remote [in time and space] from the mining districts" (Schoenberger and Silbergeld, 2000).

Mobilizing Space: *Reducciones*, Common Fields, and the 'Urbanisation of the Countryside'

The contradictions that flowed from the point of production intertwined with broader layers of the social economy. The late sixteenth century silver boom presupposed a radical recomposition of Peru's ecological wealth and its socio-spatial division of labor in ways that favored the maximization of commodity production in Potosí, and the progressive commodification of internal and external nature (land and labor) throughout the region. All of Peru was to be at the service of Potosí.[242]

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[240] Similarly large volumes of mercury appear were dumped Mexico during the colonial period. See the report issued by Acosta y Asociados (2001).

[241] See the recent study of mercury release in contemporary gold mining by Frery, Maury-Brachet, Maillot, Deheeger, de Merona, and Boudou (2001).

[242] As Vega (1608: 524) quietly understates: Potosí was "the best served with Provisions of any Countrey in all of Peru." Vega's observation finds ample empirical support in Espinosa's detailed geography of Spanish colonial America (1628: esp. 513-656).

Our attention goes first to labor recruitment. This was the colonial state's great concern, and the pivot on which the region's new town-country division of labor turned. Needless to say, the Indians were not in a hurry to work for the Spaniards. The solution was found in the *mita*, a rotating annual labor draft. An institution rooted in the Incan empire, the Spaniards reinvented the *mita* to serve thoroughly modern ends. Imposed in 1572, the colonial *mita* conscripted one in seven adult males for work in the mines, textile workshops, "and any other task… deemed worthy of the state's patrimony" (Stern, 1982: 82). While there were many *mitas*, Potosí's was by far the largest and most expansive. In the 1570s, the annual draft mobilized some 13,500 workers, drawn from a region that stretched some 800 miles north to south and as much as 250 miles east to west (Bakewell, 1987: 222).

This large-scale mobilization of bodies was predicated on the large-scale reorganization of space. The *mita's* immediate precondition was the Empire's reorganization of village life throughout the Andes. Beginning in 1567 and accelerating after Viceroy Toledo's arrival in 1569, the colonial state initiated the "wholesale resettlement of the native population" – perhaps as many as 1.5 million people, roughly the population of contemporary Portugal – into "Spanish-style towns" (Rowe, 1957:156). Replicating on a grander scale the peasant settlements of *Reconquista* Castile, these new "agro-towns" instanciated the urban primacy of Spanish colonialism: "[The] towns, not the countrysides, controlled and directed agriculture" (Gade, 1992: 472). Here was an early glimpse into Marx's "urbanisation of countryside" (1973: 479)!

These nucleated villages (*reducciones*) effected three major socio-ecological transformations, reinforcing their obvious advantages for tax collection and political control (Gade, 1992). In the first instance, the concentration of Indians into densely populated encampments provided fertile epidemiological terrain for Eurasian diseases (Andrien, 2001:57). Second, large-scale resettlement typically entailed the removal of Indians from lands prized by Spanish colonials. Often relocated to inferior lands, the new Indian settlements were plagued by "high water table[s], problems of salination, and fog and cloud cover that effectively reduced the growing season" (Ramirez, 1987:598; also 1996: 71-72; Gade and Escobar, 1982: 441).

Third, perhaps most fundamentally, the *reducciones* represented a serious challenge to the region's actually existing political ecology. Prior to European conquest, Andean settlement and landowning was premised on the principle of "verticality." The core strategy involved "working as many different microenvironments as possible" in order to ensure foods security and safeguard community (Stern, 1982: 5). Throughout the Andes, the close proximity of distinct regional environments — "the coast, the piedmont, the altiplano highlands, and the tundra steppe (puna)" — encouraged highly interdependent agro-pastoral linkages (Wolf, 1982: 59). Potato cultivation in the highlands, for instance, was nourished by fertilizer (guano) supplied by coastal communities, which in turn consumed highland foodstuffs (Larson, 1988: 19-20; Murra, 1984; Godoy 1991: 400). Throughout the Andes, there had evolved a "synchronized [pattern of] ecological relationships between coast, piedmont, highland, and puna," constituting "a finely calibrated system of food transfers" (Wolf, 1982: 59).

Verticality may have been ecologically-sound, but it was hardly conducive to the demands of the silver revolution. Such finely calibrated transfers, governed by relations of tribute and reciprocity, would have to give way to the cash nexus. The *reducciones* were therefore established on a mono-zonal rather than multi-zonal basis, eliminating "agricultural outliers in a variety of ecozones" (Gade and Escobar, 1982: 434). For Gade and Escobar, the ensuing "decline in self-sufficiency" was an "unintended consequence of the Spanish-imposed system rather than a goal" (ibid). But seems line of reasoning seems confused. Notwithstanding the intentions of specific actors, the Spanish-imposed system was premised from the very beginning on colonial hegemony over the "intense and wide circulation of indigenous commodities" such as coca, maize, and textiles (Larson, 1988: 46):

> The intensity of commercial demand for food crops and special items like coca prompted many Indians to redirect the flow of goods and labor outward, toward the mining town. The shift in the balance between agrarian production for subsistence and for commercial exchange frequently had drastic consequences for the well-being of the social whole… [E]ven the highland peoples on their 'sterile lands' could not escape the incursion of commercial capitalism… as long as colonial policies eroded the basis of 'social insurance' that traditional had buffered Andean communities from subsistence crises (Larson, 1988: 47).

To the extent that subsistence production was undermined by severing the "vertical," multi-zonal, strategies of pre-Conquest *ayllus*, the *reducciones* served as a built environment favorable to the consolidation and reproduction of the mining-centered commodity economy.

The *reducciones* insisted on a new agro-ecological order corresponding to the labor demands of the silver frontier. At its center was common-field agriculture, a cultivation system that emphasizes agro-pastoral linkages, access to commons, and community regulation of landholding (Thirsk, 1964).[243] Where verticality presumed exchanges across ecological zones, such that farming and herding were "distinctive, geographically nonoverlapping activities," common-field agriculture sundered such exchanges by stressing agro-pastoral integration *within* rather than between zones (Godoy, 1991: 396-398).

From the standpoint of the colonial state, the great advantage of the common-field system was its geographically expansive character. The new agro-ecological order mobilized land as the best way to maximize labor productivity. This in contrast to the older, labor-intensive land use practices. Thus it was not simply that Spanish colonialism carried new disease vectors that eviscerated indigenous populations. The very agro-ecological regime constructed under Spanish hegemony was premised on the scarcity of labor power. Insofar as it demanded the destruction of pre-Conquest social organization (such as the *ayllus*) and the construction of an urban semi-proletariat (and servile laboring classes on the Spanish estates), this regime sustained and indeed *presumed* the long-run demographic contraction.

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[243] The rise of capitalism was accompanied by uneven movements of enclosing and creating commons. These were shaped largely by the struggles between capital and states on the one hand, and between ruling strata and peasantries on other. These struggles unfolded, in great measure, on the terrain of access to "nature."

The new system minimized the labor power formerly allocated to supervising and guarding herds and fields, and maintained soil fertility by substituting European livestock for vertical guano transfers (Godoy, 1991: 408-409; Gade, 1992: 467). (Which tended to accelerate soil erosion, as we've seen.) The transition was accelerated by Viceroy Toledo's 1575 "edict mandating a plow and oxen for each Indian agglomeration" (Gade, 1992: 469). The 1575 edict codified an epochal shift in Andean political ecology, from a labor-intensive to a land-extensive approach:

> Where the Indians had farmed land with a dibble, the Spaniards introduced a light plow drawn by oxen… With this new instrument, men were probably able to farm land which they had not farmed before: the plow with a metal tip is a much better tool for loosening deep sod and breaking up the tangle of roots and rhizomes than the hoe… [*Yet,*] i*n its net effect, the plow also upset the balance of Indian life on the land*. *The plow is efficient only where land is plentiful but labor is scarce.* Plow agriculture does not produce as much as hoe cultivation on any given unit of land… Also, plow agriculture means that oxen must be fed, and some land must be devoted to their care… [E]very unit of land withdrawn from Indian agriculture meant a halving of the food supply on that land [assuming that hoe yield ratios were twice that of plow ratios], and thus a halving of the population dependent on that food supply. And when that land was planted to wheat to feed the Spanish conquerors [or non-agricultural workers in the mines] rather than the Indian inhabitants of that land, the growing imbalance between man and land was intensified (Wolf, 1959:198-199, emphasis added).[244]

The livestock-plow system was complemented, in fact made possible by, a second moment of ecological imperialism. This phase was marked by the invasion of Europeans' favored crops, wheat above all. Demand for wheat was high from the earliest moments of Spanish colonization, and commercial production dates from the late 1530s (Keith, 1976: 66). "In some locales [Indians] were growing it as… [a] food staple by the late sixteenth century" (Gade, 1992:465). If the common-field system reduced necessary labor by cutting supervision costs, and the livestock-plow system effectively substituted land and animal power for human labor,[245] wheat offered a further labor-saving (but land-consuming) bonus. Relative to indigenous crops, wheat demanded little labor and enabled plow agriculture by tolerating the new animals' grazing patterns (Godoy, 1991:407; Gade, 1992: 165-466).

[244] In this passage, Wolf is writing about colonial Mexico, where the impact of stockraising was unquestionably greater than in the Andes. Yet, I would suggest that the difference between the two regions is one of degree rather than kind.

[245] "The hoe made possible larger cultivated plots, from perhaps 1.0 to 2.5 or 5.0 hectares per worker. The use of the hoe meant that the inevitable invasion of weeds did not necessarily bring about the immediate abandonment of a field. It meant that second-growth forest was at less of a discount because of its likely infestation with weed seeds. The hoe permitted cultivation for prolonged periods and permitted the burning and exploitation of less-developed second growth. The extension of the period of cultivation, however, was critical for the stability of the swidden farming regime and disastrous for forest regeneration" (Dean, 1995: 76).

In early modern Europe, wheat's greatest ecological trade-off was its tendency towards low yields and soil exhaustion. Wheat "devours the soil and forces it to rest regularly" (Braudel, 1977:11; also Braudel, 1981: 114, 120).[246] It was the colonizers' great fortune, however, that the New World's fertile soils counteracted this tendency. Indeed, in coastal zones, multiple cropping with high-yields could be sustained for several years (Descola, 1968: 225). Estimates vary on just how fertile this soil was. Primary sources suggest extraordinary harvests. Espinosa says that with guano, wheat yields of 1:1,000 were possible in a district close to Potosí (1628: 518). Surely a literary flourish, although Super reports yields of between 1:50 and 1:100 (1988: 20-23).

Quite possibly, the introduction of wheat and other Eurasian grains enjoyed a period – how long it is difficult to say, but likely not more than 20 years – of substantial freedom from pests and diseases. This "yield honeymoon" (Dark and Gent, 2001) would have allowed higher yields and given the impression of endless bounty. Reports of cereal yields ranging from 1:50 to 1:100 are also found in the reports of fifteenth century visitors to Madeira (Cadamosto, 1455). Yield honeymoons, it appears, were a recurrent source of the "windfall" profits of Webb's Great Frontier (1964). Even if we take with a grain of salt the exuberant reporting of Espinosa and his contemporaries, it appears that on balance wheat cultivation in Peru supported seed/yield ratios 3-6 times higher than those obtaining in seventeenth century Europe, liberating still more labor from agriculture (Slicher van Bath, 1963: 330; Super, 1988: 20-22; Keith, 1976: 66). Wheat's ecology could not be ignored completely: the tendency towards soil exhaustion necessitated frequent fallow periods and livestock to restore fertility. Hence the importance of the common-field (Assadourian, 1992: 62). Peruvian soil did, however, prove hospitable to the transfer of a European agronomic complex that created a relative surplus population in the face of demographic contraction, and provided a crucial subsidy for early Spanish commercial agriculture.

Nor was this the end of the agro-ecological bonanza the Spaniards had stumbled upon. Also among the ecological windfalls was the potato. Not only were its labor requirements minimal. Its yields were vastly greater. While corn (maize) is also a labor-minimizing crop, a hectare planted with potatoes will yield some 5-6 *times* the food volume of a comparably sized corn field (Braudel, 1981: 158-163; Browman, 1974: 190). Contemporary maize yields in pre-Conquest New Spain and Central America were already two to three times greater than per hectare cereal output in sixteenth century Europe (Malanima, 2006: 106).[247] Even with higher wheat yields on American soil, then, potato cultivation yielded, at a minimum, twice as much as Eurasian grains.

Achieving its "clearest expression" and most durable form in those villages most heavily burdened by mining frontier's labor demands, common-field agriculture responded well to the colonial state's demand for a "reservoir of cheap labor for the mines" (Godoy, 1991: 405). The net supply of laborers increased. But only for a time. The *reducciones* and common-field agriculture helped to create a regional commodity-

[246] da Silva (1964) makes much the same argument for millet growing in early modern Spain.

[247] Of course output by weight is a crude measure that does not translate easily into adequate nutrition. It is however quite clear that the diet of early modern Europeans – peasants especially but not only – suffered from a declining protein content and some variant of what White (1962) calls "amino starvation." Subsistence crises persisted in Europe until the end of the seventeenth century (see Appleby, 1980).

oriented political ecology that sustained demographic decline into the eighteenth century and thus the demise of the very labor surplus it had created.

Providing the administrative and spatial framework for the *mita*, the *reducciones* established the conditions for yet deeper transformations of land and labor in the service of capital. While it is customary within environmental history to explain these transformations in terms of the power of the market,[248] our story of the silver frontier so far suggests that the geographical expansion of the commodity system was predicated on a wider ensemble of socio-ecological relations. Foremost among these was power of the state to create and sustain the conditions for expanded commodification. This was no mere "Smithian" dynamic (*pace* Brenner, 1977). To be sure, colonials established commercial agriculture in response to commercial opportunities, especially those arising from the mining frontier. (How could it be otherwise in a region where something like one-third of the silver produced stayed put?[249]) But this development presupposed the disrupting effects of Europe's social and biological expansion, which transformed indigenous society in ways that encouraged a significant (if still partial) turn towards commodification.

We can identify three main sources of disruption linked to the silver frontier's commercializing impulse – 1) land expropriation; 2) stockraising and the imperial moment of Crosby's "Columbian Exchange" (1972); and 3) the spatio-temporal dynamics of the *mita* itself. The first, as we have seen, was the colonial state's relocation of native communities. This often amounted to outright land theft. Concentrating scattered Indian settlements, the *reducciones* opened up vast new expanses for colonial agriculture and stockraising (Ramirez, 1987: 598; Charney, 2001:17-18, 44). And this was only the beginning. In the half-century after 1570, the land appropriation escalated still further. Was it happenstance that the turning point in Peru coincides with a seigneurial offensive in Spain that led to the widespread dispossession of small cultivations and rising concentration of landownership?[250] The mechanisms of dispossession were different, but in Peru and Castile alike the number and size of large estates increased several times over (da Silva, 1964). In Peru, this was made possible largely through the state's "direct intervention… accelerat[ing] the distribution of land to the Spanish settlers" (Assadourian, 1992: 60). European conceptions of private property were beginning to supplant indigenous notions of communal property (Ramirez, 1996: 73-74; Andrien, 2001: 81-82). And since landholdings were useless without labor, the colonial state mobilized an agricultural *mita* five times larger than New Spain's (Assadourian, 1992: 61) – a differential that reflected the two regions' differential silver output. By 1630, haciendas "dominated the urban and mining markets" for maize, and presumably wheat as well (Assadourian, 1992: 62; also Stern, 1982: 109)

This dual process of land clearance and land appropriation – whose greatest impetus was the mining frontier – was undoubtedly made easier by rapid depopulation owing to Eurasian disease (Smith, 1970; Keith, 1976: 42-47). But as I've suggested, depopulation cannot be explained solely in terms of the initial epidemiological onslaught. Among the

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[248] See, among others, Cronon (1991), Merchant (1989), Worster (1990), Richards (2003).
[249] See Assadourian, Bonilla, Mitre, and Platt (1980: 24-25). This is we should say a contested figure and one necessarily given to fluctuations. For starters, see Stern's conversation with Assadourian (Stern, 1985: esp. 134).
[250] See da Silva (1964).

factors driving prolonged demographic decline was the proliferation of Old World animals deliberately introduced to aid the colonial project (Vassberg, 1978: 47; Mann, 2002). Pigs were a big factor. As Melville puts it, "anyone who has [had] to deal with pigs in their garden will know the remarkably short period of time needed for just one pig to wreak havoc" (1994: 50).

Obviously central to the political economy of the mining frontier, these livestock did more than carry disease. Particularly in the case of sheep and cattle, Eurasian beasts entered into competition with the overall *system* of indigenous cultivation, dramatically undermining these societies' socio-biological reproduction (Crosby, 1972: 98-99; Parry, 1963: 246). The classic instance of this process is New Spain in the sixteenth and seventeenth centuries, where the livestock economy was also given life by the silver mining frontier (Chevalier, 1963: 93-94; Simpson, 1952; Sluyter, 1996; Wolf, 1959; Melville, 1994). There were, to be sure, important points of divergence between colonial New Spain and Peru – foremost among these the Andean traditions of llama- and alpaca-herding, which facilitated indigenous stockraising after Conquest. Nevertheless, in both regions the underlying logic of the agro-pastoral "footprint" was the same. By the late sixteenth century, a rising cattle population inflicted widespread damage on Indian fields, leading peasants to move "their fields outside the range of the roaming beasts… Once the peasants abandoned the land, the Spanish moved in permanently and grazed it or cleared it" (Ramirez, 1996:73-74). Once relocated to the *reducciones*, Andean peasants found little respite. These colonial nucleations, alas, were located at some remove from the fields, often several kilometers or more distant. Hence, a century later, the clear trend was for peasants in the *reducciones* to re-establish themselves closer to the fields "to guard the crops from livestock damage" (Gade and Escobar, 1982: 441; also Stavig, 2000: 100).

Depopulation played its role in the withering of the remarkable hydraulic infrastructure of the Inca Empire – Wittfogel (1957) was moved to place the Incas alongside the Egyptians and Chinese in his theory of hydraulic despotism – but so did the Eurasian livestock invasion. The Andean chronicler Guaman Puma (Felipe Guaman Poma de Ayala), writing between 1600 and 1615, vividly describes the agro-ecological transition:

> And so throughout the kingdom [before the Conquest] all lands produced food… And the Inca kings commanded that no one should damage or remove one stone, and that no livestock should enter the aforementioned canals [irrigation works]… But now this law no longer applies. And so all the fields are destroyed because of a shortage of water. On account of this the Indians lose their lands… For nowadays the Spaniards let loose their animals, their *mule trains* or their cows, their goats and pigs, and they cause great damage. And they take the water and destroy the irrigation canals so much so that no amount of money could repair them. And the little amount of water that remains, that also it taken from the poor Indians. And so the Indians abandon their towns (Poma de Ayala, c. 1615 [1980]: 885, emphasis added).[251]

[251] Waman Puma's testimony finds support in a 1574 lawsuit brought by the Mizque Indians of Cochabamba against a Spanish landowner: "According to the account contained in Toledo's *visita*, the Indians complained that the colonist had stolen their water rights by diverting a main canal, and that he was

Naturally, where the colonials were moving aggressively to establish cash crop production, wheat for instance in the Cochabamba valley basin (Larson, 1988), the story was different. Cochabamba, subordinated only in 1539, was too arid to support the emergence of large-scale agriculture that sustained Potosí. Instead of destroying Incaic hydraulic infrastructure, the Spaniards appropriated it. "In some cases," Zimmerer writes, "the colonial Spanish and their workers destroyed the off-takes of Indian canal arrangements in order to divert irrigation into their own waterworks. In many cases, however, they preferred the tactic of usurping the intact Indian waterworks" (2000: 164).

Potosí's voracious appetite for labor, satisfied in large measure through the *mita,* was a third source of disruption. Knitting together the region's pueblos in a new town-country division of labor, the *mita* created a favorable disease environment whose effects were felt in "murderous epidemic" (Lovell, 1992:436; also Cole, 1985: 28). This contradiction was reinforced by others. By extracting hypothetically "surplus" labor from the villages, the *mita* undermined socio-ecological reproduction over the short- and long-run. In the first instance, the mita often withdrew labor at "crucial moments in the agricultural cycle," further destabilizing labor-intensive cultivation (Stern, 1982: 89). This would have been bad enough, all things being equal. But of course all things were not equal. The disruption of the *mita* intruded at the very moment when the imposition of the common-field system necessitated a quantum leap in the village-level coordination of stockraising and agriculture. Formerly separated spatially, under pre-Conquest principles of verticality, the "radical transformation of land tenure" effected by Toledo's grand strategy after 1571 placed this agro-pastoral regime under one roof (Zimmerer, 1997: 50). Zimmerer, looking at Conquest-era Pautarcambo, a key coca-producing zone intimately linked with Potosí even though 500 miles distant, cuts to the heart of the contradiction. "Any shortcutting" of the coordination between stockraising and cultivation – that is, the very coordination that the *mita* threatened to undermine – "was likely to result in crop damage. The map of new partitioned lands… inferred deteriorating soil fertility and worsened erosion in areas nearest villages due to the contracted periods of fallow and the loss of community control over cropping and livestock" (1997: 51).

When *mitayos* returned, many were too sick to return to work the land, others found their fields "deteriorating or unworked" (Stern, 1982: 87; also Newson, 1985: 55). But many did not return. There was a long-term hemorrhaging of labor, as *mitayos* left permanently (becoming *forasteros*), many of them taking up residence in the mining camps and haciendas (Andrien, 2001: 86; Godoy, 1991: 406).[252] By the early seventeenth century there were some 76,000 Indians – an early mining semi-proletariat – in Potosí, quite distinct from those workers bound by the *mita* (Cole, 1985: 66). Between 1581 and 1609, villages within the Potosí mita lost one-third and one-half their population, with even sharper declines in some locales (Bakewell, 1987: 231; Barber, 1932: 105; Cobb,

trying to steal their lands by devaluing them. At each attempt of Mizque Indians to rebuild the canal system, Diego de Valera [the landowner] was said to order his oxen teams to be used to destroy the connections to the canals to their fields, thereby altering water flow and sediment transport that was crucial to irrigated farming" (Zimmerer, 2000: 166). Beyond the outright theft of water, the structural pressures to reallocate labor away from pre-Conquest agro-ecological strategies – through the *mita* and taxation-tribute demands – also diverted labor away from maintenance of irrigation systems (Klaren, 2000: 49).

[252] Many Indians also left the reducciones to reestablish "diffuse settlements of pre-Conquest pattern," part and parcel of the resettlement strategy's unraveling in the seventeenth century (Gade, 1992: 472).

1947: 79-81; Cole, 1985: 27-28; Andrien, 2001: 76). This "*collective* deterioration" of village life (Stern, 1982: 89) – by means of the cash nexus and the colonial state – would over time undermine the conditions of profitability for the region's mining complex, already in the grips of a profit-squeeze from above owing to the overproduction of silver on the global market (Flynn and Giraldez, 2002).

And yet the demographic contraction did not stabilize during Potosí's decline in the later seventeenth century – at least not everywhere and in many regions in which the *mita*'s geographical reach was *initially* weakest. By 1672, the viceroy Conde de Lemos inveighed against local officials who compelled villagers to travel to Potosí for the mine work *even though* the villages could pay cash (Premo, 2000: 83) – a sure sign of rising labor costs even in the era of the Cerro Rico's secular decline. (Which we can explain in part by the broader tendency for the silver frontier's ecological contradictions to run ahead of its immediate economic contradictions.) The labor draft was undermining the socio-biological basis of the whole complex. Quite understandably, the viceroy was concerned with tax revenues – as were contemporary Absolutist states *within* Europe (de Vries, 1976: 30-83). Given the progressive commutation of labor dues into cash payment, depopulation meant declining cash revenues for the Crown. Conde de Lemos argued in 1673 that "if [the male villagers] are continually forced to work [in the mines], they abandon their lands, houses and families in order to liberate themselves, to the grief of their children of wives" (quoted in Premo, 2000: 83). A year earlier he made much the same argument, specifying the growing problem of malnutrition – one of the hallmarks of underdevelopment from its earliest moments (Galeano, 1973; Castro, 1966) – contending that the mita's labor draft had so disrupted village agriculture that "the women and children are left without anything to eat" (quoted in Premo, 2000: 83).

Village depopulation, the formation of a mining semi-proletariat, and declining ore quality in Potosí combined to favor the gradual substitution of cash payments for labor service. However uneven in practice, generalization of the cash nexus would significantly alter the relation between indigenous society and the land. It was becoming "clear to all concerned that the *mita* was little more than a heavy tax burden," even as early as the seventeenth century (Andrien, 2001: 76). In 1606, silver payments satisfied some 20 percent of the *mita*'s obligations. Two decades later, the figure would climb to somewhere between one-third to one-half (Andrien, 2001: 62; Cole, 1985: 37). "Whatever the actual fraction of the *mita* that was satisfied in money, the sums involved were enormous" (Cole, 1982: 37). The indigenous political class (*kurakas*) responded by turning to commodity production, largely as a bad solution to a worse situation. Eurasian crops such as wheat and barley were especially favored (Godoy, 1991: 306; Spalding, 1975: 111). While some *kurakas* grew rich, more generally commodity production was associated with rising indebtedness and land alienation (Ramirez, 1996: 119). The political ecology of colonial taxation therefore favored a radical simplification of pre-Conquest agriculture, favoring Eurasian cereals over those "diverse [American] crops [such as the potato] that were hardy and rarely failed completely" (Zimmerer, 1996:55). This was a development fraught with unhappy implications for indigenous society's socio-biological reproduction:

> As tribute and other community obligations increased, these lands were often sold or rented to discharge debts. Shortages of labor and land at

> times [of] increased extracommunal demands on Indian communities led to food shortages and even famines. These situations resulted not only in acute starvation in some cases but also in malnutrition, which increased the susceptibility of Indians to illness and disease and probably reduced the effective birthrate through maternal malnutrition during pregnancy and lactation (Newson, 1985: 56; also Stern, 1982: 151-152).

The increasing frequency of famines and the generalization of malnutrition that ensued (Cook, 1981; Klaren, 2000: 49) expressed the dietary moment of what we might call *extroverted primitive accumulation* in the Americas. An *ecological surplus* was extracted from the bodies and fields of the indigenous peasantry in a way that paralleled the extraction of surplus labor, in both instances for the benefit of accumulation centers abroad rather than the creation of a home market.[253] This was the "disarticulated" – *and therefore intrinsically globalizing* – nature of the New World's metabolic rift in the transition to capitalism.

Potosí's Decline in World-Historical Perspective: Ecology, Capital, and the Spaces of Accumulation

Potosí's mines would remain important silver producers until the nineteenth century. However *important*, it is clear that the Cerro Rico's moment in the sun was over by 1640. Maybe earlier. Bakewell identifies 1615 as the definitive moment of decline in silver output (1975), although its relative decline would not become fully apparent until the end of the century. Potosí's output was essentially the same in 1715 as it was in 1640 (Garner, 1988: 903). And although it would make an "impressive recovery" in the seventy years after, surpassing its earlier high water mark of the late sixteenth century, this would give way to sustained contraction almost immediately (Garner, 1988: 903). This depression – was it coincidence that that these were also the years of the Tupac Amaru revolt? – would endure "at least until 1810" (Garner, 1988: 303).

Peru's loss was however Mexico's gain. Silver mintage quadrupled in New Spain between 1706 and 1798 (Brading and Cross, 1972: 576).[254] Given the extent of smuggling and the informal economy, the increase was likely even more spectacular. New Spain accounted for nearly two-thirds of world silver output (64.4 percent) by the close of the eighteenth century, at the very moment of Peru's mining depression (c. 1780-1810) (Dobado and Marrero, 2005: 3). It was, Spate observes, "an almost exact reversal of the position of a century earlier" (2004: 195). Where Potosí had once dwarfed Zacatecas' output in the seventeenth century by a factor of seven to one, now Guanajuato alone – New Spain's leading silver producer and in contrast to seventeenth century Potosí merely a *primus inter pares* – outstripped Potosí's output in the later eighteenth century (Spate, 2004: 195).

Why the shift from Peru to New Spain? The leading explanation turns on diminishing ore quality and therefore rising costs in Peru, coupled with relatively richer ores in New

[253] The European peasantry too was subjected to a similar logic of dietary immiseration, albeit with less gruesome consequences (Moore, 2003b).
[254] Dobado and Marrera (2005: Figure 1) argue for a fivefold increase in output over the eighteenth century.

Spain, whose exploitation was enabled by Madrid's decision to supply cheap mercury from its Almaden mines (e.g. Bakewell, 1987; Brading and Cross, 1972; Garner, 1988). There is much to this line of reasoning. We may also discern the outlines of a political-ecological set of contradictions that overlay and reinforce those emanating from society, politics, and world-economy. We might, in other words, identify the broader eco-geographical patterns from the standpoint of contradictions issuing from the modern reshaping of nature and material life.

Among the unusual features of the Peruvian silver frontier is that Potosí's expansion *begins* at the moment of overproduction. "Thus *in the long term*, the value of silver increased from the thirteenth to the sixteenth century, until roughly 1550" (Braudel, 1981: 459). What this means is fairly clear. The imperial and capitalist agencies behind the silver commodity frontier were able to drive down costs to such an extent that they were able to outrun downward price movement. (Aided and abetted, of course, by geological good fortune.) This was a successful strategy through the 1620s, possibly a little longer. It was a very modern story. For the reshaping of space, and the speed of transformation, sets American mining apart from anything that had come before.

There were three decisive moments to this historical-geographical movement: 1) the success of the *mita*; 2) the relation of East Asia to the emergent capitalist world-economy; and 3) the production of nature. Each moment was contradictory, self-propelling and therefore self-limiting. The very speed with which the Potosí veins were exploited at once led to rising costs apace with (and partially independent of) declining ore yields, and reinforced the tendency towards global overproduction of silver – whose price fell about one percent per annum between 1540 and 1640 (Flynn and Giraldez, 2002: 404-405).

Potosí was able to skate ahead of the curve, at least until the 1620s, for reasons that go far beyond the introduction of the mercury amalgamation process. The technical moment is indeed crucial, although perhaps not nearly so much as Bakewell (1984, 1987) and Braudel would have it (1981: 460). The *mita* and the socio-spatial strategy of the *reducciones* were equally decisive moments. This imperial refashioning of Peru was of course the American face of primitive accumulation (*one* of its faces), working its gruesome logic at a scale and speed unfathomable in the European heartland, or even the Scandinavian and Baltic peripheries. The historical-geographical specificity of primitive accumulation in the Americas, what I have called *extroverted primitive accumulation*,[255] is dismissed at one's peril. As we shall see in the Chapter Four, it was dialectically bound to the transformation of nature across the breadth of the early modern world-economy.

Primitive accumulation in Peru was particularly successful in one crucial respect. In contrast to New Spain, the *mita*'s spatial program enabled the colonial state to marshal a huge supply of low-cost *and tractable* labor even in the midst of sustained demographic crisis. It was no accident that New Spain's ascent to the commanding heights of world silver production awaited the revival of its demographic base. Certainly geology had something to do with the differences as well. The Cerro Rico *was* the silver commodity

[255] Finding inspiration in Semo: "The process of *primitive accumulation*, with its manifestations of pillage, usury, monopoly hoarding, crisis, and multiple exploitation, which helped the formation of early capitalism in the midst of feudal society, found an ideal setting in New Spain. But there the result was the reverse of what took place in the metropolis; hence, it would be more appropriate to talk of a process of *primitive accumulation and disaccumulation*" (1993: 70).

frontier. There were other mining centers, but none came close to Potosí during its zenith. The relatively unicentric character of Peru's mining frontier, then, facilitated imperial control in a way the polycentric silver frontiers of New Spain did not.

If the imperial refashioning of the Andes was crucial, so were the competitive and conflict-ridden relations of early modern geopolitics and the world market. This is a second crucial aspect of Potosí's rise and demise. By the mid-sixteenth century western Europe's silver exports to the Baltic and to South and East Asia were ramping up (Frank, 1998). Possibly as much as half American silver exports would end up in Asia (Frank, 1998: 131-164). Flynn and Giraldez put the figure closer to three-fourths (1999: 23), although this may be too high if we believe Assadourian and his colleagues, who maintain that one-third of Andean silver production was retained within the regional economy (Assadourian, Bonilla, Mitre, and Platt 1980: 24-25). Regardless of the precise figures, it is quite clear that relative underproduction of silver in Asia braked the crisis of overproduction in the Americas. For Europe had little to sell in Asia except for American silver; and Asia was so commercially dynamic – albeit commercial in a thoroughly premodern sense – that it was desperately short of sound money. There was for instance no "price revolution" in early modern India despite the Portuguese- and then Dutch-led exportation of specie on a massive scale (Frank, 1998: 156). And though Chinese demand, which was central, slowed by the early sixteenth century (Flynn and Giraldez, 2002), it seems clear that such silver exports to zones outside the Europe's Atlantic-centered division of labor represented an important means of attenuating the profit squeeze on American mining. Potosí, then, was able to run ahead of the price curve for reasons turning on the fundamentally globalizing character of early modern capitalism.

The third factor is the most difficult to ascertain, and this is the issue of environmental degradation. The interpretation I have outlined allows for both strong and weak positions on the relative weight of ecological degradation – encompassing the disruption of socio-biological production and the health of workers alongside deforestation, soil erosion, and agricultural fertility. It is clear that ecological conditions and contradictions within Potosí were not *the* (singular) cause of decline. But it also is difficult to argue that they were epiphenomenal, or simply annoying externalities, which is the implicit argument of the literature (Bakewell, 1984; Cole, 1985). There were serious ecological problems set in motion by the silver commodity frontier – deforestation, soil erosion, socio-biological crisis, worker mortality, and so forth. In what sense did these problems translate into ecological crisis?

The question is well placed and misplaced at the same time. To the extent that accessible supplies of low-cost raw materials and labor were degraded and therefore rendered more costly, it is clear that ecological transformations were implicated in the broader crisis of Peru's *commodity economy*. For the direct producers, the crisis of the commodity economy permitted a "lucky regression towards self-sufficiency" – it was the peasantry who benefited from the "disappearance of money" and the movement towards "ruralization" in the early eighteenth century (Assadourian, Bonilla, Mitre, and Platt 1980: 31-32).

But to the extent that our focus is laid upon "ecological crisis" as an absolute or self-evident rather than relational category, we miss the broader significance. Which is namely this. Early modern capitalism was governed by an ecological regime that operated within – *and created* – a biophysical space that was friendly to ever-renewed geographical expansion. It was an extensive ecological regime. This is not to say that India or China did not expand; there were important, coterminous movements of settler expansion, resulting in widespread forest clearance among other transformations (Richards, 2003; Marks, 1996). But these were not *globalizing movements* and this is the point. Capitalism's early modern ecological regime was extensive in the sense that it generated socio-ecological contradictions that were resolved through renewed geographical expansion. Often this expansion was overseas rather than overland, and it was an expansion where people followed commercialization rather than the other way around. These were epochal ruptures with premodern modes of geographical expansion.

The centrality of ecological contradictions in the unprecedented global expansion effected by Europe's empires and capitalists after 1450 – ecological contradictions that comprise Braudel's material life, the social organization of nature (transportation or labor supply issues, for instance) as well as "absolute" shortages (whatever these may be) – is what deserves our attention. From this angle of vision, privileging the nexus of ecological contradiction-geographical expansion, we can explain that the scorched earth ecological transformations of the post-1945 era were unlikely to materialize in the early modern world (although they sometimes did) because two things would happen first: 1) the regional commodity economy would experience a crisis of profitability, therefore driving capital out of those sectors and removing the direct pressures of ecological overexploitation; and 2) relative shortages of, say, timber or cereals or soil fertility would drive capitalist actors to seek greenfields, close at hand where possible, farther afield when necessary.

And so the socio-ecological contradictions of the first modern metallurgical frontier, in Central Europe, gave way to the Peruvian silver frontier. And thence to New Spain. Mexico's silver mining boom during the eighteenth century would play out in a distinctive geographical setting, but within the same overarching geography of sequential overexploitation. The conventional narrative has it that the eighteenth century silver boom was materialized almost entirely through mercury (e.g. Lang, 1968). And while it is true that cheap mercury from Spain flowed in – Almaden's production increased fourfold in this century (Dobado and Marrera, 2005: 24) – it turns out that smelting continued to serve as a major technique for processing ore. At the very apex of the silver boom, during the first years of the nineteenth century, one-quarter of all silver – at a time when New Spain was responsible for two-thirds of world output – was smelted (Dobado and Marrera, 2005: 22). Taking the century as a whole, between one-third and two-fifths of all silver was smelted (Dobado and Marrera, 2005: 22; Brading, 1970: 669). While amalgamation's share generally moved upwards during the most rapid phase of expansion (1768-1805), there were also sharp reversals of this trend. Just over 70 percent of silver was amalgamated in the late 1760s, whereupon it began a decline that would revise this figure to just under 60 percent by the early 1780s (Dobado and Marrera, 2005: 22).

The environmental effects of such widespread smelting – not to mention massive timber demand for construction (Lipsett-Rivera, 1990: 469-470) – were evident by the early nineteenth century. Simonian thinks New Spain's forest cover may have been reduced from three-quarters to one-half between Cortes' arrival in 1519 and 1800 (1995: 43). If true, this would be a stunning figure indeed, especially considering Mexico's demographic reversal over this period – its six million inhabitants by 1800 were somewhere between one-quarter and one-half the pre-Conquest population (Burkholder and Johnson, 1994: 99, 263). How much of this forest clearance stemmed from mining and the commodity logic of the silver frontier? Braudel quotes an 1826 French consular official on the conditions around Guanajuato, New Spain's largest silver producer:

> Where there was wood, this was used; but it is scarce on the plateau of Mexico, and the richest mines, those Guanajuato for instance, are more than thirty hours away from a forest. The English miners were quite amazed to encounter these obstacles which had been pointed out by M. Von Humboldt twenty years ago (quoted in Braudel, 1983: 42; see also Ayala, 2006; Avalos-Lozano, 2006).

By the second half of the eighteenth century "the stage for ecological crisis was effectively set" (Endfield and O'Hara, 1999: 415). There was a striking synchroneity between New Spain's greatest mining boom (1768-1805) and the onset of agro-ecological crisis. In pointing to the broadest outlines of this crisis here, we can begin by pointing to yet another synchroneity – New Spain's agrarian order entered a period of sustained crisis at the very moment when western Europe's agro-ecological regime began to falter. Declining yields in cereal agriculture coincided with escalating deforestation, rising soil erosion, and growing conflicts over access to the commons – forests, but especially in Mexico also water (Lipsett-Rivera, 1990; Endfield and O'Hara, 1999: 410-416; for Europe see Blaikie and Brookfield, 1987b: 128-136; Pomeranz, 2000).

This was partly a replay of an older dynamic, Seccombe's "feudal-agrarian cycle" (1992: 190). In this scheme of things, rising population densities drive the expansion of arable land at the expense of pasture, thereby reducing the long-run conditions of fertility (see Chapter One). And indeed throughout late eighteenth century Europe "great expanses of heartland were ploughed up, marshes drained, forest cleared and pasture converted to arable" (Abel, 1980: 206, 204-219). But of course such movements of agricultural expansion were hardly confined to Europe. This was happening in New Spain as well. The demographic revival that began in the late seventeenth century accelerated after 1740, doubling the population over the next seventy years (Brading and Cross, 1972: 577). And here too, as in Europe, we see deforestation, enclosures of the forest commons, sharply escalating conflicts over water between indigenous communities and colonials, and agricultural stagnation relative to population growth (Lipsett-Rivera, 1990; Endfield and O'Hara, 1999; Riley, 2002: 366).

Was this simply the expression of a commercialized feudal order? Yes and no. My view is that the feudal agro-ecological dynamic *was* in play, but it was no longer the independent variable – or in the Americas after 1492, it *had never been* the independent variable. For it was not just the "backward" colonial zones or the (equally?) backward French who confronted agrarian crisis; the English too saw their yields stagnate by the middle of the eighteenth century (Pomeranz, 2000). In New Spain, the independent variable was the commodity economy – it was no "capitalist" economy in the ideal type rendering of the term (e.g. Harvey, 1982, Brenner, 1977), but then, neither is today's global economy, with nearly 80 percent of world population effectively cut out of consumer markets (Barnet and Cavanagh, 1994). Whatever analytical weight we wish to give the concept of capitalism in the analysis of New Spain's environmental history, it is evident that New Spain did not respond to the world economic contraction of the seventeenth century by de-commodifying on balance (as Europe did in the immediate aftermath of the Black Death), but rather by strengthening its home market and internal commerce. The expansion of the haciendas so closely associated in the older literature with the revival of the natural economy was in fact the expansion of the home market. Silver mining was of course the chief agent of capitalist "deepening" in late colonial Mexico. The demographic revival, rising social pressures on land and water, and the silver boom were inseparable phenomenon.

It is from this vantage point that we can now direct our attention back to Europe, to follow the environmental transformations in the wake of the silver fleets.

CHAPTER FOUR
‘Amsterdam is Standing on Norway’
American Silver & the Remaking of the European Environment, 1450-1750

> *In history up to the present it is certainly an empirical fact that separate individuals have, with the broadening of their activity into world-historical activity, become more and more enslaved under a power alien to them…, a power which has become more and more enormous and, in the last instance, turns out to be the* world market… [Thus,] *the transformation of history into world history is not indeed a mere abstract act on the part of the ‘self-consciousness,’… or of any other metaphysical spectre, but a quite material, empirically verifiable act, an act the proof of which every individual furnishes as he comes and goes, eats, drinks, and clothes himself.*
>
> – Karl Marx and Friedrich Engels, *The German Ideology* (1846: 55, 58)

It is said that one cannot be in two places at once. It is a truism. But is it true? “Amsterdam is standing on Norway” – a popular saying in the Dutch Republic of the seventeenth century. A curious expression but one that ably captures the essential point. Amsterdam, the crown jewel of seventeenth century capitalism, was built atop a veritable underwater forest of Norwegian origin (Sögner, 2004: 47).[256] To set foot on an Amsterdam wharf was, in a quite tangible way, to stand on Norway. But there was more to it than this. The proverb spoke to the geographical juxtaposition of two places, it is true. Perhaps less immediately evident is the way that it speaks to the emergence of a new kind of place altogether. The place of the capitalist world-economy.

As Marx and Engels suggest, amongst the peculiarities of place in the modern world is the awkward interdigitation of the places of daily life and the place of world accumulation. (That there have always been other places – states and empires, cities, regions, *inter alia* – warrants mention, but their reconfiguration in the early modern era turned on creative responses to the particularities of world accumulation.) Many places occupied the same plot of earth, one on top of the other.

And so we might ask, Could the early modern Castilian merchant or *hidalgo* be in two places at once? Yes and no. To be sure, one could hardly walk down the streets of Potosí and Sevilla on the same morning. And yet over the course of the long sixteenth century it was increasingly the case that whether one happened to be frequenting the

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[256] Sögner (2004) credits the expression to Holger Jacobaeus (1650-1701), a Dane who lived in Leiden and later became rector of the University of Copenhagen.

markets or prowling the bawdy houses of Potosí or Sevilla, one inhabited different places and the very same place, *all at the same time*. This was the place of Braudel's "vast but weak" capitalist world-economy (1961). (Not to mention, in this case, the global empire of Philip II.) Which was at the same time a capitalist world-*ecology*, that is to say a patterned and expansionary matrix of nature-society relations that responded in decisive ways to the gravitational pull of accumulation (Moore, 2003c; Braudel, 1972).

Here was a place to be reckoned with. A big place for sure, and a place full of many other places without a doubt, but is this not true even of small towns and neighborhoods?[257] Perhaps not fully modern (what is?), but unquestionably a place that was *increasingly* modern in a powerfully geographical sense. Namely, one in which local history is transformed into world history. After 1492, developments on either side of the Atlantic were ever more crucial to those on the other. They were, in the language of climatology, "teleconnected" (Bjerknes, 1969). The teleconnections might be strong and immediate; operate subtly, so as to obscure their full significance; or become weaker or more forceful over time, depending on regional location and global shifts. They were, however, at all turns operative. *This* is amongst the irreducible geographical facts of the modern world.

The Great Frontier & Commodity Frontiers: European Expansion or Capitalist Advance?

How this curious sort of place, the capitalist world-economy, came to be is a matter of some debate. My position can be stated simply (Moore, 2002a). Capitalism, if by this we mean a historical system premised on endless accumulation, emerged out of the global conquests of the "long" sixteenth century (1450-1640) (Braudel, 1953). It was, in other words, inseparable from Webb's "Great Frontier," an epochal movement of geographical expansion that Webb believed was limited to the New World, but which in fact included northern Europe as well (1964). The point can hardly be overemphasized.

[257] "Place has to be one of the most multi-layered and multi-purpose words in our language" (Harvey, 1993: 4). Although my angle of vision differs from Harvey's, he is quite correct in steering for the middle ground between unyielding universalism and particularity, "that opaque world of supposedly unfathomable differences in which geographers have for so long wallowed" (1993: 5). I would suggest, however, that Harvey has yet to comprehend the modern world-system as a place with its distinctive set of particularities; preferring instead the invocation of systemic-level tendencies (absent their historical development) and thence finding particular instances of these general tendencies. This is a method of explanation with a very long history – and a useful one too – and also one that tends to posit the relation between actors (bourgeois and proletariat) theoretically in the absence of constructing these categories historically, that is as they have emerged through time and space in the actually existing capitalist system (on the latter approach, see Hopkins, 1978: 209; McMichael, 1990). As Peter J. Taylor puts it, "place can exist at different scales. This is not always the way that place is interpreted. There is a widespread tendency to equate place with local… There is good reason why places are often viewed as local: 'humanizing' space is most easily accomplished through micro face-to-face contacts. But there is no need to limit place-creation to this one process, especially in political studies where the imagined community of the nation [e.g. Anderson, 1983: JWM] with its homeland place is central to so much research… Providing place with the same multiple-scale property [relations as space] means that relations between place and space can be explored beyond the local up to and including the geographical limit of the whole Earth as both place and space" (1999: 98-99 and esp. 95-108 *passim*). From a much different geographical perspective, but making the same argument about place as irreducibly multi-form and also multi-*scale*, see Yi-Fu Tuan's *Place and Space* (1977: esp. 194-260).

Capitalism did not form within Europe and then expand. To be sure, the overseas expansion of Europe's empires figured prominently in the process. Nor was this a case of the capitalist impulse merely waiting for its day in the sun, hidden all along in the structures of European feudalism. Rather, by 1492 and especially after the financial crises of 1557 (see Chapter Two), Europe's ruling strata turned towards a strategy of endless global conquest – with the strategy of the commodity frontier at the center – only as the option of last resort.

The long fourteenth century crisis (c. 1290-1450) had not only eviscerated the apparatus of feudal domination by removing the demographic surplus that was its foundation. The crisis had also worked powerfully to change the balance of class forces in the western European countryside. These now favored peasant, not lord. The states and seigneurs strove mightily to reimpose serfdom, but to no avail. This contracted the surplus available to the states and seigneurs, who responded by trying to win in battle what they had lost in the class struggle, inaugurating a long century of endless warfare (North and Thomas, 1973: 80-81; Strayer, 1970; Wallerstein, 1992). It was a struggle with epochal implications. For the geography of "parcellized sovereignty" overlaid the increasingly capital-intensive nature of warmaking to call forth rising demand for ready cash (Anderson, 1974; McNeill, 1982; Parker, 1996; Arrighi, 1994). The states sought to win in battle what they had lost in the class struggle. The massive borrowing that ensued was a central moment of primitive accumulation – the creation of public debts an important and under recognized moment of Marx's account of this process (1977: Part VIII). Urban capital, which had been hit hard by the fourteenth century crisis, had retained some of its economic muscle through the fourteenth century depression, muscle it was now able to leverage vis-à-vis the states to change the rules of the game. It was a movement that empowered the accumulators of capitalist power and weakened the accumulators of territorial power. Thus were laid the conditions for a new and uneasy dialectic of territorial and capitalist power.

As a general rule, "European" expansion would thenceforth privilege commodity relations. In putting it this way, we have stuck to the convention – the "expansion of Europe" in the traditional scheme of things is set into play with the colonial and mercantile advance into the Americas, Africa, the Indian Ocean. But is this perhaps an instance of confusing the parts for the whole? On the one hand it is certainly true that the new empires of Portugal, Spain, the United Provinces, and Britain vigorously pursued coercive-intensive strategies that aimed to control the social formations and commercial networks of the extra-European world. (With varying degrees of success.) That they did so largely in the fashion of longstanding "redistributive" empires is hardly in doubt (Pearson, 1987). But were not these movements of "European" expansion also directed towards frontiers *within* Europe, now propelled by competitions of capitals alongside the rivalry of empires? Was not this intertwining of capitalist and territorial power among the hallmarks of the rise of capitalism, a transition marked by the long-run extension of commodity relations within and outside the European theatre? It is out of this line of questioning that I have come to doubt that the geographical expansion of European power after 1450 is best characterized as European. The long sixteenth century was an era of decisive rupture with the longstanding civilizational dynamics of something we might call "Europe." It is any event quite certain that by the fifteenth century, the economic recovery from the long medieval crisis had set new dynamics in motion. The extension of the geographical arena for commodity production and exchange was now in the vanguard. This was the road to surplus accumulation at the dawn of the modern world. How could it have been otherwise in western Europe, where empowered peasantries fought the states and seigneurs to a standstill?

This new road to accumulation – the endless accumulation of capital – was blazed by the commodity frontier. Above all in silver and sugar, but as we shall see presently also in forest products, cereals, fisheries, and other metals, here was an ingenious strategy of advancing the commodity system. States, merchants, planters, shippers, peasants, seigneurs, and many others pioneered (often in spite of themselves) new regional commodity complexes that were premised on the rapid exploitation of ecological wealth.

Pivoting on the commodity frontier strategy, the uneasy of fusion of merchant-finance capital, commodity production, seigneurial power, and military conflict that accompanied and indeed enabled the first tentative advances towards the capitalist mode of production after 1450 effected two world-historical ruptures of signal importance. In the first instance, ecological wealth – from forests, fields, mines, and communities (qua labor power) – would be extracted in the quickest way possible. (Extracted, we should note, from these agrarian spaces and conveyed into urban-centered production and accumulation.[258]) Waste was of little concern so long as it failed to enter the register of profitability.[259] The rapid movement of ecological overdraft tended to undermine the socio-ecological conditions of production and therefore eventually the conditions of profitability – typically within 50-75 years in any given region. Once the extraction of this regionally-delimited ecological wealth faltered – perhaps from the scarcities resulting proximately from commodity production, but more likely scarcities differentially created by social resistances intertwined with ecological shifts and market flux – this modern instanciation of the metabolic rift compelled the search for new commodity frontiers (Foster, 1999; Moore, 2000a, 2000b, 2003a, 2003b).

This was, and was not at the same time, about the escalating *scale* of demand. The environmental history of the rise of capitalism turned decisively on *economies of geographical concentration and "economies of speed."*[260] While economic growth was sustained through geographical expansion and therefore the era's ecological regime is rightly called *extensive*, the uneven synergies of generally rising demand and generally escalating competition (between and amongst states and capitals) translated to agro-extractive strategies of hit-and-run – hit where the ecological wealth was most accessible (cheapest), extract it as fast as possible, and then move as quickly as possible once declining ecological returns registered a significant contraction of profitability. In commodity frontiers as ecologically diverse and geographically distant as North Sea fisheries, Norwegian timber, Brazilian sugar, Peruvian silver, and Polish cereals, we see regional commodity regimes ascend to strategic primacy in world accumulation over the course of 50-75 years, only to meet with relative decline just as rapidly. (Regional booms therefore did not lead to the absolute collapse of commodity production – this was the

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[258] To state the basic tendency. Agrarian manufactures – so-called proto-industrialization – were of course an important part of the story (Scott, 2002a, 2002b).

[259] A conservative objection to ecological waste in the spread of capitalist production, such as trees cut down and left to rot because they did not meet specific economic requirements, would remain an enduring feature of the modern world well into the late nineteenth century (e.g. White, 1980).

[260] To borrow a phrase from Chandler (1977).

medieval pattern. Rather regional sugar, or timber, or silver complexes became, at best, second-tier producers.) Thus Antwerp's and then Amsterdam's successively more expansive metabolic rifts during the long sixteenth century, and the commodity frontiers they entrained, cannot be comprehended solely in quantitative terms of, say, demand for raw materials and grain. The expansion of market must be paired with the transformation of the environments, and the eventual exhaustion of the regional ecological regimes (such as Polish seigneurialism or Brazil's sugar plantocracy) that rendered such transformations useful and profitable.

The full import of these regional transformations can therefore only be assessed in light of an ecohistorical matrix that compelled ceaseless efforts to reduce turnover time in concert with maximal resource-extraction, accelerating the rise and demise of raw material zones beyond anything known in previous modes of production. The upshot was a succession of commodity frontiers in many basic sectors of the European economy – from forest products to grain, from metallurgy to whaling. As a consequence, the primary expression of local environmental pressures at a systemwide level was not (*could not be*) rising prices but rather *the geographical expansion of the world capitalist system*. This is not to say that price rises did not occur; they were, however, consistently revised downwards through geographical expansion – sometimes through colonial or semi-colonial expansion, but also through developmental shifts such as the transition to coal, made possible by *vertical* expansion, into the depths of the earth. This lies at the heart of modernity's *first* metabolic rift – several have followed – and thence at the heart of early capitalism's rapacious global ecological fix strategy. Once greenfields turned brown, the search began anew. Some greenfields were "out," others (as with coal and then oil) were "down."

This was the foundation of a thoroughly modern ecological regime predicated on the spatial fix of endless conquest. By-passing the empowered peasantries of the West, commodity-centered production in the Americas and in northern Europe satisfied capitalists, nobles, and Crowns, although never all equally. Moreover, feudalism's eco-demographic tendency[261] towards a declining rate of seigneurial levy[262] was at first greatly attenuated by commodity-centered expansion, and over time, largely displaced. Global expansion enabled a way out of premodern cycles of boom and bust whereby commercial efflorescence invariably gave way to demographic-ecological crises (Goldstone, 2002). These latter Europe's early modern imperialism would consistently export by extending its hegemony through the endless commodification of nature. By 1492, it seems, Europe's ruling strata had discovered not just America, but a new and radically transformative political ecology of expansion.

Put schematically, the argument runs as follows. Ecological contradictions mobilized by the expansion of commodity production and exchange implied and indeed necessitated regional ecological crises. These were resolved, recurrently, through renewed geographical expansion, often but not always outside of Europe. Such expansion did not spring forth from a fully formed capitalist order but rather was a condition of its very birth.

The Americas and northern Europe were not incorporated into an already existing capitalist world-economy; the capitalist world-economy emerged from their articulation.

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[261] And indeed the broad spectrum of civilizations organized around politically-enforced tribute.
[262] A phrase I have borrowed from Bois (1978).

This expansion was fundamental to the consolidation of the system within Europe, no less than outside it. Thus early capitalism as a whole developed so rapidly *because* it generated successive local ecological crises, not in spite of them. These contradictions developed most rapidly and most extensively in those regions entirely new to commodity production (such as the New World), or in those places where the "natural economy" was historically predominant (such as northern Europe). In these zones, the implantation of commodity production latched onto indigenous ecological wealth (including local supplies of labor power), drawn into the circulation of capital as a "free gifts" (Marx). The ensuing rapid commodification of land and labor pushed these regional ensembles of "fictitious commodities" (Polanyi, 1957) to the breaking point. The stage was set for the rapid exhaustion of land and labor, establishing a remarkably consistent cyclical phenomenon of boom and bust. Thence the search for new frontiers began anew, and with it the cycle of expansion, crisis, and expansion.

Here was an epochal transformation of time and space indeed, some three centuries before the Industrial Revolution.

Reworking the Origins of Modernity: Place, Region, and the Globalizing Production of Nature

If the sixteenth century world-economy was a place, one of many occupying and producing the space of early capitalism, the tasks of unraveling the mystifications of this space necessarily involve a "dialectical tacking" between inside and outside, large and small, and the manifold ways in which these are reworked in quantitative and qualitative fashion. Such a dialectical tacking brooks neither nomothetic conceit nor idiographic temptation. We are dealing with totality and we are dealing fragments; the challenge is to resist the temptation to "becom[e] mired in the vastness of particularisms… without incarcerating complex and contradictory social experiences within the prisonhouse of …. 'epochal labels' (Roseberry, 1989: 14)" (Pred and Watts, 1992: 2).

It turns out that this sort of argument has been easy to advance and difficult to realize.[263] In what follows, we shall follow American silver from its arrival in Sevilla. My intent is to track the emergence of the capitalist world-economy *within* Europe, by tracing the "diaspora of silver," flowing by 1545 from its latest vein in the Andes (Stein & Stein, 2000: 40). The story here is, then, only surficially one of the impacts of monetary circulation on the environments of western and northern Europe. It is rather an accounting of the dialectic of place in the capitalist world-ecology that begins and ends with the transformation of production, and therefore one that begins and ends with the production of nature in a thoroughly modern sense – above all the tendency to treat

[263] Several promising efforts suggest themselves: Pred and Watts (1992), McMichael (1990), and Tomich (1990, 1991, 2004). Elsewhere, I have argued for a production of scale perspective, developing what I have called a "shifting unit of analysis" approach (2002b). My perspective combines the sensibilities of the production of geographical scale with the methodological orientation of historical sociology to view historical capitalism (and specific national trajectories and transitions within it) as irreducibly multilayered. In this reckoning, one may view the same historical-geographical transition – say, the rise of monopoly capitalism in the late nineteenth century United States – from multiple scales, from the shop floor to region to national political economy to world-system. Each scale opens a fresh angle of vision from which to comprehend the whole, allowing for the systematic recomposition of the whole without succumbing to determinations arising from the *a priori* privileging of this or that scale, or scalar axis.

nature as a "free gift,"[264] through which ecological wealth is extracted in unsustainable fashion, giving rise to successive moments of geographical expansion. Elsewhere I have discussed in some detail the ecological holocaust of Spanish colonialism in the Andes. Spanish Peru after 1545 was reshaped to serve Castile's imperial ambitions, and the faceless logic of accumulation for accumulation's sake (Chapter Two; also Moore, 2003a, 2007). It is a story of capitalist dynamism attended by all manner of human and ecological devastations – widespread deforestation, the destruction of indigenous agriculture, catastrophic flooding, the spread of famine and the imposition of structural food insecurity, not to the mention the wholesale resettlement of more than a million souls into Spanish-style towns, perhaps the first of modernity's strategic hamlets.

And this is where the discussion of American silver often ends. But the transformation of the Andes was part and parcel of the transformation of Europe. Potosí is, then, better considered a point of departure than a point of closure. It is not just that the rise of capitalism made possible the rise of Potosí, although this is certainly true. It is equally certain that the rise of Potosí made possible the expansion of capitalism *within* Europe. Once again, this has been easier to say than to show. In one sense we are now moving from one region to many, from Potosí and Spanish Peru to a succession of regions within Europe – Castile and Aragon, the United Provinces, Norway, Poland, and Russia. (And many others). In another sense, however, I am tracing the rise of a distinctive, *singular* world region (place) upon which the history of capitalism would pivot for the next three centuries.

While the "Atlantic economy" often gets the good press (e.g. Davis, 1973), and rightly so, this may be too much of a good thing. For the Atlantic economy was not one but many regions. Indeed, the decisive regional economy of early capitalism – stretching well into the nineteenth century – was not the Atlantic at all, but rather an extended North Atlantic zone. This capitalist North Atlantic was home to the most effective accumulators of capital in the centuries after 1492 (first the Dutch, then the British) precisely because capitalism demands the incessant reworking of nature, and it was the social natures of the North Atlantic that provided the very raw materials indispensable to consolidation of capitalism – timber, naval stores, metals, cereals, whales. Starting from a nucleus that comprised the British Isles, France, the Low Countries, and parts of Scandinavia, the capitalist North Atlantic would emerge through successive commodity frontier movements – at various turns limited and propelled by geopolitical struggles – that would, by the late eighteenth century, incorporate Finland, the greater Vistula Basin, the present-day Baltic states, Russia as far as the Urals, and North America. It would of

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[264] The phrase, often credited to Marx, is more precisely that of the English translator of the edition of Capital, Vol. III, published by Charles H. Kerr & Co. (1909) and subsequently reissued by International Publishers (1967, III). (The translator, curiously, is unidentified in the International Publishers edition.) In discussing the tendency of capitalist agriculture to exhaust the soil ("the decreasing productiveness of the soil"), Marx observes that "natural elements entering as agents into production, and which cost nothing, no matter what role they play in production, do not enter as component of capital, but as a free gift of Nature to capital, that is as a free gift of Nature's productive power to labour, which, however, appears as the productiveness of capital, as all other productivity under the capitalist mode of production" (1967: III: 745, Chapter 44). David Fernbach's useful translation phrases this language of free gift somewhat differently. Here, Marx is translated as referring to such free gifts, instead, appearing as "free natural power of capital" (1981: 878-879).

course become progressively intertwined with the plantation economies of Wallerstein's "extended Caribbean" (1980: 175) and Braudel's "global Mediterranean" (1972).

As a consequence, this part of the story offers a distinctive geographical perspective from that of the Americas, from Bahía or Potosí or Bridgetown. The methodological premise is a shifting unit of analysis approach that treats successive geographical units (places) as vantage points from which to view the emergence of patterned interactions – always provisionally, uneasily stabilized and subject to violent change – over long historical time, and within the globalizing "place" of the world-economy, and the capitalist North Atlantic in particular (see esp. Moore, 2002b).

Regional environmental history and its interweaving with capitalist transition tell us an indispensable part of the story. Indispensable, but nevertheless partial. So long as capitalism and capitalist transition is handled as a bundle of abstract and place-less tendencies, the inevitable "context" to the real stuff of local and regional history, it is impossible to construct a holistic account of modernity's socio-ecological contradictions and creations over the long run. It is, for starters, quite evident that the motive forces of change surveyed in Spanish Peru could not be squarely located within Spanish Peru, or even Spanish Latin America. Nor would it be reasonable to impute all agency to the steamroller of a frequently-caricatured world-system.[265] The task is to identify the strategic relations of territorial and capitalist power at multiple scales and across multiple regions from the standpoint of modernity's globalizing movements of uneven development. For a world-historical interpretation finds inspiration in the interweaving of scalar narratives and the rejection at every turn of a scalar reductionism or place-centrism. Insofar as our perspective is world-historical, scalar reductionism is impermissible. The world-scale included!

The Modernity of Spanish Imperialism and the Limits of Medieval Political Ecology

All of which is meant to foreground an immodest proposition. Imperial Spain, through "the deadly alchemy of permanent war, capitalist accumulation, and the new enclosures" (Retort, 2005: 43), transformed Peru's forest-equivalents into silver and thence back again into forest-equivalents. Here I use the language of forest-equivalents as

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[265] See especially Stern's critique of Wallerstein's world-historical studies (1988a, 1988b). This is the most widely-cited critique of the world-systems perspective within the American historical profession. This is a critique premised on the assumption that "world market" and "world-system" are synonymous in Wallerstein's narrative. Just how Stern managed to draw this conclusion is, however, not clear. Wallerstein, who began his career as a political sociologist of African decolonization, premised his conception of the modern world-system on competition within the interstate system – this is what distinguishes world-economy from world-empire. But the political interpretation goes still further. Much of the first volume of *The Modern World-System* is taken up with the political sociology of state formation in the European world-economy (Wallerstein, 1974: esp. chapters three and five). The regional-scale dialectic of class conflict and state formation is central to the story of the emergence and reproduction of the world market. A line of argument that Stern makes for Latin America, emphasizing the agency of regional-scale actors such as political elites and regional bourgeoisies. Stern has, therefore, given us a Hobson's Choice between region and world-scale that would best be jettisoned in favor of an approach that emphasizes relations between the parts.

a useful metaphor, albeit one with evident material implications – one could neither move capital nor project military power without access to gigantic volumes of forest products.

Talk of forest equivalents may seem shamelessly anachronistic. But in fact the notion of forest equivalents dates, at the *latest*, from the seventeenth century. Addressing the 1669 Forest Ordinance in France, Brown puts the issue squarely before the bar: "In order to secure the full benefit of the device it was found necessary [by the French Crown] to divide the… forest, not into *equal*, but into *equivalent* portions – subdivisions, not of equal area, but of equivalent produce" (1883: 45, emphases in original). Indeed the Ordinance itself reads as a spectacularly modern text in certain respects. The Ordinance mandated "triganometrically [*sic*] measured lots" and provided guidelines to inspectors to render these lots "more regular" within a five percent range of error (Anonymous, 1669: 103-155, Chapter XV). My point is not to suggest that these measures were generalized across Europe (they were not), but rather to identify such measures as expressive of an emergent, underlying logic premised on the radical abstractions of the law of value, then in formation.

Put schematically, the deforestation of Peru in the service of Potosí enabled the Empire to pursue its territorialist ambitions on a grand scale, but at the ecological cost of deforestation on an extended scale within Europe, and thence (back again) within the Americas. American silver flows "hardly provided substitutes for," and at the same time made possible, "Europe's supplies of iron, copper, lead, tin, zinc and other utilitarian metals" (O'Brien, 2007: 84). All of which, in the New World and within Europe, compelled the retreat of the forest and the ever-extended quest for sylvan wealth. Thus deforestation emerges as not merely a sad story of modernity, but as constitutive of multiple reorderings of its systemwide division of labor. The transformation of forests into forest-equivalents was itself a novel development. It found expression in multiple forms, from state forestry initiatives, to the homogenizing impetus of the commodity form in its world market manifestation, to the abstract metric of the long sixteenth century's "quantitative revolution" (Fernow, 1911; Crosby, 1997).

"Whenever West Europeans reached the huge forests of Norway, Poland and the New World," Braudel observes, "such forests, if they were accessible by sea or river that is, immediately joined the category of capital goods" (1982: 241-242). This was an unusual turn of events indeed. These forests were subsequently fed into the vast but weak leviathan of expanded accumulation, either directly, indirectly, or both. Forests were now first and foremost "capital goods" *in addition to* their status as resources.[266] Herein lies the hidden secret of European expansion, the commodity frontier. It was this commodity-centered strategy that enabled (and then reinforced) the ongoing displacement of landed wealth by monetary capital that gained traction during the long fourteenth century's feudal crisis (see Moore, 2002a).

So let us turn from American to European political ecologies, and thence to the relations between them. This will allow us to take a step back to consider the bigger picture of capitalism not purely as world-economy, but also as world-*ecology* – that is,

[266] Here is not the place for extended critique but let us note for the moment that for Braudel, capital means resources that are struggled over by capitalist and non-capitalist strata. In Braudel's view, capital is a thing and not a relation. Its political-ecological corollary is an essentially passive rather than active view of the production of nature, although Braudel is astute enough to recognize, empirically if not conceptually, the latter (see Moore, 2003c).

the material life of the world-economy (Moore, 2003c). Deforestation certainly occurred in Spanish Peru. And deforestation, along with all manner of other environmental transformations, was linked to with rising costs in the mining sector, a situation the colonial state sought to attenuate through the progressive extension of the town-country division of labor (Moore, 2003a, 2003b, 2007a).

But this dynamic was hardly unique to the colonial world. While the theory of "sequential overexploitation" is one readily applied to the extra-European world – where overexploitation and relative exhaustion in one region gives rise to a frontier movement that promises relatively free supplies of land and labor (Gadgil & Guha, 1992) – it is clear that the same logic was at work *within* Europe, and *between* Europe and the colonial world. Silver nourished the arteries of territorialist power, feeding Spain's imperial ambitions, which in turn fed the appetites of capital accumulation. Spain's imperial project presupposed the capacity to transmute silver into military power, and this entrained widespread material transformations. This was the logic of forest equivalents as symbolic (and in time practical) deforestation. The violence of abstraction inscribed in the logic of this new (modern) imperialism made it possible to think of forests as forest equivalents.

The ensuing material transformations were not only geographically expansive, but *expansionary*. The endless accumulation of capital is the endless conquest of nature. The failure of Charles V to transform the European world-economy into a world-empire had by 1559 given birth to a *de facto* balance-of-power stalemate that would be codified at Westphalia in 1648. With silver shipments made into a steady flow of ready cash thanks to the magic of Genoese finance, Spain after 1571 – when the restructuring of Peru had reached critical mass – had become at once more powerful than, and less able to dominate, its European rivals.

The twists and turns of Europe's geopolitics turned crucially on the cascading and geographically uneven transformations of local and distant environments. Silver is one optic through which to bring these uneven transformations into focus. The material-ecological implications ran this way. Spain was powerful militarily but its economic base was weak. That is to say, its aggregate productivity was low, in agriculture but also in manufactures. This meant that its cost of waging war was higher than its rivals, the Dutch above all. This was bad enough in any era. In the era of the "military revolution," it was nothing short of disastrous. The cost of war was skyrocketing, and this favored states that were able to pursue a capital-intensive rather than coercion-intensive strategy of statemaking (McNeill, 1982; Parker, 1996; Tilly, 1990). The balance-of-power meant that small military-territorial gains were won at great expense. And rising expense signified rising material throughput, and therefore escalating pressure on local political ecologies across Europe. Consider, for starters, the escalating concern over forest management in England (Albion, 1926), France (Bamford, 1956), Sweden (Heckscher, 1954), Germany (Fernow, 1911), and Spain (Goodman, 1997, 1998) during the sixteenth and seventeenth centuries. There was in every case inexorable (if cyclical) pressure for renewed geographical expansion in response to local overexploitation. Such expansion unfolded differentially – sometimes within the territorial state, sometimes through colonial expansion, sometimes through the world market. (The most successful states, such as Britain, were able to take advantage of all three, which explains something of the origins of the Industrial Revolution.) But, and here's the punchline, such expansion ultimately depended on the capacity of the states (and not only the states) to fork over the dough. And *this* depended in great measure, between 1559 and 1648, on access to American silver, itself won through a colonial political ecology that insistently pushed outward the commodity-centered divisions of labor in Latin America, *and a semi-colonial political ecology that did the same in the Capitalist North Atlantic*.

The military revolution implied, among a great many other things, a geometric expansion of shipbuilding. Over the course of the long sixteenth century, Europe's shipping grew fivefold.[267] Perhaps more (Maddison, 2002: 59; Ozveren, 2000; van Zanden and Horlings, 1999: 36; Unger, 1992). The relationship between deforestation and shipbuilding should not be overstated in its formal dimensions. Shipbuilding did not compel forest clearance, given its specific timber demands, especially but only for masts – it is likely that the iron inputs for ships outstripped all other timber demands. (A 400 ton vessel might need as much as 100 tons of iron [Braudel, 1972: 303].) The expansion of shipping was, however, an index of systemwide demands on forests, since everything these vessels carried turned on the forest in one way or another. Even textiles depended on wood dyes and potash for bleaching, and cereals derived from extensive agriculture always represented some measure of subtraction from the forest.

Where so much attention has been lavished on the history of forest exploitation and the price of forest products (Williams, 2003; Allen, 2003), the crucial issue pivots on the ecological *regimes* that mediated access to the timber. These regimes were systemic and regional both. For the moment we focus on the latter. These regional ecological regimes encompassed juridical frameworks, class relations, and business organization no less than the infrastructure, tools, financing, and labor power implicated in cutting and moving timber (of whatever sort) from the forest to the point of consumption. Nevertheless, the very selectivity of shipbuilding timber demands, in concert with the urgency of those demands, meant that shipbuilding played a role in the enclosure of European forests (and the frontier movements associated with it) out of all proportion to its absolute material throughput. There was, then, unrelenting pressure to extract as much as quickly as possible, and then to move towards greener pastures whenever relative overexploitation created problems. To say shipbuilding timber was to say commodity frontier.

For Spain, the big obstacle in the way of a vibrant shipbuilding sector was its essentially medieval political ecology. There was no dearth of forests in Castile and Aragon. In this respect Spain was certainly better off than the ascendant Dutch (McNeill, 2004: 397; also Albion, 1926: 169). But Spanish Absolutism had all manner of local custom to contend with. And the Dutch had two things the Spanish did not: peat, and the Capitalist North Atlantic. The first was geographical good fortune. The second, geographical good fortune combined with bourgeois ingenuity.

Let us begin with Spain. There were, even from the late fifteenth century, pressures coming from all directions that drove up the cost of shipbuilding timber. One source was Spain's agro-ecological crisis, which begin in earnest during the 1580s and would not relent for nearly a century. Exhausted land was abandoned, and new lands cultivated. Not infrequently these lands were cleared from forest. Indeed, it seems likely that the arrival of Spain's agro-ecological crisis, which hit home with a vengeance in the 1570s (da Silva, 1964), had been delayed by carving out new arable land from the forests earlier in

[267] It bears noting that there was considerable overlap during this era between merchant shipping and warships.

the century. It was, in Hamilton's words, a century of "rapid deforestation" on the peninsula (1938: 177). In 1520, wood was so scarce around Medina del Campo the chronicler and Court historiographer Antonio de Guevara complained that "the firewood cost us as much as the stew in the pot" (Guevara, 1520: 93). By the 1590s, "the supply of firewood and charcoal was running short in much of Castile" (Sella, 1974: 393).[268] By 1612, in the northwestern province of Galicia, home to strategic timber reserves, a Crown official:

> Identified one of the principal causes of forest depletion to be 'the practice in this kingdom [Galicia] of making clearings in the oaks in order to burn them and sow wheat. And at times it happens that in burning the cleared section a league or more of the forest is burned.' Seeking to rectify this, he approached the peasant farmers. They said that 'unless they make the clearings they will have no ground for sowing, and they will perish' (quoted Goodman, 1997: 83).

The situation was much the same in Guipuzcoa as early as 1580 (Goodman, 1997: 94).

Shipbuilding also had to face down competing industries. Vizcaya, home to the shipyards of Bilbao, was dominated by "the most important" ironmakers in Spain (Goodman, 1997: 91). Already by 1547, Philip, acting as regent in the absence of Charles V, issued new regulations mandating tree planting around the shipbuilding centers in Vizcaya. The preamble to the 1547 decree expressed concerning over what it saw as mounting timber scarcity driven by the region's shipbuilding industry (Goodman, 1998: 90). Was this mere alarmism? This is possible, although it seems insufficient as an explanation. Philip's legislation occurs on the eve of a prolonged "state of crisis" in Spanish shipbuilding, beginning in the 1560s (1986: 22). In the 1610s, a Crown forest inspector complained that Vizcaya's ironworks consumed so much charcoal that "this [situation] had to be watched because it could cause shortages *for everything*" (quoted in Goodman, 1997: 91, emphasis added). As if this were not bad enough, Spain's iron sector found itself undercut by the forest-rich Swedes at this very moment (1620s) (Davis, 1973: 153) – financed, we may recall, by the Dutch (Barbour, 1950: 36-37, see Chapter Two). And from the 1620s, we see a rising number of conflicts between the Castilian state, seeking to protect shipbuilding timber, and the metallurgical sector, the charcoal burners and owners of forges above all (Goodman, 1997: 82, 88, 92)

Around Barcelona, the problem was not iron but glass. A quite modest glassworks operation could strip the surrounding forests in no time at all. The Catalonian situation reminds us that it was not *necessarily* the absolute shortage of timber at play. Rather, the chief difficulty was the political economy of this ramshackle thing we call "Spain" – an idea rather than an established territorial fact, Kamen reminds us (1994). In Catalonia, where Philip's galleys issued from the Barcelona shipyards, "the forests were being consumed to supply fuel for furnaces for glass manufacture" (Goodman, 1998: 92). Here

[268] By the 1670s, there was serious talk in Madrid about moving the Court elsewhere. The supply of woodfuel, drawn from a twenty-league radius around the city, had reached a critical situation (Goodman, 1997: 69-70). Even a conservative estimate of a league (2.4 miles), this meant that firewood was scarce within a zone that comprised nearly 23,000 square miles!

was the Castilian replay of Central Europe's "battle for wood" a century earlier (see Chapter Two; also Westermann, 1996). Barcelona's municipal council called for shutting down the glassworks, with only modest results. The crux of the matter was this. Philip II simply could do as he pleased. He acted within the contradictions of Spain's ecological regime, within which the hold of Spanish absolutism was far from absolute, throughout the peninsula, and especially beyond Castile. "The complex of medieval 'liberties' presented a singularly intractable prospect to the construction of a centralized Absolutism" in early modern Spain (Anderson, 1974: 65).

It was the very persistence of these medieval liberties that resulted in a critical mass of "grants of privileges… to monasteries and individuals," such that the Crown could no longer easily harvest the timbered lands surrounding Barcelona. Instead, shipbuilding timber was trucked in from thirteen leagues distant (in Montseny and Arbucias), "bringing great increases in transport costs" (Goodman, 1998: 93). This distance, about thirty miles, represents an upper limit to overland transport before the nineteenth century; it must have been costly indeed. By 1586 the fiscal crunch was so severe that shipbuilding timber, including precious masts, was rotting in the Montseny forests as workmen awaited the royal paymaster. The scenario would repeat itself in 1589. Nor would the Crown's woes diminish thereafter. "Later [in the early seventeenth century] when the sources of pine masts at Arbucias seem to have been exhausted, searches further afield reached out to the extensive pine forests of the Pyrenees" (Goodman, 1998: 93). Predictably, this meant still higher transportation costs (ibid: 93). The masts "reached Barcelona with difficulty" (ibid: 95).

Spain was, then, faced with multiple episodes of relative deforestation that throttled domestic industry. Crucially from our point of view, this forest clearance was sufficient to provoke a "sharp rise in the prices of forest products in the first half of the seventeenth century" (Hamilton, 1938: 177). The general situation was bad enough. A more serious threat to Spain's imperial ambitions was the rising cost of *shipbuilding* timber. Around Bilbao, "the long timbers needed for masts and spars had been used up by the *early* sixteenth century" (Phillips, 1986: 23, emphasis added; also 49, 80). Goodman thinks there was never an absolute shortage of masts, even if they were not quite up to par with Baltic supplies (1998: 89). But these local supplies were difficult (and costly) to reach. And wasn't this the crucial variable? Rising local costs meant that by the early sixteenth century, a growing volume of masts and naval stores were imported from Baltic (Phillips, 1986: 23, 49, 80). Castile was importing lumber from Flanders — probably of Baltic or at least German origin — by 1534 (Klein, 1919: 321). By 1575, the commander Escalante de Mendoza observed that "most of the materials used in construction were of native production, *with the conspicuous exception* of masts and spars which were... imported from Prussia by way of Flanders" (quoted in Usher, 1932: 203). In the later sixteenth century, Braudel reports on "marked deforestation in the western and central Mediterranean… notably in Sicily and Naples[:] the very place where one of the great shipbuilding efforts for Philip II's navy was centred" (1972: 142). Having decimated his Neapolitan supplies, Philip went global. In the 1580s Philip "tried to buy, or at any rate marked for felling, trees in Poland" (Braudel, 1972: 143). Ozveren believes the Barcelona shipyards had in any event entered a period of "irreversible decline" by the 1590s (2000: 22). Was this not principally a symptom of rising timber costs? By 1630, the situation had gone from bad to worse: "The Spanish yards were [by] then dependent upon [Baltic] imports for tar and pitch, for masts, for hemp" (Usher, 1932: 203). This was a disastrous situation for the material basis of Spanish power. Spanish shipping in the century after 1570 entered absolute and not merely relative decline. Iberian and Italian fleets shrunk 17 percent while the British and Dutch fleets expanded nearly threefold (Maddison, 2002: 59). The decline of Iberian ship*building* was even greater than these figures suggest. Castile, for once both wisely and quickly, externalized production to Havana, which became by the mid-seventeenth century "the busiest site of shipbuilding in the Spanish empire" (Ozveren, 2000: 30). By the 1640s, American-built vessels constituted "at least" 40 percent of the Spanish fleet, 75 percent of which were built in Havana (Ozveren, 2000: 35). Another third was foreign-built, probably of Dutch origin (Parry, 1966: 249).

Spain's shipbuilding crisis was but one expression of a bigger problem. Silver allowed Philip to pursue a two-front war, buying ships, guns and men even as the Castilian ecological formation withered in its capacity to supply these. It is clear that Castile was deindustrializing. If not in absolute terms (although this was often the case, as in shipbuilding), then certainly in relative terms – and isn't this the decisive variable at the end of the day? The political ecology of such deindustrialization is much less apparent. When Perry Anderson (1974: 71) cogently opines that it was American silver which allowed Spanish Absolutism "to dispense with the slow fiscal and administrative unification which was a precondition of Absolutism elsewhere," that "the colonies, in other words, could act as a structural substitute for provinces," would it be imprudent to say much the same about the Empire's ecological regime? That the colonial reordering of Andean political ecology enabled Castile's agro-industrial complexes to reproduce an essentially medieval mode of ecological production, the ecological complement to those enduring "autarchic patrimonies" such as Barcelona?

The Political Ecology of World Hegemony: Dutch Capitalism & the Rise of the Capitalist North Atlantic, 1450-1750

Spain's deindustrialization was hardly self-contained. One man's loss would be another man's gain. The Low Countries, whose mercantile and manufacturing centers had developed in the century since 1450 as pivotal nodes in the integration of northern and southern, eastern and western, Europe, emerged from the great depression of the 1550s as a leading contender for world economic primacy. Spain lay inbetween one world region (the Mediterranean) that was in decline, and another, the extended Caribbean, that was moving through an unprecedented commodity revolution in sugar by the 1650s. The Dutch, for their part, lay inbetween the commodity frontiers of the extended Caribbean and the increasingly capitalist North Atlantic. The Spanish had neither the capital, timber, nor food to make a go of it. The Dutch did.

The two economic zones, Spain and the Low Countries, were closely intertwined. The Low Countries had been an important part of Charles V's dynastic patrimony. Upon his abdication in 1556, Philip retained formal political control. (At least for a time.) Whatever modest differences in economic development existed in the fifteenth century, the gap widened considerably over the "first" sixteenth century (1450-1557) (Braudel, 1953). From the standpoint of world trade, Spain began to look more and more like a colonial exporter, sending wool (but increasingly fewer *woolens*) and bullion northward to the Netherlands in exchange for textiles, metal goods, grain, and as we have just seen, naval stores (Boxer, 1965: 24; Anderson, 1974: 75).

Of course, the Dutch were not *producers* of this exported grain and naval stores. They were, rather, the producers of the means of production – that is to say, ships – that enabled Baltic grain and timber to materialize in Castile. For shipbuilding, along with textile and iron manufacture, was the era's leading value-added sector (Bunker and Ciccantell, 2003b: 15-18). For good measure the Dutch also produced half the Baltic's textile imports and a growing volume of Spain's (Wilson, 1957: 41). Flemish and Dutch capital could therefore pursue a high productivity strategy in shipping and shipbuilding, and consequently dominate the carrying trade between northern and southern Europe, a key source of hard currency surplus for the Dutch (Barbour, 1950: 52). The Low Countries accounted for nearly 85 percent of this trade in the mid-sixteenth century (Braudel, 1984: 207).

The chief point of difference between the Mediterranean trade and the decidedly semi-colonial Baltic trade was that Spain had Potosí and the Poles did not. Braudel calls the Baltic "a sort of America on Europe's doorstep" (1984: 207). During the ensuing Dutch revolt – the Eighty Years' War (c. 1566-1648) – there would be no de-linking with Iberia (Boxer, 1965: 23-24). Spain and the Netherlands "were neither willing nor able to break off relations" (Braudel, 1984: 208). Spain could not do without naval stores and grain; the Dutch, without Portuguese salt (Israel, 1982: 210-211, 413). The grain situation became increasingly dire as the "second" sixteenth century wore on (1557-1648) (Braudel, 1953). Spain "was at the mercy of foreign grain, hardly any of which, by the end of the sixteenth century, came from the Mediterranean" (Braudel, 1984: 208; also Israel, 1982: 52-53).

There was, then, a conspicuous gap between the military capacities of Spanish Absolutism and its economic basis. Philip II's imperial project foundered on the effort to subordinate the eminently modern Low Countries – "home to the most advanced centres of urban industry in Europe" (Mandel, 1963: 5) – to the centralizing imperatives of Spanish Absolutism. But in terms of capitalist production and business organization, the Dutch had gone far – and the Spanish had not – over the course of the first sixteenth century. The fiscal demands of Habsburg imperialism, even before Philip, consequently had "gravely strained the traditional loyalty of the Netherlands" (Anderson, 1974: 70). Charles V's conflict with France drew heavily on the Dutch economy but did so by "assign[ing] a larger and larger role to the States in the collection and management of finance" rather than by "increasing Habsburg control" (Darby, 2001: 15). Philip was therefore already on shaky ground when he moved "to make the Netherlands a net contributor to imperial finances" in the 1550s (de Vries and van der Woude, 1997: 371). This was an explosive situation to be sure. Even if we do not wish to go so far as Mandel and Anderson in characterizing the Dutch revolt as the modern world's first "bourgeois revolution" (Mandel, 1963: 5; Anderson, 1974: 75), it is nevertheless evident that the stage was set for a clash pitting the precociously modern military apparatus of Spanish Absolutism against the precociously modern capitalist organization of the northern Netherlands. And much to the detriment of Spain, the former fed the latter. Fielding an army of 60,000 soldiers – Spain's "Army of Flanders" (Parker, 1972) – required a gigantic stream of specie to flow from Seville to Antwerp:

> These payments buoyed the otherwise depressed economy of [Flanders]…, but they buoyed the Republic even more, for much of the specie arriving in the Spanish Netherlands flowed directly to the North to balance the South's massive trade deficit (de Vries and van der Woude, 1997: 371).[269]

The connection with developments in Potosí can now be viewed more clearly. Spain exerted relentless pressure in the colonies to sustain and maximize production (Chapter Three; also Moore, 2007a). This was effective so long as Spain was able to deploy its greatest asset, military power, against relatively weak adversaries. Under these conditions, the primitive accumulation of silver was as effective as "modern," productivity-maximizing production. Within Europe, however, Spain's greatest strength turned to weakness. The Spanish-Habsburg regime sought to deploy its military capacities, bolstered by American silver far beyond the strength of any single contemporary power in aggregate terms, against a regional-scale territorialist-capitalist alliance in the Low Countries. And Dutch economic prowess, as it turned out, could be translated into military power much more readily than Spain's military prowess could be transmuted into capitalist power. Thus, the Dutch were able to hold the Spanish at bay, reproducing a long-term situation – over the course of the second sixteenth century – in which European geopolitics at once reinforced the primitive accumulation of capital in the colonies (and the semi-colonial North Atlantic), *and* pushed forward the expanded reproduction of capital in the northern Netherlands. Locked in struggle through to Westphalia in 1648, the political economy of world power would therefore propel Europe's powers ever outward in search of mass commodities and the capital they generated. (Was not the Dutch conquest of the Spice Islands propelled by Portugal's efforts to keep them out of the Indian Ocean?)

All of which suggests an elementary but rarely analyzed dimension to this world-historical geography. Not only were the economies of Peru, Spain, the northern Netherlands, and the Baltic intertwined, *so were their ecologies*. If Amsterdam was central to the emergent world-economy – Europe's "greatest commercial entrepot" even in the sixteenth century (Boxer, 1965: 20) – this had everything to do with the environmental history of the northern Netherlands as it emerged from late medieval crisis. The Low Countries had suffered little from the ravages of the Black Death relative to the rest of central and western Europe. Coupled with much weaker structures of seigneurial power, in *socio*-historical perspective we would expect a return to the seigneurial *status quo ante*. But this is not what happened. The crisis that emerged in the maritime Low Countries at the end of the fourteenth century was a crisis not of men but of soil. It was at this point that

> what turned out to be a very large – and rapidly growing – part of the rural population suddenly found itself, *due to profound ecological disruptions*, unable to make a living by arable farming and compelled to find productive activities in which they could successfully compete on the

[269] And let us add the massive outmigration from Antwerp following its sacking in 1585. Between 1585 and 1622 Amsterdam grew from a city of 30,000 to 105,000, one-third of which "were immigrants or their first-generation descendants" (Boxer, 1965: 21).

> market. *Unlike anywhere else in Europe*, the subjection of the agricultural population to dependence on the market and the rise of a large market-dependent population involved in trade and industry in the town occurred to a very great extent as part of *a single process of agrarian transformation*. The emergence, on the one hand, of Dutch clothmaking, brewing, shipping, shipbuilding and peat digging – much of which was oriented to export – and, on the other, of Dutch dairy and cattle raising, were thus two sides of the same extraordinary process of ecologically driven separation of the direct producers from their means of subsistence leading to the transition to capitalism, and they must be understood together (Brenner, 2001: 206, emphases added).

Herein lie the origins of the "Dutch road," and its distinctive response to the specificities of feudal crisis. "Ecological processes" acted in a manner "strikingly analogous to 'the so-called primitive accumulation' that deprived agricultural producers of their land in England" (Brenner, 2001: 208). Here the social basis of modern economic growth is revealed as not social at all, but rather as irreducibly socio-*ecological*!

The full story of the Dutch "economic miracle" has been told elsewhere and need not detain us here (de Vries and van der Woude, 1997; Wallerstein, 1980: 36-71; Arrighi, 1994: 127-158; Israel, 1989). The political ecology of this miracle remains however largely invisible. Two ecohistorical strands deserve further attention.

In the first instance, there is the relationship with the Baltic and its grain and timber. The rising productivity of Dutch agriculture and industry, driven by their intertwined market dependence that found its source in the ecological crisis of the long fourteenth century, enabled the maritime Low Countries to move from strength to strength in the global expansion on the first sixteenth century. Here was a virtuous circle indeed. Dutch primacy in the Baltic trade reinforced its domestic agricultural revolution. Dutch farmers, freed from the imperative to cultivate cereals (a low-profit line), shifted to dairying and other high-profit pursuits.

Cheap grain in turn underwrote the rapid growth of the non-agricultural workforce over the course of sixteenth and seventeenth centuries. The population of the northern Netherlands more than doubled over this period, while the rural population increased by just one-third (de Vries and van der Woude, 1997: 208). Somewhere between 30 and 60 percent lived in cities, three-quarters of them in "large" cities with 10,000 or more people (Wallerstein, 1980: 45; Berry, 1990: 103; DuPlessis, 1997: 72). Amsterdam, with just 11,000 residents in the early sixteenth century (de Vries and van der Woude, 1997: 358), tripled in size by the 1580s, and reached 200,000 by 1650 (Davis, 1973: 180; Wallerstein, 1980: 45) – a nearly twenty-fold increase in just a century! Already by 1560, Baltic grain met 15-23 percent of Dutch needs (de Vries and van der Woude, 1997: 198; Elliot, 1968: 48). By the turn of the century, probably half the population of the most urbanized, and therefore most commercialized, provinces (Holland, Utrecht, Friesland, and Groningen) relied on grain imports for their daily bread (de Vries, 1974: 172).

But why *Baltic* grain? The explanation turns on some combination of environmental history and political economy. In the first place, when we say Baltic grain what we really mean is *Polish* grain. And this had everything to do with the geography of the situation. Poland was, to put it crudely, a frontier zone. It had been so since the great colonizing movements of the eleventh century, but now the frontier meant something entirely different. With relatively abundant land and a balance of class forces favorable to the forcible extraction of surplus, Poland was the only cereal zone in Europe from which significant surpluses could be won. Sicily had come online in the early sixteenth century, but was showing signs of exhaustion, along with the rest of the Mediterranean, by the end of the century. It was in any event under the hegemony of Spain. Poland, in contrast, was relatively free for the taking, and it retained plentiful supplies of fresh soil.

Our second point concerns the political economy of the situation. By the later sixteenth century, the Dutch innovation in the Baltic was to capitalize on the favorable conjuncture provided by huge silver flows on the one hand, and "booming western demand for Baltic grain" on the other (Davis, 1973: 180). Dutch manufacturing prowess was significant but insufficient on its own to forge a neo-colonial relation with the Baltic.[270] Dutch trade with the Baltic may have been semi-colonial, but it was a strange sort of colonialism, one in which the *Dutch*, not the Poles, ran a persistent trade deficit. Ready cash was therefore the decisive intervening variable (Braudel, 1984: 209).[271] Ready cash meant silver – Attman puts the volume at some 50 tons *annually* during the seventeenth century (1983a: 10-12)[272] – and silver could be got most readily from the Spaniards. (Hence the importance of Dutch surpluses with the Mediterranean and the New World.) "There is little doubt that the Baltic was the drain down which disappeared much of the American silver which Spain mortgaged to Amsterdam for Dutch imports. The ultimate destination of much of the contents of the Silver Fleets was the [Danish] Sound" (Wilson, 1949: 153-164; 1951: 235). An overstatement, no doubt – we have learned so much about the Manila Galleons and the flow of silver to the Far East in recent decades (Flynn and Giraldez, 2002; Frank, 1998) – but it is nevertheless quite clear that large volumes of American silver were flowing into the Baltic by way of Amsterdam (Attman, 1983a: 31-37, 103; Barbour, 1950: 52; Barrett, 1990: 250-252). And nowhere in Europe did American silver "cause the price of agricultural products to soar" more than in Poland (de Maddalena, 1974: 308).

Just how much American silver flowing into Spain wound up in Dutch hands? Barbour thinks 15-25 percent, but cites higher estimates too (1950: 50; also Attman, 1983b: 29-31). Whatever the precise figures, the acquisition of American silver was sufficient to transform the economic geography of northern Europe. At least sufficient, that is, once integrated into the political economy of Dutch world power. There is no call for bullion fetishism here. But silver served ably as a socially-recognized medium of exchange in an era when confidence in the world market was shaky at best (Chapter Two). Quickly recognizing the power of ready cash, the Dutch capitalized on the situation by pursuing what Wallerstein calls a system of "international debt peonage" (1974: 121-122; also Malowist, 1959). Superior access to mobile capital allowed Dutch

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[270] The language of semi-colonialism is, without a doubt, deeply anachronistic. Nevertheless, the flavor of the relationship is aptly conveyed. Like post-colonial societies of the later twentieth century, in Poland and elsewhere, formal independence overlapped with new inequalities of economic power.

[271] Among other things, it reduced the price of credit relative to English merchants (Lambe, 1657: 9-10).

[272] Attman (1983a: 10-12) takes pains to emphasize that this is an enormously conservative estimate, one that omits overland transport of specie, and relies heavily on registered exports from European ports. On the other hand, de Vries and van der Woude sound a sceptical note, arguing that Dutch "invisible" earnings from shipping and commercial services had a moderating effect on Attman's estimates for bullion exports from the Republic (1997: 84-87).

merchants (through Gdansk/Danzig intermediaries who bore much of the risk) to make advance payments to Polish landowners:

> This prevented sale on an open market. It allowed the merchants rather than producers to decide the optimum moment for world resale. And since the money lent tended to be expended by the time of delivery of the goods, if not overspent, the producer was always tempted to perpetuate the arrangement… [Dutch] merchants could thereby take the profits of the price revolution and multiply them (Wallerstein, 1974: 122; also Braudel, 1982: 419-420; Malowist, 1958, 1959, 1960).

What I would like to stress about Poland's deepening financial dependence on the West – which a long list of historians have characterized as colonial in essence if not form (e.g. Elliot, 1968; Malowist, 1959; Stavrianos, 1981) – is how such financial mechanisms called forth a thoroughly modern political ecology. While Poland's (under)development owed something to the peculiarities of settlement expansion in the medieval period (Brenner, 1985), the *consolidation* of a cash-crop monocultural regime in rye and wheat, worked by serf labor, owed much to the Dutch organization of credit and trade. By absorbing Polish agricultural surpluses into its North Atlantic town-country division of labor, the Dutch were able simultaneously to facilitate their movement into high-profit lines (both agricultural and industrial) *and* block the incipient development of mercantile and manufacturing activities in eastern European cities. In Poland, no less than in the Americas, economic power and financial innovation – seemingly limited to the social-financial sphere – were closely intertwined with the commodity-centered production of nature. (We shall have opportunity to return to the question of Baltic cereals presently.)

Was this "merchant" capitalism? In part, yes. But mercantile activity takes the explanation only so far. This was far more than buying cheap and selling dear, although, then as now, this was one aspect of the situation. To begin a more compelling explanation, we might observe that shipping and shipbuilding were in themselves only tangentially about buying cheap and selling dear. Beyond this, the fruits of merchant capital accumulated through the Baltic trade were fed into urban manufacturing, for instance sugar refining and textile manufactures. We might recall as well that this "external" moment of Dutch agro-ecological innovation was complemented by an "internal" agricultural revolution. Dutch agriculture was the Continent's most advanced (DuPlessis, 1997; Wallerstein, 1980; Davis, 1973; Grigg, 1973; Slicher van Bath, 1964). At a time when grain yields stagnated or rose only slightly throughout Europe, Dutch agriculture surged forward in the sixteenth and seventeenth centuries (Davis, 1973: 110, 116; de Maddalena, 1974: 312). Grain and milk yield ratios were "double or triple those achieved… outside the Netherlands" around 1600 (DuPlessis, 1997: 73). Some rye and wheat continued to be cultivated – indeed Dutch yields were the highest in Europe in the later sixteenth century (van Houtte and van Bruten, 1977: 85). But this was only part of the story. The "invasion" of cheap Baltic grain reinforced the effects of the ecological disruptions identified by Brenner to drive Dutch farmers towards cattle and dairy production, as well as industrial and garden crops (de Vries and van der Woude, 1997: 195-234). "Numerous villages that had reported extensive arable land devoted to grain in the fifteenth century had none in the seventeenth" (DuPlessis, 1997: 72-73; de Vries and van der Woude, 1997: 200; van Houtte and van Bruten, 1977: 85).

From the Forest a Mighty Empire Takes Shape: The Timber Commodity Frontier and Dutch World Power

Very little of the Dutch-led economic revolution – which was also an ecological revolution – was possible without timber and forest products, or without fresh land carved out of the forests. Everything turned on the forests. In this respect the Dutch occupied an even weaker geographical position than did Castile. Peat compensated for the lack of forests to some degree, and could be used for industrial and domestic heating. To this extent, urban pressure on the forests for charcoal and firewood was correspondingly reduced.[273]

But ships could not be built from peat. "Of all the European powers, the Dutch had the most unfavorable ratio of domestic forests to overseas ambitions" (McNeill, 2004: 397; also Albion, 1926: 169). Indeed the *immediate* hinterlands of Dutch shipbuilding centers offered less good timber than even Venice, perhaps the most widely cited case of early modern timber scarcity (Braudel, 1982; Perlin, 1989; Appuhn, 2000). And yet, if the Dutch had such little timber in their hinterlands, why do we find, in 1653, Sir Walter Raleigh lamenting England's backwardness to the Dutch? The United Provinces' access to the "exceeding Groves of Wood in the East Kingdomes" yielded "huge piles of Clapboard, Firdeale, Masts and Timber… in the Low Countreyes, where none groweth" (Raleigh, 1653: 26). Over the next few pages, we will trace the commodity-centered conversions of American silver into shipbuilding timber and Baltic cereals, which were of course transported in those floating forests, the merchant marines of northwestern Europe.

Wherever Dutch capital set ashore, they set in motion new commodity frontiers in grain and timber. And this meant strong if uneven pressure on those forests within the orbit of Dutch power. There is no need to postulate a continental forest crisis to make the argument that these commodity-centered environmental transformations were implicated in recurrent waves of geographical expansion and relocation within northern Europe.[274] These transformations owed much to the remaking of New World political ecologies, in turn reinforcing a systemwide dialectic of sequential overexploitation and geographical expansion. (The devastations of the sugar commodity frontier in Brazil and then in the Caribbean were of a piece with Europe's great merchant fleets.) Thus American silver intersected with the Dutch agricultural revolution and its attendant competitive edge in manufacturing to drive forward a series of cascading environmental transformations, effecting the widening and deepening of the specifically capitalist economic geography of northern Europe.

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[273] Peat gave the Dutch a cheap source of energy for a range of manufacturing activities that would otherwise have been quite limited in the thinly-forested Low Countries. It was not inexhaustible however, and by the later seventeenth century peat extraction was characterized by the same logic of rising costs and frontier movement that we've identified for the forest products sector, among others (see de Zeeuw, 1978).

[274] The debate over forest crises in early modern Europe dates back to Sombart (1921) and surely even earlier. It has revived in recent years with the resurgence of environmental history (see Malanima, 2006; Warde, 2006; Williams, 2003).

We may begin with shipbuilding timber. Over the course of the early modern era, Dutch capital would cast "an ever-growing net over the timber-producing capacities of Norway, Poland, and the Baltic states alike" (Jacks, 2000: 23). But this was less *one* net – the fishing metaphor seems especially relevant for the Dutch – than a *succession* of nets. Nets as webs of entrapment and as networks of power, this succession of commodity frontiers constituted the geographical law of motion underpinning the "national" triumphs of the Dutch-, and then British-led North Atlantic. It was the skill with which these nets were cast, and the quality of the nets themselves, that would give Dutch shipping (and therefore Dutch power) a decisive competitive edge over its competitors through at least the mid-seventeenth century, driving down shipbuilding costs to one-half to one-third those of the English (Albion, 1926: 156; Barbour, 1930: 267; Wallerstein, 1982: 109).

The first of these nets would be cast upon Norway's southwestern coast. If "the economic life of the Scandinavian countries was honeycombed by Dutch enterprise," as Violet Barbour observes (1950: 118), in Norway, Dutch capital was the Queen Bee (also Braudel, 1984: 251-254). The dramatic expansion of Dutch shipbuilding – whose tonnage increased *ten times* between 1500 and 1700 (Sella, 1972; Unger, 1992: 260-261) – moved like clockwork with the movement of Dutch capital into southern Norway. Norway (formally incorporated into the Kingdom of Denmark) emerged as Holland's principal timber colony after 1550. Sawmills spread like wildfires as the Dutch advanced; nowhere to be found less than a century before, there were over 500 mills by the end of the sixteenth century. Sögner sees "large scale" timber purchases by Dutch merchants from 1580 (2004: 45), but Lunden puts the decisive shift between 1528 and 1560, when the number of ships exporting timber increased more than sixfold (2004: 201). What ensued was one of modernity's first great logging booms (Sevetdal and Grimstad, 2003: 14).[275] So important was Norwegian timber that the advance of Dutch capital across the North Sea and the introduction of the greatest technological innovation of Dutch world primacy – the *fluitschip* (or "flyboat" as it is sometimes translated) – coincide almost perfectly. The Dutch timber trade with Norway took off in the 1580s; the first *fluitschips* appeared in 1595, manufactured, yes, from Norwegian pine (de Vries, 1976: 117-118; Derry, 1979: 142).

The semi-colonial strategy employed by the Dutch in the Polish grain trade found its sylvan counterpart in the Norway timber trade. Dutch merchants "fetched the timber in their own ships, trading with the peasants on very cheap terms and leaving scarcely any profit" (Kiaer, 1893: 332). Norway's role as a colonial zone becomes sharper in contrast to the Swedes – the chief distinction between Norwegian and Swedish timber exports, at least up to the 1660s, was the former's role as an exporter of largely unfinished timber (Heckscher, 1954). It was Norway's double subordination, to the Dutch economically and to the Danish politically *and* economically (through the unequal extraction of tax revenues), then that goes far to explaining its poverty during the "Norwegian night."[276]

[275] Representing a geographical shift from the more-distant Baltic (Malowist, 1958).

[276] "It is a problem," Lunden reflects, "how the population of Norway could remain so poor through all of this period 1500-1814 [roughly the period of the 'Norwegian Night'], and above all how the native economy could remain so under developed [I would say *underdeveloped*], the degree of urbanization remaining so low. This is a problem, regarding the 200-year head start of Norway in export of timber to Western Europe, and regarding the rather gigantic dimensions of the trade, relative to the size of the population. *This seems a major problem,* not only of Norwegian agrarian history, but of general Norwegian history as well. Nevertheless, the problem has as yet recovered little attention from historians. It seems

As in the Baltic, the Dutch strategy in coastal Norway deployed the power of ready cash on a massive scale to buy when prices were lowest and to sidestep the middleman (Barbour, 1930: 273). So successful was this strategy that Dutch shipbuilders obtained masts and shipbuilding timber at prices *below* those of their Norwegian competitors (Barbour, 1930: 273)! No wonder, then, that Norwegian and Baltic timber displaced Rhine Valley sources in the early seventeenth century (Unger, 1997: IV, 9).[277] Moreover, the North Sea was by definition a free trade zone relative to Europe's heavily regulated river networks:

> Rivers… were encumbered with man-made obstacles: mills, fish-weirs, and, above all, tolls. *The Rhine was probably the most heavily encumbered*, probably because there was more to tax than elsewhere… Further impediments, most burdensome on the Rhine, were the 'staple' and 'transshipment' rights exercised by some riverine cities. *So obstructive were they that they were at this time hastening the decline of the land route between Italy and northwestern Europe in favor of that by sea* (Pounds, 1990: 244, emphases added; also Bamford, 1956: 35).

While it would be unwise to speak of generalized deforestation, there were indicators of scarcity in shipbuilding timber and naval stores by the 1660s (Davis, 1973: 190).[278] By this point, the Dutch were importing 300,000 m^3 of timber annually from Norway (Sipkens, 1996: 36) – de Vries and van der Woude (1997) put this figure closer to 375,000 m^3 – or the natural increment of 150-190,000 hectares. The Danish Crown began selling its forest holdings in Norway to pay its war debts at this time (Sevetdal and Grimstad, 2003: 14). Undoubtedly construction timber fetched a good price in the aftermath of London's 1666 fire. Together, the century-long expansion of *both* forest products sectors (shipbuilding timber and naval stores) and the iron-sector combined to "inflict [wood] shortage, and *in some places devastation of the forests*" (Sevetdal and Grimstad, 2003: 10, italics added; also Berg, 1997). Kiaer observes a noticeable "thinning of the forests situated along the coasts" by mid-century (1893: 332), inducing a shift

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reasonable that a clue to solving the problem is the inclusion of Norway in the Oldenburg state, implying that 66-50 percent of the Norwegian-accounted state revenues were shipped off to Copenhagen" (2004: 203, emphasis added). But did not Dutch primacy in the timber trade siphon wealth as effectively (more so?) as Danish taxation?

[277] Rhenish and Elbian sources would become important suppliers after Westphalia (1648), which coincides with Dutch decline (Barbour, 1950: 91). German sources were available, but on balance these were not frontier sources, and therefore posed all manner of social and ecological barriers to treating nature as a free gift.

[278] Kirby and Hinkkanen are however sceptical (2000: 98-99). "The growing preference of shipbuilders for composite rather than single masts from the seventeenth century onwards might be seen as a sign that the Norwegian forests were no longer able to supply the stick timber required, but it might also have been brought about by other factors, such as cheapness or ease of construction" (2000: 98). But was not "cheapness" one of the fundamental expressions of timber abundance or scarcity? Moreover, composite masts were clearly second-rate masts, especially from the standpoint of strategic interests. Addressing the supply problems of the French navy in the seventeenth and eighteenth centuries, "the French navy was therefore obliged to use 'assembly masts' made of piece of jointed wood ringed with iron, *but they lacked flexibility and broke if overloaded with sail*. Compared with the English [who had access to northeastern Baltic supplies by the eighteenth century], French ships could never show an extra turn of speed" (Braudel, 1981: 363, emphasis added; also Bamford, 1956; Albion, 1926: esp. 170-171).

towards eastern Norway's timber zones by the later seventeenth century (Sögner, 2004: 45).[279] Increasingly it became a "necessity" to "float timber from the interior" to sustain exports (Kiaer, 1893: 332; also Sögner, op. cit.). Smout and his colleagues identify the same trend in their analysis of Ryfyllke, an important timber region in southwestern Norway. By the middle of the seventeenth century, "the best timber was cut out and the smaller, remaining trees proved less saleable" (Smout, McDonald, and Watson, 2005: 125). Only timber "in smaller dimensions" remained a major export item in the southwest (Sögner, 2004: 45). Lillehammer puts it more baldly (1986). Observing a 75 percent decline in the production (rather than export) of boards in Ryfyllke be between the 1660s and 1680s, he argues that "what… seems to have happened was that further deforestation in the easily accessible woods" in the region drove the crisis (Lillehammer, 1986: 108). "The boom," Smout and his colleagues observe in surely deadpan fashion, "had not produced sustainable forestry" (Smout, McDonald, and Watson, 2005: 125). By one reckoning, in the century after 1650, Dutch timber imports from Norway declined from 130,000 *lasts*, approximating 260,000 tons, to just 38,000 *lasts* (Sicking, de Bles, and des Bouvrie, 2004: 7).

The collapse of Norway's timber exports was surely influenced by factors other than forest depletion pure and simple. Denmark sought to mobilize Norway's resources in classical mercantilist fashion. The Danish Crown barred the export of masts and "other big stocks" in 1640 "under the pretext of Norway running out of timber" (Tossavainen, 1994: 74; also Lunden, 2004: 202). Pretext? Or was it perhaps that relative depletion now threatened Danish power? Would not the pressure to apply mercantilist measures have been even stronger under conditions of escalating relative scarcity? Norwegian masts "were described as the worst in Europe as early as 1637" (Bamford, 1956: 137). No doubt an exaggeration (the source is English), but surely one with more than a kernel of truth. Norway

> had supplied masts and timber to the Hanseats for centuries, and more recently [, between 1550 and 1650,] the Spanish, Dutch and English demands had drastically reduced the available supplies. The metallurgical industries and the enormous demands of the Norwegian lumbering industries, unrestrained by forest legislation or effective conservation measures, did much to ruin what remained of the forests, and to destroy the mast traffic in the last three decades of the seventeenth century (Bamford, 1956: 136-137).

By the later seventeenth century, escalating "supply problems in Norway" led the Dutch to resume the long march of the timber frontier. This time towards first the southern, then the northeastern, Baltic. Dutch ships would reach as far north as Archangel (Tossavainen, 1994; Kotilaine, 2003: 311). The Baltic timber trade quadrupled in volume between 1661 and the 1690s. In the 1660s, 1.5 million "pieces" of timber passed through the Sound. Nearly that many (1.3 million) were shipped in 1689 alone (Unger, 1959: 215). In Russia, the fur trade was quickly eclipsed by naval stores – these latter "the most

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[279] A century later, in the 1790s, the Dutch sailor Cornelius de Jong observed the "depletion of the wood lands due to the intensively cutting of trees. The government ought to intervene and to consider limits to the deforestation, he thought" (Bruijn, 2004: 98).

rapidly growing categories of Russian exports" by the 1690s (Kotilaine, 2003: 306) – in exchange for Dutch metalwares and munitions.[280] Indeed, Dutch capital moved into coastal Russia to establish the first sawmills much as they had done a century before in Norway (Ozveren, 2000), and just as they had poured into Sweden a century earlier to establish a modern iron and copper industry (Barbour, 1950: 119). Meanwhile, Finland saw a "particularly striking" rise in timber exports by 1700 (Unger, 1959: 215; Åström, 1975, 1978).

Albion sees a succession of Baltic timber frontiers in the century or so after 1670, organized around Danzig, Memel, and Riga in their respective turns (1926). The turning point was almost surely occurred some time earlier. Between 1610 and 1640, Danzig's exports of ash and "finished planks" declined by 85 percent, falling to almost nothing by 1650. Among the forces driving the sharp decline? In part war with Sweden, but also the "destruction of the Polish-Lithuanian forests" (Stone, 2001: 198). If Albion gets the timing wrong, he is quite correct about the overall geographical movement (also Smout, McDonald, and Watson, 2005: 124-131; Kirby, 1990: 229-232). The frontier would roll onwards well into the nineteenth century. By the 1880s around Konigsberg, timber supplies from its 27,000 square miles of once-thickly forest terrain, were "gradually becoming scarce and dear. The distance to haul [was] increasing" (Brown, 1885: 247). This frontier movement was driven by the very intersection of endless accumulation and rising material throughput that lay behind the expansion of the silver commodity frontier to the New World. The "Baltic timber trade," Albion reminds us,

> was not a matter which affected Dantzig, Riga, Longsound, and other timber *ports* alone. Extending even into Bohemia, Galicia, and the Ukraine, it afforded employment to men living hundreds of miles in the interior… [As] the old sources of supply grew inadequate [because of overcutting, it] became *necessary to go farther and farther up the rivers and deeper into the woods away from the rivers in order to find suitable tress, which naturally increased the price of timber*… Even the rivers grew shallower as a result (Albion, 1926: 143, 145, second emphasis added; also Richards, 1990: 168).

The shipbuilding timber frontier was expansionary out of all proportion to its material demands. Even in the late eighteenth century shipbuilding timber made for perhaps one percent of European consumption (Warde, 2006: 40-41). The sector's disproportionate demands stemmed from two mutually reinforcing reasons. First, shipbuilding timber was highly selective and dependent upon slow-growing, "old growth" trees such as oak. Shipbuilders, because they needed "grand and 'outsized' timbers,… vociferously feared scarcity. This was in part because the curved 'compass timbers' required for ships' parts *were not generally found conveniently amassed*" (Warde, 2006: 40, emphasis added.) Most shipbuilding timber was simply out of reach. High transport costs precluded moving timbers more than a few kilometers. Just how far this timber could be hauled overland is uncertain. Estimates vary. Albion thinks the limit was twenty miles from the

[280] All of which was implicated in the transition to a "new era in Russian economic history" characterized by its integration into the world capitalist system (Kotilaine, 2003: 311; Wallerstein, 1989).

rivers (1926: 145). This is almost surely too generous.[281] Looking at the early *nineteenth* century, Pollard sees twelve miles as the "farthest possible distance [overland] for transporting timber or grain" (1974: 38; also Braudel, 1981: 365; *pace* Berg, 1997). In the mid-nineteenth century U.S., timber was rarely hauled for more than two miles, although heavy snows might allow sledding for some distance farther (White, 1980).

Baltic cereals were the second major vector of sequential exploitation nourished by the silver trade. Combined with "agricultural expansion… together [timbering and agricultural clearing] degraded the forests of the Vistula basin and more generally those of southern and central Poland" (Richards, 1990: 169). Szczygielski sees a century-long advance into the forest after 1550, predicated on the extraction of masts, naval stores, potash production and other forest products (1967). There was, as Szczygielski puts it, a movement of "exhaustive cultivation" in full flower by the second sixteenth century (1967: 97).

Tossavainen (1994) accounts for this ecological overdraft not simply in terms cumulating pressures, but in the competition between forest sectors predicated on the rate of profit. Two sectors stand out, tar and pitch suitable for protecting ships from water damage, and potash, crucial for bleaching fabrics preparatory to manufacture. Both were devastating. They were perhaps the only activities in the European world-economy – aside from agricultural clearing pure and simple – that came close to realizing total deforestation. Deploying the same power of ready-cash that we saw in the cereal trade (in fact the two were functionally related), beginning in the sixteenth century, Dutch merchants "encouraged Baltic peasants to convert from a traditional forest economy to agriculture based on wheat and flax for export." The result was a series of short-lived regional booms in tar and pitch extraction that decimated the forests and drove down the price of tar (for the Dutch) below that of western European competitors (Loewen, 2005: 239-240).

Potash was no less important, and equally voracious of the forest. Potash production relied on the oak stands as much as shipbuilding timber:[282]

> [A]shes and potash were commodities which gave to a middleman especially high profit compared to the export of timber. For instance, in the middle of the seventeenth century the middleman in a loading port had a profit from 40 to 90 per cent in the trade with potash, while in the timber trade the most important single type of timber, clapboard gave only 16 per cent profit… Danzig merchants were using either subcontractors who felled the timber and burned the ordinary ashes needed in the refining process of potash, or the local magnate got an advance payment of a

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[281] Although Brown (1885: 241) thinks overland haulage of trees as far as 30-40 miles was "by no means unusual" in late nineteenth century Poland. This would have been possible only at very high prices (which, Brown argues, was indeed the case) and very low wages, which Brown does not mention, but which is certainly possible in a region where timber haulage would have served as a by-employment for peasant cultivators.

[282] The situation with potash was no simple expression of merchant capitalism, of buying cheap and selling dear. Potash was so profitable because it was a strategic use-value. It was central to the high value-added strategy of Dutch capitalism: "Where did the biggest profit margins lie in textile manufactures? Not in spinning or weaving or growing wool but in the refined technology of dyeing and dressing the cloth which provided the key to the control of the markets" (Wilson, 1968: 31).

> certain quantity of potash delivered to Danzig. *The subcontractors and landowners did not care about the future of the forests*. They felled large areas totally empty of hard wood such as oak and beech, best suited for potash production. *When the forest was cleared, the subcontractor simply made an agreement with another landowner who still had suitable types of timber. This was especially disastrous to the oak, because it takes decades before oak is big enough to be used for waynscot*[283]... The short-sighted clear-cutting of forests together with the internal and external factors already mentioned were enough to cause a disaster in Danzig's timber trade (Tossavainen, 1994: 73-74, emphasis added).

Such was the deforestation around Danzig – "the unreasoning greed of man [had] destroyed these trees" – that sand dunes invaded (Wessely, 1873: 221-222 quoted in Brown, 1884: 96-97).[284] By the early eighteenth century the dunes had advanced not only over nearby "meadows and fields,… [but also had] completely buried" two nearby villages (ibid). By the close of the century, the problem had advanced such that only state intervention averted its "growing danger… [to the] commerce of Danzig" (Wessely, 1873 quoted in Brown, 1884: 120-121). In the 1870s, Bebel would attribute frequent and severe flooding on the Vistula to the "devastation of forest," which he called a "mad sacrifice… for the sake of 'profit'" (1879 [1988]: 204). No wonder that in "Poland we meet with only very few forests capable of giving an idea of the ancient forest state of the country," Brown observed in the 1880s (1885: 21).[285]

The dramatic expansion of Baltic cereal exports began in the 1550s, reaching four times the volume of a half-century earlier (Malowist, 1959; Tielhof, 2002: 43). About half these shipments originated in Poland, and about sixty percent were carried in Dutch bottoms until the mid-seventeenth century (Bogucka, 1978: 14; Glamann, 1974: 461).[286] Poland itself, at least the "Poland" shaped by the expansive region comprised of the Vistula and its tributaries,[287] became a vast monocultural zone. By the end of the sixteenth century, grain would constitute 70 percent of exports; by the early seventeenth century, 80 percent (Bogucka, 1978: 14). Hoffmann puts the figure closer to 90 percent as early as 1550 (2001: 136). No wonder that Glamann (1974: 459) sees in the sixteenth century Poland the "lopsided development of agriculture and forestry under the massive pressure

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283 Waynscot or wainscot was a type of high-quality planking, made from oak, used in shipbuilding.

284 This had happened earlier on the Baltic coast, during the Thirty Years War (1618-1648), when "the Swedes, who needed money, cut down vast areas of forest in Pomerania with the result that many regions were afterwards invaded by sand-dunes" (Braudel, 1981: 365).

285 Much better off was Poland's southern neighbor, Hungary, which Brown characterized as considerably "less devastated than Poland" (1885: 22).

286 Three-fourths of the Baltic grain arriving in Amsterdam was re-exported in the seventeenth century (Glamann, 1974: 461).

287 "The river system [of the Vistula] seems to have contained a larger volume of water than in our day, since the water-table was higher, thanks to the extensive forests. The Polish lowlands placed few obstacles in the way of river traffic, which operated along a whole network of rivers with the Vistula as the main artery. This means that the Vistula carried grain and timber belonging geographical to other regions… The supplying districts associated with the Vistula trade were thus in the sixteenth and seventeenth centuries substantially bigger than the 'hinterland' drained by that river alone – *which is itself bigger than that of the Rhine*" (Glamann, 1974: 458, emphasis added). Indeed Wazny's (2002) dendrochronological studies indicate that timber was drawn from the far south of Poland, close to the Czech and Slovakian border.

of western demand"! While the Dutch were urbanizing rapidly – the urban population nearly tripled between 1500 and 1600 – Poland was rapidly and structurally de-urbanized. The number of people living in cities fell by almost *one-third* over the seventeenth century, even as aggregate population increased 20 percent. Of major European countries, only Spain suffered a meaningful drop in urban population, and this by just five percent (calculated from Allen, 2000: 8-9). The ecological moment of this double reconfiguration of town and country is easily missed but simply stated. Towns consumed forest products at a ferocious pace – above all timber for construction and charcoal for manufacturing. All things being equal, less urbanization in seventeenth century Poland meant more resources for the United Provinces.

What Marx once observed for the relationship between England and Ireland in the early nineteenth century might just as well be applied to the relation between the northern Netherlands and Poland: "Ireland is at present merely an agricultural district of England which happens to be divided by a wide stretch of water" (1977: 860). But if the political economy of uneven development seems rather straightforward, the question still remains: Was there a significant *political ecology* of uneven development in the long sixteenth century? There is ample evidence by this point to indicate that environmental devastations ranged far and wide in the conquest of the Americas, from the canefields of Bahia and Barbados, to the mining centers of Potosí and Zacatecas. But were these ecohistorical moments of a New World exceptionalism, perhaps the straightforward outcome of a rapacious European colonialism? Or were they, perhaps, moments in a world-historical pattern that extended to the Vistula, to Stavanger, to Viborg? What we have seen suggests that this was more than a replay of premodern empire-building; that empires were in play, but they no longer were the independent variable.

Other questions present themselves. Was there a political ecology of underdevelopment for the North Atlantic as well as the New World, one that reinforced and sustained the political ecology of uneven development on a world-scale? Were there, in others words, a multilayered and overlapping series of "metabolic rifts" between Amsterdam and Poland, between Amsterdam and Spain, Seville and Peru, Potosí and Peru? Does Marx's concept of metabolic rift – the creation of an "an irreparable rift in the interdependent process of social metabolism" between town and country (1981: 949) – hold for the era of manufacture and the rise of the world market as well as for the era of large-scale industry?

Our evidence suggests an affirmative answer to these questions. The emergence of Poland as a vast cereal export zone was predicated on an equally vast movement of forest clearance. Williams (2003: 176) and Richards (1990: 169, 177) sees the rapid and large-scale transformation of Baltic forest into arable land. Between 500,000 and 700,000 hectares of forest were sacrificed to feed the Dutch, English, Iberian, and Mediterranean socio-ecological formations. Just how much of this was concentrated in Poland remains unclear. But even if we take the low end of Richards' estimate, 500,000 hectares, this translates to a scale and speed of deforestation unknown before in human history, *except for the deforestation ongoing at the very same time (1550-1750)* in northeastern Brazil (see Dean, 1995; and for an upward revision of Dean's estimates, see Chapter Six).

How much grain was flowing from Vistula breadbasket? Richards figures an annual average of 60,000 tons of cereal passing through the Sound during the sixteenth century. This may be too conservative. Malowist (1958) reports 10,000 lasts – one last amounting roughly to two tons – exported from the Baltic to western Europe at the end of the fifteenth century, and then a significant jump to 40,000 lasts (80,000 tons) by the 1540s. Shipments rose to around 100,000 tons by the late 1590s and to 120,000 tons a year by the 1618 (Tielhof, 2002: 43). Of course it is difficult to factor in the tremendous oscillations of the trade, generated by climate and war, but the Richards-Williams estimate on deforestation appears sound. Even "today [1979] the view of the land on an aeroplane journey from Warsaw to Cracow still shows the way in which the long fields thrust into the forests" (Braudel, 1981: 364).

The fate of the forest and the fate of the soil were therefore dialectically bound. Perhaps Poland's high yields in 1550s – just barely above the European average – owed something to reclaiming arable land from the forests? If so, this would explain at least part of the subsequent downward revision of yield ratios, evident even before cereals prices declined in the early seventeenth century. Szczygielski (1967) sees the two movements, forest clearance and declining yield ratios, closely linked in Poland. There were, he points out, two principal strategies for sustaining a grain surplus, even in the face of a medium-run tendency towards soil exhaustion. One was sustaining output "by deviating from the fundamental principles of rotation in tilling the soil" (Szczygielski, 1967: 97, 94). The second strategy was necessitated by the first. Exhausted land was abandoned, and new arable carved from the forest. Thus were soil exhaustion and deforestation closely intertwined. It is quite certain that the process cannot be explained solely in terms of the extension of the modern world market. We can be equally confident that the expansionary cycle of forest clearance and soil exhaustion was not the unmediated outcome of a peasant-seigneurial cycle, as we witnessed during the long medieval expansion. World market forces were strong, but not *that* strong; the peasant economy was expansionary, but not *that* expansionary. It was rather a situation in which the two forces combined in unstable and dynamic tension, preserving in crucial respects a set of pre-capitalist arrangements, even as these latter were entrained within the gravitational pull of Dutch-led capitalism. It was a combination, in other words, that was more than the sum of its peasant and Smithian parts.

We have seen that cereal exports crested sometime in the first quarter of the seventeenth century. Poland had sustained a strong demographic expansion in the sixteenth century, which meant primarily an expansion of the peasant economy (McEvedy and Jones, 1978: 73-77). This accounts for one moment of the drive into the forest. Meanwhile, the threefold expansion in cereal exports between the 1540s and the early seventeenth century constituted another, linked but relatively autonomous driver. What emerges is the more-or-less typical pattern of commodity frontier development within early modern Europe. Poland in the second half of the sixteenth century remained, as it had been for medieval Europe, an open frontier, for the peasant economy and market-oriented seigneurs alike. During this half-century, "there still seems to have been enough… virgin land to satisfy seigneurial ambitions for demesne expansion, so that land held by peasants was only occasionally absorbed" (Blum, 1957: 829). After 1600,[288] however, the seigneurs moved strongly against the peasantry:

[288] It was precisely at this moment, the early decades of the seventeenth century, that land scarcity began to materialize in the sugar frontier zone of Brazil's Reconcavo (see Chapter Six).

> The expropriation of peasant holdings became much more general, so that an ever-increasing number of peasant holdings were reduced to cottars, left without any land at all, or had the size of their holdings much reduced (Blum, 1957: 829).

Whether or not this is synonymous with a market-driven "second serfdom" is another question. The point I wish to underline is that the drive towards the expropriation of peasant holdings, as Blum puts it, and the drive into the forest, were dialectically joined. They were movements of a singular socio-ecological process expressive of the commodity frontier. While the socio-spatial moment is crucial, so is the matter of timing. For the cereal and timber commodity frontiers (or was it perhaps a singular frontier?) produced not space alone, but also time. We see, once again, a 50-75 year cycle of expansion and ascent, followed by decline – an especially dramatic decline in the case of seventeenth century Poland.

It is therefore not terrifically surprising that we see an agro-ecological crisis within Polish cereal zones by the middle of the seventeenth century. Tielhof identifies soil exhaustion as a serious problem from the 1660s (2002: 54), at which point Szcygielski begins to speak of a "catastrophic" decline of agricultural productivity (1967: 86). Moreover, the ramping up of corvee labor by the market-oriented nobility deprived poor peasants of animals, thereby undermining a key source of soil fertility (Wallerstein, 1980: 132). That yields were declining is widely agreed, from 5:1 in the mid-sixteenth century to 3:1 (or lower) in the mid-seventeenth century (DuPlessis, 1997: 82; de Maddalena, 1974; Topolsky, 1962). As if that wasn't bad enough, widespread deforestation led to mounting soil erosion problems as early as the seventeenth century, likely intensified by the cold, wet winters of the Little Ice Age (Klimowicz and Uziak, 2001).

Was this crisis the outcome of the market-orientation of Polish agriculture, or perhaps the resurgence of a seigneurial-agrarian dynamic? The late seventeenth century was an era of "severe agricultural depression" across the Continent, which in certain respects replayed the crisis of the long fourteenth century (Abel, 1980: 182; Seccombe, 1992). The question is one of relative causal weight. Abel provides one clue, suggesting that the depression was "less pronounced" in Scandinavia "because subsistence agriculture *still played a larger part* in the management of farms and estates than in the neighboring countries," above all "east Germany and Poland" (1980: 178-179, emphasis added). The expansion of the peasant economy, it would seem, insulated regional economies from the seventeenth century downturn. This was the diametric opposite of the logic of the fourteenth century's crisis. Danzig's grain exports fell some 90 percent between the late sixteenth century and the early eighteenth. It was, then, not the weakness of capitalist advance in the Vistula that drove the crisis; it was rather a crisis that emerged out of more than a century of capitalist restructuring.

Poland was by the late seventeenth century undercut decisively by English grain. Surely we can explain this in terms of rising English agricultural productivity and the capitalist relations that enabled it (Brenner, 1985). But wasn't this higher productivity achieved in part by what Overton (1996: 117) describes as the "cashing in on reserves of nitrogen under permanent pasture for short-term gain," gains that would turn to stagnation after 1750? And wasn't Danzig also undercut from the other direction by "a shift towards the eastern Baltic" in the world grain trade by the eighteenth century

(Glamann, 1974: 462)? This shift would in turn reproduce on an extended scale the deforestation that characterized the earlier phase of the cereal commodity frontier – creating, for instance, widespread deforestation in Estonia and elsewhere in Baltic Russia towards the end of the eighteenth century (Veski, Koppel, and Poska, 2005: 1384; French, 1983: 30-41). It was, Wallerstein wryly observes, a “self-consuming method” (1980: 133). But self-consuming for whom? For the peasantry, certainly. For the seigneurs, probably. But thanks to the magic of the commodity frontier, a self-expanding method it surely was for the accumulators of capital.

Fishing the Commodity Frontier

If world environmental history is to become more than a succession of regional case studies, our most pressing task is to identify synchroneities, and then relational movements (teleconnections), between these regions. The teleconnections between the Low Countries and the extended Baltic zone do not end with the metabolic rifts instanciated in the grain/timber/silver nexus. Among the more surprising synchroneities is the near-simultaneous decline of herring fisheries and Poland’s agricultural crisis. Dutch herring exports traveled far, in the first half of the seventeenth century between one and two thousand *tons* of the salted fish were consumed in Warsaw, and on average 15,000 tons a year for the Baltic as a whole (Unger, 1980: 263). By 1640, the Dutch were hauling in 40,000 metric tons of fish annually, about 80 percent of which was exported (de Vries and van der Woude, 1997: 251).

Apparently this was too much. Especially when reinforced by Danish and German competitors, “who responded to growing Dutch [harvests] by increasing their own catch” and in the process “destroying their own fishing grounds” (Munro, 2006: 18). (Did this lay behind the “final collapse” of the Scania fishery in the 1620s [Unger, 1980: 272]?) By 1650, the North Sea’s herring fisheries were in trouble. Richards sees a “long, slow decline” (2003: 51). But was the crisis perhaps more pronounced, a bellwether of Dutch hegemonic crisis? (Recall that Norwegian timber imports had faltered and Polish agriculture was in crisis at this very moment.) De Vries and van der Woude see a “precipitous decline in the herring catches after the 1650s” (1997: 419; see esp. 25-251). This was no small matter for an economy in which one-fifth of the population depended on the fisheries, directly or indirectly, for their daily bread – the value of the 200 million herring caught in the 1650s exceeded that of English woolens (Munro, 2006: 19). It is in any event clear that herring yields per boat were declining, a difficult state of affairs for a sector characterized by very low labor productivity and a “structurally low level of profitability” (van Bochove and van Zanden, 2006: 568). Yields declined and with it the rate of profit, which fell by more than half between 1640 and 1700 (van Bochove and van Zanden, n.d.: 8).[289] The same historical-geographical pattern was at play in Dutch whaling grounds as well. These began to show “quite certain” evidence of declining yields at the same time as herring (ibid: 9). The Dutch economy could not do without either – the herring trade kept the shipyards in business (with nearly 500 *busses* in the water during the 1640s) and whales provided the raw material for such crucial industrial products as

[289] Here I cite the unpublished version of van Bochove and van Zanden paper, which does a better job of highlighting the declining profitability of the herring industry than the published paper.

bone (for textiles), soap, lubricants, and lamp oil (Munro, 2006: 19; Richards, 2003: 609-610; Wallerstein, 1982: 96).

The solution was of course an old one by the mid-seventeenth century – extend the frontier. Build a bigger net. (Or harpoon, as the case may be.) Thus the period between 1640 and 1670 marks the decisive turning point in northwestern Europe's fisheries and whaling grounds. Fleets rapidly moved north and west into Arctic zones. Commenting on whaling, Richards ably captures the grim logic of these aquatic commodity frontiers:

> No allowance was made for any sort of conservation or sustainable use of stocks. The Arctic bowhead herds became an open-access resource without any discernible management or restrain on the part of the users. From the early sixteenth century to the mid-nineteenth, as bowheads were killed off, *the whalers shifted to more and more distant, difficult and dangerous regions*…. Over the entire period, *and in each phase of the hunt*, there was a slow reduction in productivity as the number of size of whales caught declined. For example, in the 1670s each Dutch whaling ship took an average each year of 6.4 whales… [I]n the 1770s, the annual average catch was down to 2.2 animals (Richards, 2003: 610, emphases added).

For whaling the movement was strongly outward. Herring declined in relative importance to the world-economy after the seventeenth century – the catch was no larger in 1800 than it was in 1600 (Poulsen, 2006: 3). By the eighteenth century, herring would give way to cod. As so often was the case, a new frontier entailed a changing of the guards – Dutch *busses* gave way to the aggressively expansionary English- and French-cod fleets. Nevertheless, the geographical restlessness of the herring commodity frontier persisted within the limits of low profitability. The eighteenth century witnessed a succession of local fishery booms on the coasts of Scotland, Norway, and Sweden, none of which "flourished for more than 50-60 years at a time" (Poulsen, 2006: 2 and *passim*). (A by-now familiar temporal cycle.) Already in relative decline, the Dutch were boxed out of these resurgent fisheries, which explains the industry's failure to revive profitability. Meanwhile cod rose to prominence and outstripped herring production several times over; but the Netherlanders' moment in the sun had passed and the English now led the way. By the 1780s, the world cod harvest approached 400,000 tons.

This was, then, an early instance of the product cycle taking hold and reshaping "local" geographies in such a way as to necessitate continued expansion. If the outward movement of the herring frontier was articulated with the Baltic grain frontier – both showing signs of exhaustion by the mid-seventeenth century – the global extension of the cod frontier was metabolically linked to the sugar commodity frontier's movement into the Caribbean, at the very moment when the North Atlantic nexus of grain, silver, and herring was coming unraveled. Here was a definite rupture with premodern patterns. The North Sea fisheries had been overexploited in the seventeenth century. Three centuries prior, these fisheries had also shown definite signs of stress in the wake of the long medieval expansion (Hoffmann, 2005). But in the long fourteenth century, the ecological crisis of the sea and the ecological crisis of the land led to the crisis of the feudal order as a whole (Chapter One; also Moore, 2002a). In the seventeenth century, the ecological crises of the herring and whaling sectors led not to the crisis of capitalism as a mode of production, but to the unraveling of Dutch world power. The globalization of the North Atlantic fisheries, then, carried out by French and especially English fleets, was one moment of global expansion and restructuring that was the *sine qua non* of early capitalism. On the cod frontier no less than in whaling and herring, "fishing pressure diffused over [an ever] wider area and bore upon new cod stocks… In response to local scarcities, cod fishers moved to new, unexploited coastal regions" (Richards, 2003: 567-568). It was a frontier movement that fed, and was in turn nourished by, the depredations of Caribbean's sugar commodity frontier (Moore, 2000b, 20003a, 2003b). The sugar plantations ravaged the soils of the West Indies through their mobilization of African slaves fed on cheap salted fish – whose cheapness rested upon the cod frontier's capacity to treat the North Atlantic as a free gift to capital, in turn a particular expression of early capitalism's extensive ecological fix strategy. So inexpensive was the imported fish that Caribbean planters in the 1650s found it cheaper to buy fish from New Englanders than to allow slaves to fish for themselves (Ligon, 1657: 35).[290]

There is a startling synchroneity to the patterns here. While all commodity frontiers went through boom and bust cycles that were regionally specific, combined they created a roughly connected world-time. This is the 50-75 year cycle.[291] I have used the metaphor of teleconnection to convey,[292] albeit in rough and ready fashion (but then, was not this the reality of early capitalism?), the proliferation and intensification of "large, statistically significant signals" in one region and "equally large signals" in another (Bjerknes, 1969). Of course the task of the historian in this context is rendered all the more challenging by the unrelenting reality of a polycentric system that was still in formation and still expanding. Early capitalism was no closed system. (Is it today?)

Wallerstein (1980: 133) sees a 50-60 year cycle of new agricultural exploitation and thence soil exhaustion for eastern Europe in the early modern era. Was this not remarkably similar to the Central European (1460-1520) and Potosí silver cycles (1573-1630? And to the high point of the Dutch-led whaling commodity frontier, c. 1661-1719 (Richards, 2003: 600)? To the Dutch-led boom in Norwegian timber (1580-1630)? And also to the sugar commodity frontier in successive movements across the Atlantic, from Madeira (1470-1520), to São Tomé (1530-1580), to Pernambuco (1570-1620) and Bahia (1620-1670) in Brazil, and thence towards the Caribbean by the mid-seventeenth century? All of which suggests that these commodity frontiers were increasingly occupying the same "place" of the world-economy, even as this place quite evidently transformed (and was in turn shaped by) distinctive socio-ecological conditions and specific regional contexts. The patterns of boom and bust were still loosely, and yet increasingly, teleconnected through the circuits of capital and the machinery of empire.

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And now we can connect the world-historical dots of forest clearance, which we have talked about in terms of "forest-equivalents." The dramatic expansion of the Baltic grain

[290] "[T]he planters are so good husbands, and tend their profits so much, as they will not spare a Negro's absence so long, as to go to the *Bridge* and fetch it [the fish]" (Ligon, 1657: 35).

[291] It is not, as near as I can tell, directly bound to Kondratieff waves, although it is possible that such price movements are in dialogue with ecological contradictions of the commodity frontier.

[292] Borrowed from meteorology (Bjerknes, 1969) and deployed by Davis, although without reference to the global socio-ecological developments he traces, to examine the late nineteenth century El Nino cycles (2001: esp. 240-245).

trade over the course of the sixteenth century was, among many other things, a period of rapid forest clearance. Not just because of arable's expansion at the expense of forest, although this was important. Grain of course moved on ships, and shipbuilding was aggressive in pushing the division of labor ever outward. Petty estimated Dutch shipping at 900,000 tons in 1676 (1690: 5) Spotting these ships a generous life span, of say ten years, this meant 90,000 tons of shipbuilding annually, which would have depended upon 126,000 m^3 of timber.[293] (And this for the Dutch alone.) Using Warde's ratios, this would have translated into about 1708.5 acres annually (2006: 50). But here the figure is surely misleading. Not just any timber would do, as Warde notes. His yield figures, presuming 73.75 m^3 of timber per acre, may be reasonable for certain kinds of shipbuilding timber (planking for instance) but it strikes me as rather too optimistic for the most strategic materials, hulls and above everything, masts. There is evidence that suggests a much lower yield for shipbuilding timber. Perlin, citing a 1593 source, finds that 1,740 "mature oaks" made for 2,000 tons of shipbuilding timber (1989: 175). If so, we may build from Naish's observation that 2,000 such oaks (1,740 tons) could be extracted from about 50 acres (1957: 493).[294] Combined with standard weight-to-volume conversions for hardwoods,[295] this produces a yield of 39.4 m^3/acre for shipbuilding timber (97.24 m^3/ha). This would explain why southern Norway in the 1650s was running low on shipbuilding timber – not from lack of forests but from the "cherry picking" characteristic of the shipbuilding timber trade.

"Everything conspired against the forest," Braudel once observed (1981: 364). The Andean mining frontier consumed forests (or their functional equivalents such as Peru's Icho grass), its silver precipitations flowed to Castile in massive convoys built of wood, who upon arrival disgorged their treasure into private and public coffers, fueling among other things Spain's imperial ambitions. Such ambitions enabled substantial shipbuilding and ironmaking within Spain, which consumed the forests and therefore undermined the Empire's capacity to make its own iron and launch its own vessels. Even these activities depended upon imports of quality timber (such as masts) and especially grain from northern Europe. In the same breath, the enormous silver inflows allowed Castile's ruling strata to dispense with the kind of internal restructuring, within the administrative apparatus broadly conceived, and (more corrosively over the long run) within the agro-ecological and industrial spheres. Thus the "crisis of the seventeenth century" hit earliest in Spain; its essentially medieval agriculture reproducing the ecological crises of the seigneurial-agrarian cycle in a manner strikingly reminiscent of the fourteenth century crisis. Within Spain, only the southern frontier zone of Guadalquivir escaped this fate, precisely because it was a frontier zone (de Maddalena, 1974: 300). But this was no feudal crisis. Things were now quite different. Spain's "agricultural revolution in

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[293] My calculations derive from Warde's estimates of 210,000 tons of shipping requiring 295,000 cubic meters of wood, for the British navy in 1812 (2006: 50). Bamford (1956) reports that ships could last up to three decades, but this is an exceptional upper limit, and refers to well-maintained ships-of-the-line rather than merchant vessels.

[294] Or forty trees an acre, a figure that is about ten percent higher than Warde's guesstimate of 35.3 trees an acre (2006b: 50), and just below what Smout and his colleagues find for seventeenth century Scotland, at 42.9 "mature" oaks/acre (Smout, MacDonald, and Watson, 2005: 97).

[295] Assuming 6400 lbs for a standard hardwood cord (3.62 meters) (State of South Carolina, 1999). This is a high estimate, in favor of forest productivity. For the detailed technical discussions, see Moore (see Chapter Two).

reverse" (Braudel, 1972) was neither isolated nor universal. Spain agro-ecological woes were teleconnected with the colonial ecological revolution in Peru (and not just Peru), to the agricultural revolution in the Low Countries of the first sixteenth century, and thence to the "economic regression" and ecological crisis of Poland in the mid-seventeenth century. From the standpoint of *modern* environmental history, what differed in this seventeenth century "crisis" – a crisis in but not of the system – was the *uneven articulation of capitalist and medieval political ecologies*. As such articulations go, it was creative. It was destructive. It was globalizing. How little things have changed.

It is at this point that we may turn now to the greatest engine of socio-ecological transformation in the early modern world, the sugar commodity frontier.

CHAPTER FIVE

'The greatest want the Inhabitants suffered was of Wood, there having been nothing else in it before'

Madeira, Sugar, & the Conquest of Nature in the 'First' Sixteenth Century, 1452-1557

> *In the long march toward the modern world-system*, mass *commodities – gold [and silver], sugar, slaves, cotton, coal, oil – have been its beasts of burden. They have sometimes served as markers for entire historical epochs… They are the motors of production, the ultimate hard currency of exchange*.
>
> – Retort (2005: 39)

Silver was not alone among the decisive mass commodities shaping the origins of capitalism. Its fraternal twin was sugar. Not identical for sure, but each so closely resembling the other that the modernity of silver was unthinkable in the absence of sugar. If bullion, the slave trade, and sugar were the definitive mass commodities of their times, sugar was the strategic motor, driving a radical extension of commodity production most evidently. But sugar's contribution goes far beyond the reworking of production and consumption relations. This epoch-making mass commodity was also central to the creation of the Atlantic economy in its formative centuries – its ports, its credit mechanisms, its information networks, its manufacturing activities. Above all, sugar made slavery modern, and slavery made the modernity of sugar. The sugar commodity frontier and modern slavery were not identical twins so much as they were conjoined. They were the American pillars of early capitalism's ecological regime. Slaves were no mass commodities in the absence of sugar. And the profitability of silver and gold extraction was sustained by the capacity of the sugar planting, trading, and warehousing – with all their manifold multipliers and linkages – to absorb surplus capital and therefore carry the flag of capital into new spaces at home and abroad. Sugar was, Blaut opines, early modern capitalism's "largest single generator of value" (1993: 198). Whether or not this is true remains open to debate.[296] Commodity determinism is a treacherous road. The spirit of Blaut's observation is, nevertheless, entirely on the mark.[297] Sugar was decisive

[296] As we have seen, the Atlantic's silver and metallurgical complexes rivaled sugar's dynamism. (Albeit with the temporal unevenness characteristic of extractive zones. See also Blackburn's masterful analysis of the significance of the sugar plantation sector for the British Industrial Revolution (1997: 509-580).

[297] "In 1600 Brazil exported about 30,000 tons of sugar with a gross sale value of 2,000,000 [pounds sterling]. This is about double the total annual value of *all* exports from England to *all* of the world in that period. It will be recalled that British exports in that period, principally of wool, are sometimes considered paradigmatic for the 'awakening,' indeed the 'rise,' of early-modern Europe... The rate of accumulation

to world accumulation – not more or less than silver but certainly in distinctive fashion – because it was profitable, and because it was generalizable throughout the tropical world. Wherever water and warm weather met up, the plantation model could be imposed.

This entailed two epochal relational shifts. On the one hand, the generalizability of the plantation model not only meant that rival empires were keenly interested in getting their hands on a cut of the action. This was also true for silver, as we have seen. In contrast to silver's rather sparse geological depositions, however, rival empires could intervene *directly* in sugar production. At least in principle. So long as an empire's geopolitical muscle enabled it to do so, every major European power internalized sugar production within their colonies. Some more successfully than others. There were, from the earliest moments of the sugar commodity frontier, multiple production zones under multiple imperial jurisdictions, yet competing within a unitary world market. Here was combined and uneven development for sure – the combined development of the capitalist world market (in general) and the sugar commodity complex (in particular) was driven forward in specifically modern fashion by their distinctive forms of geographical unevenness. Such unevenness was in part the precipitation of variable concentrations of territorial power and accumulated capital. But these variations in themselves were deeply intertwined with environmental transformations. From the capacity to launch and maintain effective merchant fleets, to the concentration of mobile capital in cities such as Lisbon and Antwerp, the production of nature and the accumulation of capital constituted a singular (if uneven) historical-geographical movement.

My goal in this chapter is twofold. First, I consider the broader conceptual and historical-geographical issues that attend to the environmental history of sugar. In the second half of this chapter, I begin the world-historical narrative of the modern sugar frontier, through an account of the rise and demise of Madeira, the European world-economy's leading sugar producer in the later fifteenth and early sixteenth centuries.

Madeira & Modernity: Small Island, Large Footprint

Madeira is a small island with a large place in the origins of the modern world. Lying some 560 kilometers west of north Africa, Madeira was home to the modern world's first cash crop boom, a sugar revolution. Among environmental historians, Madeira's claim to fame rests on the island's deforestation (Perlin, 1989; Williams, 2003). The Portuguese name for the island – "isola de Madera" – translates literally as "island of timber" (Cadamosto, 1455 [1937]: 8). When the first settlers arrived in the 1420s, the Venetian traveler Alvise da Ca' da Mosto (Cadamosto) reports, they found "there was not a foot of ground that was not entirely covered with great trees" (Cadamosto, 1455: 9). By the 1560s, when the great poet-adventurer Luis de Camões visited the island, he remarked

was so high at the end of the sixteenth century that it was able to generate enough capital to finance a doubling of its capacity every two years... At the close of the sixteenth century,... production costs, including the cost of purchasing slaves, amounted to only one-fifth of income from sugar slaves" (Blaut, 1993: 191-192).

that Madeira, once famed for its sylvan bounty, had long since become an island of timber in name only (Camões, 1571 [1996]: 296).[298]

What happened between the 1420s and the 1560s? What was behind such a rapid transformation of the island's ecology? And what does it tell us about the environmental history of the modern world, of ecological imperialism, and of the political ecology of capital accumulation? These are the questions this essay shall take up.

When one encounters the history of Madeira, among the first things one learns is the island's ecological origin myth. The first settlers, confronting an impossibly dense sylvan landscape, set fire to the forest. Cadamosto's is only the most frequently-cited account. "So great was the first conflagration," he tells us, that the first settlers were forced "to flee its fury and take refuge in the sea, where they remained, up to their necks in water… for two days and two nights. By this means they razed the great part of this forest, and cleared the ground for cultivation" (Cadamosto 1455: 9). The fire "took such possession, that it burnt seven years continually, and was seen far off in Smoak and Sparks like *Mount Aetna;* so that afterwards the Island being plentiful of Grain, the greatest want the Inhabitants suffered was of Wood, there having been nothing else in it before" (Faria e Sousa, 1695: 4-5).

There was, in other words, a baptismal fire. Like all baptisms, its symbolic power rested in the cleansing of sin, washing away the human hand in the destruction of the island's forests. The fire had escaped human control, and prepared the island, first for the cultivation of cereals, then sugar, then wine. The enduring social power of this origin tale rested on its explanation of the rapid deforestation that did indeed occur during the first century of settlement, and its explanation of the timber scarcity that beset the island for centuries to come. It was an explanation that enjoyed significant traction – especially amongst English travelers – not least because it located the causes of environmental change in an accident of colonization rather than its systematic (and systemic?) consequence. Thus Samuel Purchas in the 1620s writes that "[i]n the yeere 1420 began that Plantation [Madeira's settlement], and the thicke Trees being by *Consaluo* set on fire, continued burning seven yeeres: *which destruction of Wood hath caused since as great want*" (1625: 6, emphasis added). More than two centuries later, J.A. Mason took the same view, noting that "the colony sustained much inconvenience from the want of timber" as a result (1850: 156). Madeira's deforestation was, in other words, registered not only in the physical landscape; it was inscribed as well in the collective memory of how this landscape was shaped.

This origin myth speaks to two salient facts. First, Madeira was indeed deforested rather quickly. Madeira's sugarmills pushed back the forest at unprecedented speed after 1450. By 1510 some 200 square kilometers of forest, more than one-quarter of the island and over half its accessible forest, had been cleared. Our second fact is implied by the first. Once the island's sugar complex had collapsed definitively in the 1520s, Madeira

[298] "We passed the great Island of Madeira,
Called such for its many stands of trees,
[the site] that we first peopled,
[now] more famous for its name than for its glory" (Camões, 1571: 296).

Even earlier, by the 1530s, the timber situation on Madeira was such that João de Barros, in the first volume of *Decadas da Asia*, observed timber scarcity on the island more than two decades before Camões penned his wry comment on Madeira's deforestation (cited in Prestage, 1933: 39).

did experience "great want" when it came to timber. It was no accident that even timber for the casks of the Madeira's famed wine was shipped from New England in later centuries (Duncan, 1972: 124, 153-155; Lyall, 1827: 361).

Nor was it accidental that such want followed on the heels of modernity's first sugar revolution. Sugar was the original cash crop of European expansion. It was perhaps the definitive "mass commodity" of the European world-economy in its long sixteenth century (1450-1640). Sugar was, we know quite well by now, wrapped up in the making of early capitalism, pivotal in the formation of the slave trade, precociously industrial in its agro-ecological organization, important as a source of investment capital for the Industrial Revolution, dynamic in its interweaving of production and consumption relations in everyday life (Mintz, 1985; Blackburn, 1997; Galloway, 1989; Schwartz, 2004; Sheridan, 1974). But just what, pray tell, does the history of sugar tell us about environmental history? And what can the environmental history of the sugar frontier tell us about the rise of capitalism, and possibly, about long-run patterns of environmental change in the modern world?

What, indeed? In this essay, I shall argue that the origins of today's environmental crisis can be found in the origins of the modern world, and that the origins of the modern world owed much to the the political ecology of the sugar commodity frontier from the Mediterranean to the Atlantic in the fifteenth century. To utter the word "commodity" is often to think of market and machine, surely amongst the powerful legacies of a nineteenth-century social science shaped the myths and realities of industrialism. From the standpoint of the rise of capitalism, however, to speak of sugar as mass commodity is to highlight its production of nature, its capacity to extract as much as possible, as quickly as possible, from local environments. And then, to move on. To say that sugar was a mass commodity is to say, in other words, that sugar was also a commodity *frontier*, that capitalism developed *through* the ecological crises that attended every sugar complex, *not in spite of them*.

If the conquest of the Atlantic was destined to be a grand affair, it began, as all such conquests must, with a few modest steps. When the Portuguese occupied Madeira, a small island 740 kilometers square, in the 1420s, there was little intimation of what was to come. First timber, then grain, would flow from this Atlantic outpost towards a metropolitan Portugal desperately short of both. It was an essentially medieval relation, perhaps not so different from Rome's tributary exactions a thousand years earlier. This would change by the 1450s. As Europe emerged from its late medieval catastrophes, in equal measure social and ecological (Moore, 2003a), commodity production, long-distance trade, technological innovation, and geographical expansion revived, all in ways that looked increasingly different from medieval antecedents.

On the island of Madeira was launched modernity's first sugar revolution. Exporting practically nothing in 1452, Madeira emerged as Europe's leading producer by the 1490s, displacing Sicily and above all Cyprus. Developing within the protective carapace of Portugal's "monarchical capitalism" (Godinho), Madeira's sugar boom was cosmopolitan from its inception: Genoese and Flemish capitalists sustained the commerce (and soon, production) of sugar, Portuguese settlers planted cane and drew timber from the hills, Canarian, later African, slaves carved irrigation channels from the mountainsides, then carried out the grueling labor of planting and cutting the cane.

This first sugar revolution was an audacious act of ecological transformation. Madeira's sylvan landscape quickly gave way to savannas, its ashes feeding the soil, its trees fueling the great boilers that turned cane juice into crystal sugar. Such conquest was, in successive turns, self-sustaining and self-defeating, the source of the island's boom, and in time, the pivot of its collapse. Nearly 10,000 hectares were planted in sugar at the dawn of the sixteenth century, and for a few years, more than 500 hectares of forest were picked clean to feed the sugarmills, *every year*.

Medieval sugar producers, it is true, had taken a toll on the forests (Lombard, 1959), but it was never like this. In medieval Europe, deforestation was measured in centuries; after 1450, in decades. From the Saxon Erzgebirge with its silver and copper mines, to the timber districts of Stavanger, to the cereal zones on the banks of the Vistula, early modern capitalism practiced serialized deforestation (Williams, 2003) – half-century booms in which production surged and the forest retreated were the norm, from which issued the inevitable crash. Madeira's sugar revolution – along with central Europe's metallurgical boom (Moore, 2007b) – would establish this pattern.

Booming by the 1470s (nurturing, incidentally, a young Cristobal Colon), Madeira's sugar economy had collapsed by the 1520s. In 1472, the island exported 280 tons, peaking at nearly 2,500 tons in 1506. By 1530, output had fallen nearly 90 percent, back to its 1472 output. Madeira was not, in the main, outcompeted. Although its decline may have been reinforced by the subsequent emergence of new competitors, Madeira's sugar complex had already collapsed. Nor was this collapse the expression of a glutted market. Rather, it appears the Madeira's sugar complex collapsed under the weight of its socio-ecological contradictions, above all the exhaustion of the forests from which flowed the extraordinary fuel supplies demanded by the mills. New production centers would soon come online, São Tomé by the 1540s, Pernambuco by the 1570s, Bahia in the 1620s, Barbados by the 1670s, and thence Jamaica, St. Domingue, and Cuba over the course of the eighteenth century (see Table I). While these successive movements in the conquest of nature were not, in any narrow sense, ecologically-driven, neither were they socially-driven in any narrow sense. The movements of political economy were so tightly interwoven with ecological transformations that it is impossible to identify a facet of imperial power, or capital accumulation, independent from socialized nature. Ecological contradictions were profoundly implicated in each of these great movements of the sugar frontier.

Table I, The Sugar Commodity Frontier, 1450-1800

	Large-scale exports begin	World primacy
Cyprus	c. 1300	1350-1470
Madeira	c. 1440s	1480-1520
São Tomé	c. 1500	1540-1570
Pernambuco	c. 1550s	1570-1620
Bahia	c. 1550s	1620-1670
Barbados	c. 1640s	1670-1700
Jamaica	c. 1660s	1700-1730
St. Domingue	c.1700	1730-1790
Cuba	c. 1750s	1790s-1850s

Sources: Dunn, 1972; Maddison, 2001; Mauro, 1983; Schwartz, 1985; Pereira, 1969d; Fraginals, 1976; Tomich, 1990.

Madeira has received special attention from two groups of historians, those concerned the rise of the modern plantation system, and those concerned with modern environmental change. For the first group, the extension of sugar production from the Mediterranean to the Atlantic in the fifteenth century – to Madeira above all, but also to the Canaries – marked a decisive break. A break *from* what, and *to* what, remains unclear. It is clear that modern and medieval forms of social organization and commerce coexisted; some emphasize the continuities with the medieval past (e.g. Verlinden, 1970; Curtin, 1990); others emphasize Madeira's ruptures with that past (e.g. Greenfield, 1977, 1979). Still others view Madeira's sugar frontier as a quantitative development in a precociously modern sugar capitalism, dating back to fourteenth century (Solow, 1987).

For environmental historians, Madeira marks one of the earliest, and clearest, ruptures with the medieval past. The conquest of the New World, as Perlin opines in *A Forest Journey*, began with the deforestation of Madeira (1989). For Grove (1995, 2002), Madeira was the first of many island environments upon which the rapidity of modern environmental change could be observed, first-hand. When Ponting wishes to tell the environmental history of European colonialism, he begins with Madeira (1991). So does Williams in his sophisticated account of the new patterns of forest exploitation, within and outside Europe, that accompanied the rise of capitalism (2003).

So we have, on the one hand, a perspective on the origins of the plantation complex, with little concern for its ecological consequences. And on the other hand, we have a perspective on the ecological consequences of European colonialism and the sugar frontier, but with little analysis of the relations of power and production inscribed in the latter. Is there not an opportunity here, to see the rise of the plantation complex – and indeed the rise of capitalism – as an ecological no less than social project? Could it be that European expansion was neither narrowly social, as in most accounts, nor narrowly ecological, as in Crosby's famous account (1986), but driven forward by a combination of the two? That the rise of capitalism can be viewed as an epochal reworking not only of "world-economy" but "world-*ecology*"?

How then might we rework Madeira's sugar cycle as constitutive – and not simply derivative – of the rise of capitalism? The approach on offer views the political ecology of the island's successive cash crops – timber and cereals, then sugar and wine – as irreducibly multilayered. These commodity regimes were, to be sure, instanciations of the the political ecology of Portuguese empire, and an emergent capitalism. And yet, to emphasize the many scales of modern environmental history is a far cry from writing top-down history. Madeira's sugar revolution was no derivative process. For the social and environmental transformations of Madeira, in turn, shaped far more than one island's history. This remaking of earth and society also shaped, often spectacularly so, the conditions of imperial power and capital accumulation. It was an ongoing movement. Madeira's sugar revolution may have been a one-time affair, but it was not merely the product of one-time conquest; it was made possible by, and then sustained, an empire and a world-economy for whom conquest and expansion was not simply a way of life, but an existential condition.

Portugal, Madeira, & Sugar: The Origins of Ecological Imperialism

Ecological imperialism remains more slogan than concept in environmental history. For Crosby, it signifies the biological expansion of Eurasian flora and fauna (1985). Imperialism in this sense references the biological eviction of extra-European species – an essentially Darwinian process of adaptation and competition (Darwin, 1964: 60-79 and *passim*). Others have invoked the concept to capture the plunder of ecological wealth and the devastation that ensues (Foster and Clark, 2003). Both perspectives illuminate crucial moments of modern environmental history. Neither, however, regards commodity production as decisive to the task of explaining environmental change. Ecological imperialism in the modern world took shape out of processes signified by all three renderings of ecological imperialism – as biological expansion, as plunder, as commodity production. These three movements can be seen in the conquest, and subsequent commodification, of Madeira.

Over a decade before Portuguese settlers arrived on an uninhabited Madeira in the 1420s, they put ashore cows, pigs, and sheep – a strategy of ecological imperialism (in Crosby's sense) that would be repeated across the great arc of sugar's Atlantic archipelago. Madeira's ecology was consequently transformed even before human arrival. This was not always to the settlers' advantage. Nearby Porto Santo – which along with Madeira and the Desertas constitutes the Madeira island group – had been the scene of an initial onslaught of ecological imperialism a century prior.[299] So problematic were the ecological consequences of this pre-Columbian exchange that Madeira emerged as a much more attractive candidate for settler colonialism. Amongst the Eurasian animals

[299] Crosby's (1985) account – probably drawing on Azurara's chronicle (1453, I-II) – suggests that the rabbits' depredations occurred almost overnight, in the matter of a year or so. Goodfriend and his colleagues (1994) argue that this timeframe is implausibly compressed, suggesting that European travelers blown off-course from the Atlantic seaboard most likely set these animals ashore a century previous.

deposited on Porto Santo were rabbits. The latter's renowned fertility and appetite for vegetation set the stage for severe wind and rain erosion by the 1430s – "to such an extent that agriculture on the island suffered seriously" (Goodfriend, Cameron, and Cook, 1994: 311). Shades of nineteenth century Australia, to be sure (Ponting, 1991: 171)! The big difference of course is that Australia is gigantic, and Porto Santo was not. Serious problems in the former were fatal flaws in the latter. "In a very short time [these rabbits] multiplied so much as to overspread the land, so that our men could sow nothing that was not destroyed by them… [T]he multitude of rabbits [ensured that]… no tillage is possible there" (Azurara, 1453, II: 245, 247).[300] Here was among the first of modern colonialism's many "sharp ecological lessons" (Masefield, 1967: 280; also Johnson, 1987: 3). For the moment, school was out on Madeira.

The island's heavy forest cover protected the island from a similar fate. Even today, in the mountains that transect the island east to west, there survive between 15,000 and 22,000 hectares of the original laurisilva forest. The forest remains so dense that it is "almost impenetrable," except for the irrigation canals know as *levadas*, and a few paths no more than 1-2 meters wide (UNESCO, 2000: 93, 96 [quotation]; Anonymous, 1999).

How much difference a century would make. By the time of Camões' visit in the 1560s, the once-bountiful forests below 300 meters had been cleared. Madeira had, in the intervening century, moved from sugar to wine. It was a shift from a fuel-maximizing, to a fuel-minimizing, cash crop – not, as we shall see, by accident.[301]

The rise of sugar and the fate of the forest were closely connected at multiple turns. There were three basic requirements for sugar production in this era. There had to be labor power to cultivate and then process the cane. There had to be fuel for the boilers that cooked the cane juice. And there had to be plentiful land to ensure soil fertility, and to ensure a profitable scale efficiency, since cane milling and initial processing required heavy capital outlays.

The clearance of the land came first. Between the 1430s and the 1450s, Madeira's economy pivoted on cereals and timber. Indeed the two were of a piece. Timbering cleared the forest to make room for cereals, and peasant cultivators found by-employment in the timber trade. Indeed, here as in so many cases, the timber frontier arrived first. São Tomé and Brazil would also begin as timber colonies (Dean, 1995; Lebigre, 2003).

Which is not to say that Madeira's forests were cleared solely through rational extraction. This would have taken much too long. Hungry Portugal demanded cereals (Braudel, 1972: 196-197; Malowist, 1964; Serrão, 1954). The sooner the better. From the earliest phases of settlement in the 1430s, the forests were set ablaze to clear land for agriculture. It was not uncommon for fires to defy human intention, and burn wildly out of control. The fires, wasteful of nature, were a labor-minimizing way to create savannahs quickly. This surely transpired to some degree. Settlers were shipping wheat to Lisbon by the 1430s, and more than half the harvest was exported by mid-century (Serrão, 1954; Moran, 1982: 64).

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300 Crosby (1986: 75) attributes Azurara's commentary on the release of rabbits on Porto Santo to Bartholomeu Perestrello, the island's first captain donatory. (And incidentally also Christopher Columbus' future father-in-law.) While Azurara does mention Perestrello, he does not quote him directly. At least in the English translation.

301 Although with a somewhat different sequence of crops, Genoa (from which sprang the capital that powered Madeira's sugar revolution) had done much the same in its hinterland during the fifteenth century in response to serious deforestation (Lopez, 1964: 454).

However wasteful, burning facilitated cash crop agriculture in yet another way. The ash from the burned forest was worked into the soil and provided an important, albeit ephemeral, source of fertility. Once these nutrients were absorbed, yields declined, and there was renewed pressure to carve out fresh land from the forest. (Even in the absence of pressures to extend cultivation.) Cadamosto in 1455 observed that cereal agriculture, which "at first [in the 1430s] yielded a return of sixty and seventy for one,… at the moment this has declined to thirty or forty for one, *because the land is being daily exhausted*" (1455: 9, emphasis added; also Astley, 1745: 560).

Burned forest provided one source of surplus fertility. The introduction of new plants to the island provided another. Wheat was particularly significant. What is often missed in the history of European expansion and its varied projections of ecological imperialism is the tremendous windfall enjoyed by the cultivators of these new crops. The "windfall profits" of Europe's overseas expansion was far from a simple matter of plunder; a certain volume of these windfalls derived from the Improvement of the earth (Webb, 1964; Drayton, 2001). This was the phenomenon of the "yield honeymoon" (Dark and Gent, 2001). The introduction of exogenous crop varieties – above and beyond relatively untapped soil – is often accompanied by a "honeymoon" period of high yields. Endogenous pests and weeds require time to adapt to the invaders. If the human agents behind this ecological imperialism are capable of clearing forest rapidly, a new wrinkle emerges. As Dark and Gent explain:

> A clearing in a forest would have had few weeds at first, as potential seed sources would have been few while the landscape remained predominantly wooded. The potential sources of fungal pathogens will also have been limited when open areas of grassy vegetation were few, and any localized outbreaks of disease will be unlikely to have spread between clearings surrounded by forest (2001: 73).

This is one way to start making sense of the relation between Crosby's ecological imperialism and the expansionary logic of the modern world-system. To put it simply, the recurrent yield bursts that issued from the marriage of monoculture and exogenous crops implied – indeed necessitated – recurrent yield busts. Recurrent yield honeymoons, under conditions of export monoculture (highly favorable to pests, weed, and diseases), accelerated nutrient uptake from the soil and accelerated the evolution of weeds and pests. Weeds were an especially big problem. Weeding sucked up huge amounts of labor once the honeymoon was over. They evolved quickly and proliferated even more rapidly. A Brazilian source from 1753 identifies weeding as labor-intensive as planting, and an activity that required as much labor as the cutting and carting of cane *combined* (Schwartz, 1985: 142; also Watts, 1985; Peng, 1984; for Madeira, see Mauro, 1983: 206).[302] Indeed, weeds were one of the chief vectors of the soil exhaustion so frequently associated with sugarcane. To the extent that cultivators are unwilling or unable to withdraw from the market – and indebtedness enforced by the state would play an

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[302] In a footnote, Schwartz comments that his source overestimate the labor requirements of the harvest (cutting and carting) (1985: 528, n. 61), which would mean that the costs of weeding were quite possible even greater in relative terms!

enduring role in relative gravity of the market – there would be mounting pressure to find new land upon which to enjoyed a second (and third and fourth…) honeymoon.[303]

Given the relatively low profitability of cereal agriculture under colonial conditions, the tenuous basis of soil fertility constituted a decisive point of weakness for Madeira's cereal regime, which would be displaced by sugar, beginning in the 1450s. "This isle is very scarce of oile and of corne," Africanus would report in the 1520s (1600: 56). The very rapidity of this transition from grain to sugar cannot, however, be accounted for solely in terms of the island's relation to market forces; it must be viewed in terms of the broader ensemble of Portuguese imperialism. Sugar, it is true, was more profitable than wheat by the time of the mid-fifteenth century expansion; but its profitability *for Madeira* and within the Portuguese Empire was conditioned on a broader geographical reconfiguration. Madeira's cereal cultivation was not simply displaced by an abstract Smithian logic. It was displaced *because* it could be relocated to the Azores, which became "the granary of Lisbon and Madeira" (Mauro, 1983: 206; see esp. Serrão, 1954).[304] The transition to sugar depended also on cheap labor, drawn initially from the Canary Islands and thence West Africa (Vieira, 1996; Mercer, 1980). All of which is to say that the restructuring of Madeira's political ecology was dialectically bound to renewed geographical expansion, and therefore to broader shifts in the division of labor. This was a major factor, along with soil conditions and market demand, driving the transition from grain to sugar.

Isola de Madeira: From Timber Colony to Sugar Frontier

The forests were not merely burned away. There were also exploited directly for profit. Timber was an important cash crop in its own right. Madeira's forests supplied the raw materials for construction, furniture, cases and barrels for the sugar trade, and shipbuilding, among other uses. So long as accessible forests remained abundant on Madeira, which they did through much of the fifteenth century, cheap timber drove down the costs of production on the island, and in Portugal's leading cities. Cheap construction timber meant lower costs for building warehouses, docks, and all manner of basic infrastructure in an imperial economy that drew its lifeblood from seaborne trade. Lower costs in turn enhanced Madeira's competitive position in the world sugar market, and Portugal's competitive position in the struggle for commercial hegemony in the Indian Ocean.

This is little question that Madeira's timber trade was lucrative. By the 1450s Cadamosto observed "sawmills continually working timber and planks of all kinds for the supply of all of Portugal and elsewhere" (1455: 9). The mere existence of saw*mills* – presumably water-powered – is in itself suggestive. Sawmills were rare in fifteenth century Europe (Carroll, 1973: 62). Even in England, during the middle of the *nineteenth* century, just half the timber in the shipbuilding sector was milled rather than sawn by hand (Kirby and Hinkkanen, 2000). Sawmills were found in the fifteenth century world-

[303] Of course, there were other sources of surplus fertility, although nutrient imports such as guano and oilseed cakes would not be widely practiced until the nineteenth century (F.M.L. Thompson, 1968; Clark, 2004).

[304] This led, we might add, to the deforestation of several of the Azores in the seventeenth century (Tutin, 1953: 55).

economy only where market demand and capital flows *both* were strong. Thus the other major sawmilling region of the time was that other hotbed of capitalist development – the metallurgical districts of central Europe (Glacken, 1967: 340; Carroll, 1973: 62; Nef, 1964).

Were these mills making timber for Lisbon and Oporto, Portugal two major shipbuilding centers? Perlin thinks so:

> The influx of great amounts of wood could not have come at a better moment for Portugal…. The tiny ships that comprised its merchant fleets did well on relatively short trips…, but they were not designed for long ocean journeys… [The] larger ship[s], in contrast, could head out onto the ocean and catch the prevailing winds. The record size and quantity of timber arriving at Portuguese dockyards from Madeira gave shipwrights, according to the chronicler Jeronimo Dias Leite, enough material to fashion a fleet of larger ships (1989: 252-253; see also Castro, 2002).

Barker, a nautical archeologist, is however sceptical. Milled planks, he contends, "are of limited use for ship-timber" (2001: 216; also Barros, 2006). This is of course true for the specific timber requirements of hulls and masts. But sawn timber – presumably for planking and other interior construction – was often used in shipbuilding through the early modern era. Norway's great timber districts were filled with sawmills, as early as the dawn of the sixteenth century. Financed by the Dutch, this milled timber was bound for the great shipbuilding centers of United Provinces (Ozveren, 2000).

If there is some debate as to the precise distribution of Madeira's timber, we know that Portugal's timber resources were chronically deficient. While the golden age of medieval expansion had been, in Bloch's apt description, an "age of clearing" (1966; also Darby, 1956), the demographic collapse of the long fourteenth century meant that most of Europe (beyond the Mediterranean littoral) enjoyed a certain sylvan abundance by the 1450s. Not so for Portugal. The weakness of shipbuilding timber was sufficiently obvious that the Crown took an active interest in forest management from the first moments of the early modern expansion, in 1450 establishing an office to manage the royal forests of Leiria (Sardinha and Richards, 1998: 293).[305]

Nearly a century and half earlier, the Crown had ordered widespread pine tree planting in these same forests (Mendes, 2002: 11). What changed between the early fourteenth century and the mid-fifteenth centuries was the articulation of forest management with Portugal's global ambitions.[306] Already by this later date foreign timber had become "indispensable" to Portugal, imported from northwestern Europe, and

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[305] Portugal in this respect shares an important connection with Venice, both exceptionally "modern" states for the fifteenth century – and both, not accidentally part of Braudel's "global Atlantic" then in the making (1972). Venice had begun forest legislation in 1350 but presumably the demographic contraction rendered fuelwood and timber supplies more easily obtained for a century; its renewed territorial and legislative attention to timber and fuel supplies dates from a cluster of initiatives between 1442 and 1476 (Appuhn, 2000, 2002). Both states sought to protect forest spaces vital for the reproduction of the "national" society.

[306] State initiatives to protect forests during the medieval era (Birrell, 1987) had *not* been articulated with overseas expansion and the tendency towards sequential overexploitation. This has something to do with a transition from parcellized sovereignty to modern forms of the state-nature relation (Scott, 1998), including but not limited to the absolutist variant.

shipped in growing volumes from Madeira (Malowist, 1964; Serrão, 1954; Barker, 2001; Perlin, 1989). Even earlier, Danzig merchantmen were to found unloading shipbuilding timber on Lisbon's docks during the "first decades of the *fifteenth* century" (Tossavainen, 1994: 27).

Devy-Vareta is prepared to speak of an "acute crisis" of Portugal's forest regime from the very beginning of Portuguese expansion. It was, in her words, a crisis marked by "the imbalance between supply and national demand," such that forest regeneration became "increasingly difficult" (1985: 67). Her analysis therefore points to a dialectical connection between the external strategies of resource acquisition, by conquest or trade, and the internal measures of forest preservation. Such forest regulation – really, an initiative to enclose the forest from the unregulated incursions of peasants and manufacturers (smelters and glassworks especially) (Devy-Vareta, 1986) – was invariably an indicator of scarcity, although to call it deforestation would be going too far.

In themselves, efforts to limit peasant access to the forest commons were not new (Birrell, 1987). Globalizing efforts to secure new supplies through trade or colonial expansion were. As we've noted, the demographic setback of the fourteenth century ought to have created relatively greater ecological "slack" than it did. Relative scarcity translated to high demand, and therefore high prices, for construction timber in Oporto and Lisbon, booming in the opening salvos of mid-century expansion, and key nodes in the African, and later Indian Ocean, trades. The absence of such ecological slack, and enormity of the demand, accounts in part for what Pereira calls the "urgent imperialism" of Portuguese expansion between 1450 and 1525, one characterized the rapid "activation of the resources of the realm and the islands" and their ensuing "paradoxical exhaustion" (Pereira, 2006: 10; also Devy-Vareta, 1986).[307]

What is certain, regardless of the exact strategic importance of imported shipbuilding timber, is that Madeira's timber alleviated *aggregate* pressure on Portugal's relatively sparse forests at a time when the opportunities (and imperatives) for colonial expansion were greatest. Such was the volume of timber exports from Madeira, that the chronicler Azurara[308] reported in 1446 on its connection with a new architectural style (1453 [1898], II: 300).[309] There began to appear in Lisbon "lofty houses towering to the sky, which have been and are being built with wood from" Madeira (Azurara, 1453, I: 9). So plentiful was the timber, especially its prized cedars and red yews – trees that were subsequently wiped off the face of the island (Mason, 1850). Cadamosto reports new styles of furniture manufactured from Madeiran wood, especially its prized cedars and red yews (1455: 9).

We will return to the forests momentarily. It is clear that Portugal, on its own, lacked sufficient timber for its overseas ambitions. It is equally clear that Madeira was the first major step forward in the Empire's ecological fix strategy to resolve the sylvan

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307 A growing volume of timber from Latvia and Norway (via Flanders) "becomes very important" in the sixteenth century (Barros, 2006).

308 This would be Gomes Eannes de Azurara (1410-1474), the Crown's chief archivist from 1454.

309 The editors of the first English translation remark that "the wood… transported to Portugal from the islands… was in such quantity as to cause a change in the system of construction of houses in towns, by increasing the number of storeys, and raising the height of the houses, thus bring in a new style of building instead of the Roman and Arabic systems then probably followed. This probability acquires more weight in view of the system of lighting at Lisbon ordered by King Ferdinand, as appears from a document in the Archives of the Municipality of Lisbon" (1453 [1898], II: 300).

inadequacies of the metropolis. This would be a long march of many steps – it is no accident that Madeira and Brazil, two of the Empire's first colonies, were named after timber. The colonization of Madeira, from this standpoint, surely killed no less than two birds with one step. The establishment of the island as a cereal and timber colony went hand-in-hand. Indeed, these were complementary activities.[310]

This cereal-timber frontier set the stage for the sugar revolution of the 1450s in two major respects. First, in establishing a modest demographic basis for the island – there were, Cadamosto reports, 800 residents in the 1450s (1455) – the cereal-timber frontier developed a smallholder society capable of growing sugar, although not without foreign capital, as we shall. While it is sometime claimed that Madeira was the site of the modern plantation revolution (e.g. Greenfield, 1977), large-scale cultivation would never dominate the island. Madeira was an indispensable halfway house on the road to the capitalist plantation. No more, no less.

Second, the cereal-timber frontier coordinated the construction of the island's irrigation infrastructure. Sugar is a thirsty crop, and although the southern part of the island enjoys a mildly warm and humid climate, it would be a stretch to call it tropical. (Average temperatures in July are scarcely about 70 degrees Fahrenheit.) Madeira is not São Tomé or northeastern Brazil, and in contrast to these later frontiers, a sugar revolution would require a significant hydraulic infrastructure. Madeira's mountainous topography was such that freshwater sufficient for large-scale agriculture could be wrested from the island only with great effort. The first irrigation canals, called *levadas*, were built in the 1430s and 1440s. From the southern half of the island, the topography rises such that one reaches an elevation of nearly 900 meters in just five kilometers, and another 1800 meters over the next 10 kilometers (see map in Greenfield, 1977: 538). It was this "unlikely relief of the island," Lamas points out, that made the *levadas* a "gigantic undertaking" (1956: 104 quoted in Greenfield, 1977: 541). Today the *levadas* remain the island's most distinctive geographical feature, extending 2100 kilometers on an island that runs just 50 kilometers east-to-west and covers 741 square kilometers (Reynolds, 1997).

It is possible that burning and timbering reduced forest cover enough to alter the island's hydrology (Grove, 1995: 29).[311] In the fifteenth century, the Socorridos River was deep enough to float timber to the shoreline. By the nineteenth century, it was but a "mere stream" (Mason, 1850: 162).

More certain is that rising agricultural output and growing population – augmented by Portuguese voyages to the Canaries and to West Africa – required more and more water.

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[310] In mid-sixteenth century Brazil, the *engenhos* during slack periods (of which there were many more in cereal than in sugar cultivation) would set the slaves to work collecting brazilwood (Mauro, 1983).

[311] In this and many other respects Madeira established the outlines of a world-historical and world-ecological pattern: "The profit motives and mechanisms of these trading companies, especially of the East India Companies of Portugal, the Netherlands, Britain, and France, resulted in intensive cash-crop plantation activities on oceanic islands and the clearing of forests for agriculture and ship construction.

This process had already begun with Portuguese and Spanish settlement and plantation agriculture on the Azores, Canaries, and Madeira Islands during the fifteenth century, but the sheer scale of its impact was massively expanded as the European trading companies developed their routes to India, the East Indies, and the Caribbean. As early as the 1670s [and even earlier in the Atlantic islands], the catastrophic consequences of their capital- and labor-intensive activities became clear as the early island colonies experienced drought due to the drying up of perennial streams, soil erosion, dust storms, and the disappearance of animal and plant species" (Grove, 2002: 51).

The ensuing construction of the *levadas* was as global as it was transformative. Technical expertise and financing were supplied by the Genoese, Portugal provided settlers, and slaves – at first Canarian and then African – performed most of the labor. The Canarians had been dragooned by successive Portuguese invasions – there were four major expeditions alongside "numerous trips" to the Canaries between 1424 and 1446 (Vieira, 1996; Mercer, 1980: 225-227).[312] Set to work building the *levadas*, the slaves were lowered and then suspended by ropes "over the mountain precipices" to carve the water-courses "out of the solid face of the rock" (Ramsey, 1920). This was dangerous work. Building *levadas* consumed human nature at a ferocious pace. "The water had to be diverted, almost always at distant points of difficult access. The task therefore *not only was exhausting but dangerous, taking many lives and was not completed for many years*" (Lamas, 1956: 104, emphasis added, quoted in Greenfield, 1977: 541). Hundreds "perished by crashing onto the rocks below" (Ramsay, 1920; also Crosby, 1986: 78; Watson, 1983: 103).

Madeira's Rise and Fall, Part I: Sugar, Capitalism, & World-Economy, 1452-1530

Madeira's sugar revolution is usually dated from 1452, when Henry the Navigator gave his blessing to what is sometimes characterized as the island's first sugar mill. It was surely not the *first* mill. It was, very probably, the first wind-powered sugar mill, which would dramatically increase capacity, since we know that the island was producing 6,000 arrobas, or 84 tons, of sugar by 1454 (Pereira, 1969a: 82).[313] By the 1450s, modernity's first sugar revolution was in the offing. Sugar's ascent was wheat's decline. to sugar in the 1470s. "Farmers growing other crops were quickly bankrupted" (Taylor, 2005: 41). Between 1454 and 1472, sugar production increased by over 230 percent, to 280 tons; by 1506, it had expanded another 785 percent, to 2,480 tons (calculated from Schwartz, 1985; Pereira, 1969b: 454). By 1530, sugar output was back to the production levels of the 1470s, a 90 percent decline.

The decline after the 1506 peak was slow and steady for a time. But at some point in the next decade, the sugar complex's underlying contradictions compelled a more dramatic contraction of output. Even in the face of rising prices of Madeira's sugar, and no major competitors for the island's high-quality sugars, production continued its downward spiral. This is a puzzle indeed. The missing pieces, I suggest, can be found in the environmental history of Madeira's sugar complex, and the ways it fits into the broader movements of the sugar commodity frontier. While soil exhaustion stands as the most commonly-cited ecological problem of sugar (e.g. Mintz, 1959; Castro, 1966), the exhaustion of forest resources – reinforcing and amplifying the manifold socio-ecological pressures inscribed in the sugar frontier – is the most likely pivot of production *collapse*. In the absence of catastrophic erosion, capitalist agriculture has proven adept (until now)

[312] "From the middle of the fifteenth century, the references to Canarian slaves in Madeira as shepherds and mill workers are frequent" (Vieira, 1996).

[313] The Portuguese medieval arroba, in use until 1504, was 28 lbs. (Pereira, 1969a). Thereafter, it would be 34.34 lbs (Schwartz, 1985).

in managing soil fertility. The overexploitation of forest resources, however, in the early modern world posed much tougher challenges.

I shall pursue this line of reasoning in three steps. First, I offer an account of the rise of Madeira's sugar complex from the standpoint of the rise of capitalism, as world-economy and as "world-ecology" both. Second, extrapolating from production figures and other evidence, I propose a series of quantitative-geometric estimates for the extent of deforestation on Madeira. Finally, from this "historical geometry" of the sugar's frontier's advance into the forest, I build up a "historical geography" of sugar's crisis, putting the geometrical representations into dialogue with evidence on biogeographical change, labor inputs, soil exhaustion, and price history.

By turn of the sixteenth century, Madeira had displaced Cyprus from the commanding heights of the European sugar economy. The island's sugar would be found everywhere from Antwerp to Augsburg to Istanbul (Galloway, 1977: 190-191). Such was the enormity of this small island's revolution that it "cause[d] the distribution of sugar [to flow] more freely over the whole of European than had ever happened when the Mediterranean was the only supplier" (Deerr, 1949: 100).

Cyprus, which had produced 800 metric tons of sugar at its peak in 1450, produced less than half that in 1500. Madeira's production, meanwhile, soared to more than six times its Cypriot competitors (Maddison, 2001: 60-61; also Blackburn, 1997: 109). It was a changing of the guard, and not for the first time. Cyprus, home to the precocious agro-capitalism of Venetian merchant-planters a century earlier, could show, but not *lead*, the way (Solow, 1987: 714-715; Verlinden, 1970: 19-20).[314] For it would be the Genoese and not the Venetians who propelled the sugar frontier, moving it westward to the Algarve in southern Portugal, and thence into the Atlantic. By the 1490s, even Venice was drawing more sugar from Madeira than from its older suppliers in Sicily, Cyprus, and Egypt, losing in the process its lucrative trade with the English (Giustiniani, 1519: 110-111).

The rise of sugar inaugurated a revolutionary transformation of the island. Nevertheless, a key question remains. In what sense, or to what degree, was this a *capitalist* revolution? There are really two major ways to approach the question. The first is to sketch the connections from the standpoint of the emerging world division of labor. This is Wallerstein's approach (1974). Brenner calls this optic "ultra-Smithian" (1977), but it is by no means clear that viewing the world division of labor from the standpoint of world-economy is any more or less illuminating than viewing it from the standpoint of the production unit or region. It *is* certainly the case that the scalar vantage point – world-economy? point of production? – brings distinctive processes into view. Is there a way to weave the two scales together in a manner that moves beyond the banal invocation of a local-global dialectic? We shall turn, momentarily, to this task, to take to heart Brenner's argument for the centrality of social property relations as the pivot on which modern

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[314] Reporting on the sugar plantations of the fourteenth century Cornaro family, Venetian merchants-turned-Cypriot nobles, Solow contends: "[The Cornaros'] methods were fully capitalistic. The plantations were worked by emigrants from the Holy Land, Local serfs, and slaves of Arab and Syrian origin. Hydraulic mills were used to process the cane... Capital equipment, in the form of huge copper boilers, was imported from Italy. The Cornaros even refined their own sugar and exported loaves and powdered sugar. It is clear that large investments and a complex economic organization were required for the entire undertaking... The members of the Cornaro family were involved in an international agri-business. Their aim was to maximize profits by combining inputs of labor and capital from different places, processing output, and selling the product through a distant marketing network" (1987: 714-715).

economic development turns, and to weave this with Wallerstein's persuasive contention that the rise of capitalism was part and parcel of an epochal reshaping of "world ecology" (1974: 44) in the interests of Europe's leading accumulation centers.

Let me begin by stating my position simply. On Madeira in the "first" sixteenth century we find an island that was *becoming capitalist* even as it bore some resemblance to the social organisation of the medieval Mediterranean. I say becoming capitalist for three reasons. First, as we have seen, there was a secular trend towards rising commodity output. This was true not just in nominal terms, but also relative to the island, and to the Portuguese empire. Second, from the "first" to the "second" sixteenth century, there was no de-commodification, even as the sugar economy entered a protracted crisis in the 1520s. The production complex would quickly restructure around wine (Duncan, 1972: chapter three). As early as 1560, Nicols would report that Madeira, while producing some fine sugar, was "chiefly famous for its good wines" (1560: 557). Finally, the Madeiras were a crucial outpost in the construction of Portugal's global empire, one that had become "fully committed to commercial expansion" by the end of the fifteenth century (Greenfield, 1979: 116; also Malowist, 1964). Madeira reinforced the general movement towards systemwide commodification, and therefore may be properly regarded as constitutive of a broader turn towards capitalism.

Madeira may not have been home to productivity-maximizing capitalist farmers akin to those of sixteenth- and seventeenth-century England and the Low Countries. But then, Madeira was a colonial zone, and heroic yeomen rarely populated colonial zones. The colonies of the early modern world were, however, in great measure the creation of plantations, and the Atlantic islands were testing grounds for this gruesome apparatus of territorial domination and commodity production. The word plantation conjures images of the great planters of seventeenth century Brazil, or the cotton aristocracy of the antebellum American South. For this reason Galloway (1989), among others (Vieira, 2004), objects to its application to Madeira. The rightly argue that production was small-scale, when compared to later developments. But this is after all the point. The essential features of the model were in place: 1) the estate's dependence on financial and merchant capital, operating on a world-scale; 2) the slave mode of production; and 3) its tendency to mine the soil and exhaust other forms of ecological wealth, not least the laborers.

While Cypriot sugar production in the thirteenth and fourteenth centuries was organized juridically as demesne land, among other things allowing European seigneurs to levy corvées from the local peasantry (Greenfield, 1979: 92), the colonization of Madeira proceeded on a much different basis. The Portuguese Crown gave Madeira to Henry the Navigator as a colonial fief in 1433, this much is true. But if this was feudalism, it was an exceedingly unusual one. There was, for beginners, no parcellization of sovereignty. The Crown's courts retained the right to decide civil and higher criminal cases. The Crown retained its right to levy taxes (Verlinden, 1970: 207-208).

Perhaps most fundamental was the property system. The basic land grant unit on Madeira was the *sesmaria*, the size of which varied according to geographical conditions (Albuquerque and Vieira, 1988). "The law compelled landowners to cultivate their land under penalty of expropriation" (Verlinden, 1970: 219). Promulgated in 1375 on the eve of the proto-bourgeois, proto-absolutist Aviz Revolution (1385) (Vitale, 1968), the *sesmaria* was not so much a feudal or medieval institution as a specific institutional response to feudal crisis within the Portuguese social formation. The fourteenth century witnessed an unprecedented concentration of landholding within Portugal, especially in the hands of the religious Orders (Marques, 1972: 112-113; Anderson, 1974: 172; Castro, 1970: 135-138). The *sesmaria* was a mechanism through which the Crown could promote desperately needed cereal cultivation on lands that were either unused or, crucially, that had been converted to stockraising (Verlinden, 1970: 219). From this standpoint, the *sesmaria* appears as an assault waged by a precocious absolutist regime on parcellized sovereignty rather than a continuation of this system.

On Madeira, the *sesmarias* were given to settlers as land grants that could be held in perpetuity, "*provided that it was in cultivation within five years of receipt*. If cultivated, the land could be sold, given, and /or inherited as private property" (Greenfield, 1979: 99, emphasis added). The time frame was, in fact, originally a decade. In 1433, it was changed to five years, in the 1440s to three, then to even shorter periods as the century wore on (Vieira, 2004: 50-51; Verlinden, 1970: 214). These measures created the basis for a land market. Indeed, once cultivated for the specified period, "the lord could not prevent the colonists from selling their lands and settling elsewhere" (Verlinden, 1970: 209). Of special import was Henry the Navigator's surficially feudal, yet powerfully commercializing, role in establishing the island's first wind-powered sugar mill in 1452. Henry reached an agreement with his "escuidero" (squire) – a certain Diogo de Teyve – to build this mill, a relation through which the prince would receive one-third of the produce. This was no lord-vassal relation. It was, rather, a contractual one: "The prince [Henry] himself called the agreement a *contract*" (Verlinden, 1970: 216, emphasis added). Crucially, Teyve could be dispossessed if he failed:

> [S]ugar producers had to allow mills and presses to work at full output… If Teyve was successful he would enjoy a monopoly; if not, the Infante [Henry] could grant another contractor the right to construct a mill… This contract had no trace of feudal or demesnial form. It started a sort of partnership between the Infante and his squire for the production of sugar on Madeira… [This] was *the original deed of birth of sugar production on the island* (Verlinden, 1970: 217, emphasis added).

Henry may not have been a capitalist entrepreneur, but he was certainly a territorial one who drank deeply from the well of Portuguese "state capitalism." The insistence on maximizing production, coupled with a legal framework allowing land to be treated as a commodity and the Crown's increasingly accommodating attitude towards *resident* foreign merchants, explains something of Genoese capital's movement into production on the island during the 1480s. Genoese capital, and technical expertise from experience growing sugar in the Algarve,[315] had been present from the beginning (Fernandez-Armesto, 1987: 199). In 1455 the greatest sugar planter on the island was a Genovese. The last two decades of the century witnessed "at least six aristocratic Genoese families acquire extensive sugar plantations" on the island (Coles, 1957: 19; also Bovill, 1928: 22). By the early sixteenth century, fully two-thirds of the island's canefields were in the

[315] Although it was certainly not just the Genoese. Many of Portugal's migrants to Madeira came from the Algarve.

hands of "foreigners, especially Genoese and Florentines, or by New Christians" (Blackburn, 1997: 109).[316]

It was this confluence of global capital, the *sesmarias*, and the expanding sugar market that created "the basis for social differentiation among the first colonists and opened the door to the growth of large-scale properties" (Vieira, 2004: 51). We needn't overstate the case. But neither should we understate it. The Crown proclaimed in 1496 that neither land, nor slaves, nor equipment could be seized for debts (Vieira, 2004: 59). But then, by this point a transition from independent proprietors to tenant farming was well underway (Albuquerque and Vieira, 1998: 24). The diffusion of tenancy, foreshadowing Brazil's sugar regime, meant that dispossession of real property was not much of an issue; farmers (as tenants) could be ejected from the land without any dispossession of property. And in any event, as was the case with forest regulation – which always indicated forest scarcity rather than its opposite – such proclamations *against* were just as surely recognitions *of* dispossession. Land, slaves, and equipment *were* being seized for debts on Madeira in the 1490s. Otherwise, there would have been no call for Crown intervention.

The economic sociology of Madeiran sugar turned on a threefold division of labor: 1) merchant capital; 2) rich planters who owned *engenhos* (sugar mills); and 3) the majority of cultivators who owned land but not mills, and some who owned neither. (These latter would be called *lavradores da cana* in colonial Brazil.) These were, to some extent, overlapping and fluid categories.[317] Merchants owned mills. Successful cultivators became millowners. What is clear is that the vast majority were cultivators, increasingly tenants, who by the end of the fifteenth century owned just a few slaves. Over half owned just 1-2 slaves and just 10 percent of slaveowners held more than ten (Vieira, 2004: 59). In the captaincy of Funchal, the island's capital, there were 14 *engenhos* but 209 cultivators in 1494 (Vieira, 2004: 53). The cultivators were a chronically indebted class. That is to say, the cultivators were in a position where they had to sell to survive, risking in the process either dispossession, or the debt-driven surplus squeeze of labor (their own or their laborers) or of land:

> Here, *even more than in [sixteenth- and seventeenth-century] Brazil*, there were many proprietors without the financial resources to set up the basic industrial operation of a mill and thus remained dependent on the services of the [*engenhos*]… Direct sales, sometimes pledged before the harvest,

[316] Rau (1964) disagrees, maintaining that cultivation remained overwhelmingly Portuguese. It is possible that she has coded resident planters of Genoese, Flemish, and New Christian extraction as Portuguese.

[317] The categorical overlap can hardly be understated. "Merchant capital" must be comprehended as an accumulation strategy, one amongst many. Mercantile activities were primary at certain times and places, for certain clusters of business organizations, but the golden rule of capitalism nevertheless prevailed – follow the money, pursue the high-profit lines. Richard Pares' observation about the British West Indies in the seventeenth and eighteenth centuries is therefore scarcely less relevant to the earlier moments of the sugar commodity frontier: "It was characteristic of the fluidity of the economic relations in the sugar colonies at that time that a general merchant should be, at the same time or successively, a partner, a tenant and a landlord of sugar plantations" (1950: 41). In an important contribution that has yet to gain much traction, Alf Hornborg (1998) has put this argument in conceptual terms. In Hornborg's persuasive scheme of things, the conventional reckoning of stages of capitalist development – primitive accumulation, mercantile, industrial, and so forth – represents overlapping and mutually reinforcing accumulation strategies, rather than successive historical stages, over the *longue duree* of the modern world-system.

> were often used to pay existing debts… *[Here] was a system that tended to subordinate the producers* (Vieira, 2004: 53, 70, emphases added).

No wonder that Koebel refers to the island's class relations in the early sixteenth century as one in which "bitter strife became frequent and general between the two classes," the cultivators and the millowners (1909: 20). Even earlier there were signs of conflict. In 1472, Portuguese cultivators on Madeira protested against Genoese hegemony in the sugar trade, complaining that cane farms "had been destroyed, damaged and lost owing to the presence of the Genoese" (Rau, 1964: 8). By 1494, there is strong evidence of widening inequality within the classes directly engaged in production. In that year, as the sugar boom stratified property holding, the top 4.5 percent of landowners produced 25 percent of the island's sugar, where the bottom 75 percent produced just 30 percent (calculated from Galloway, 1989: 52).[318] Among the bottom 88 landholders (of 221), the average output was less than 1.5 tons (Galloway, 1989: 53). Undoubtedly aggravating the political situation was the presence of putatively "foreign" planters at the top of the hierarchy. The fifteen planters who made up 6.7 percent all producers in 1494 produced 20 percent of output (calculated from Albuquerque and Vieira, 1988: 25). The gulf widened still farther in the 1520s, as the sugar sector was gripped by crisis (Vieira, 1995).

Was there, then, a "reproduction squeeze," either simple or expanded, that led producers to overexploit the soil? It is clear that the sugar revolution quickly generated a mounting volume of ecological contradictions. At the very moment when the wheat regime definitively gave way to sugar, that is during the 1470s (Mauro, 1983: 206), conflicts escalated over water - and property-rights (Albuquerque and Vieira, 1988). Water and land became scarce in the face of the sugar invasion. Although the expansion of the *levadas* made water more available in absolute terms, demand outran supply.

The situation was much the same with land. During the 1470s "the policy of land concession [the *sesmarias*] ran into trouble… [and] the amount of arable land became more restricted" (Albuquerque and Vieira, 1988: 23). The proliferation of cane farms was so rapid that burning forest to create arable land was "recognised *as an ecological hazard and as a threat to the sugar economy*" (Albuquerque and Vieira, 1988: 23, emphasis added). There were escalating conflicts over the practice of burning, which often spread to neighboring cane fields (Vieira, 2004: 53-54). Between 1501 and 1508, the Crown ended the distribution of land through *sesmarias* specifically in response to the fuelwood demands of the sugar sector. The goal was to prevent, in Albuquerque and Vieira's words, "the *further* reduction of the forest area so necessary to sugar growing" (1988: 24, emphasis added).

Madeira's Rise and Fall, Part II: Sugar & the Conquest of the Forest

But why should it be so imperative to prevent the "further reduction of the forest area so necessary to sugar growing," precisely at the apex of the island's sugar boom? The short answer is that sugar is a fuel-intensive crop. To make one pound of sugar required

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[318] Albuquerque and Vieira provide modestly different figures: "The fifteen planters who made up 6.7 percent all producers in 1494 produced 20 percent of output (calculated from Albuquerque and Vieira, 1988: 25).

no less than 50 pounds of fuelwood. (And this, a conservative estimate.) Nearly 700 hectares of forest were sacrificed in 1506 alone to produce that year's bumper crop of 2480 tons. This was not forest exploitation along the lines of early modern coppicing, such as practiced (unevenly) in England. This was 700 hectares of forest *cut down.* In one year.

Because sugar monocultures tended to exhaust soil fertility, throughout the early modern era there was a strong frontier movement, not only across the Atlantic world, but also within the sugar zones themselves. As soils became exhausted, there was always some tendency to move towards greener pastures. It was not simply that new soils could replace worn-out fields, but that together with the fertility bonus offered from ashes, and the yield honeymoon we mentioned earlier, the call of the forest could not be ignored. Warren Dean, for instance, sees 1,000 square kilometers cleared for canefields in colonial Brazil (1995: 80). Agricultural clearing was always a secondary vector of deforestation, but an important one nevertheless. Madeira's challenge was comparatively great in this regard, because the potential arable was so circumscribed by the island's dramatic topography. To confound matters still further, Madeira's climate kept land productivity relatively low and the growing season relatively long, and this meant that considerably more land was required to produce the same volume of sugar – compared to São Tomé in 1550 or Brazil in 1600.

Madeira occupies 741 square kilometers, most of which prior to colonization, say 90 percent (about 670 square kilometers), was covered with dense laurisilva forests, along with cedars and red yew.[319] Much of this forest was inaccessible. The island's dramatically vertical topography meant that no less than one-quarter of this forest was inaccessible to settlers in the first sixteenth century. Today, 150 km^2 of old-growth *laurisilva* survives today, in the mountains that cover the northern half of the island between 600 and 1492 meters (UNESCO, 2000: 93).[320] How much forest was accessible? Given the technology of the era, and skills demanded to clear forest effectively, I am doubtful that we are looking at more than 400 square kilometers within reach of settlers, *and* available for commercial use. It is one thing for a peasant to cut fuelwood for the home, quite another to feed the maw of a sugar complex disciplined by the world market.

Madeira's potential mass of arable land was exceedingly modest. In contrast to Barbados two centuries later, room for expansion into the interior was limited. Where Barbados is unusually flat, Madeira is essentially a mountain rising up out of the ocean. On the southern coast, cane might climb the mountainsides as far as 400 meters. But no farther. (And recall that such elevations were typically reached within three or fewer kilometers from the coastline.) Albuquerque and Vieira see a 2.5-kilometer "corridor [of arable] parallel to the coast." There was considerable variation, shaped by differing microclimates on the northern and southern coastlines, comprising in their view a theoretical maximum of 300 square kilometers (Albuquerque and Vieira, 1988: 23). This is probably too generous. The island stretches 50 kilometers east to west with a steep incline virtually everywhere (Calvert, 1979: 45). A maximum of 200 square kilometers of potential arable is probably closer to the mark; this was, in any event, the area under

[319] On the laurisilva forests, see Parsons (1981).

[320] This "main forest is believed never to have been felled or cut and includes some massive old trees, believed to be over 800 years old" (UNESCO, 2000: 94).

cultivation in the mid-20th century (Câmara, 2006: 217). And of course, all land was not equally desirable, especially those even a few kilometers distant from rivers or *levadas*.

It is impossible to know precisely how much forest was cleared prior to the onset of the sugar cycle in the 1450s. We know that wheat cultivation and viniculture was present from the 1430s. By mid-century, "in the western part of the island, standing in the farm of João Gonçalves…, the harvests [of wheat and vines] stretched as far as the eye could see" (Serrão, 1954: 339). So the area of cultivation was not insignificant.

But how much forest would be cleared over the next century? And how can we *know* the extent of forest exploitation and its effects? For Madeira, we have four basic kinds of evidence. One is found, of course, in the primary sources. Another is constituted by the work of specialist historians. A third category draws on the biogeographical evidence of environmental transformation. Finally, there are quantitative extrapolations based on sugar production figures, fuel consumption, and forest area. If handled gingerly, the *geometrical* representations of environmental transformation that emerge from this last category can serve as useful heuristic guides. Such historical *geometry* tells us little on its own, but in dialogue with other forms evidence, it becomes indispensable to the explanation of changing environments (at multiple scales) and economic development broadly conceived – this is to say, such historical geometries are crucial to the construction of historical *geographies* of the early modern world, and its commodity frontiers above all.

Let us begin with production. On the matter of Madeira' sugar output, we have reasonably solid figures (Pereira, 1969a,b,c,d). From these figures, which I have reconstituted into five year, moving averages, we can build out two major vectors of forest exploitation: the expansion of cultivation into the forest, and the expansion of fuelwood exploitation. Our first table presents this data for the period from the beginning of sugar production on the island, to the peak of production, at the dawn of the sixteenth century.

Table II, Sugar and the Fate of the Forest: Madeira, 1445-1509

Period	Canefields (expansion of arable)	Sugar produced (annual)	Annual fuelwood	Deforestation for fuel[321] (5-year period)	Cumulative Deforestation (cultivation + fuel)
1445-1449	200	40 tons	2,000 tons	56 hectares	256 hectares
1450-1454	300 (+100)	60 tons	3,000 tons	83 hectares	439 hectares
1455-1459	450 (+150)	90 tons	4,500 tons	125 hectares	714 hectares
1460-1464	600 (+150)	120 tons	6,000 tons	167 hectares	1031 hectares
1465-1469	900 (+300)	180 tons	9,000 tons	250 hectares	1581 hectares
1470-1474	1350 (+450)	270 tons	13,500 tons	375 hectares	2406 hectares
1475-1479	2025 (+675)	405 tons	20,250 tons	563 hectares	3644 hectares
1480-1484	3050 (+1025)	610 tons	30,500	847 hectares	5516 hectares
1485-1489	4000 (+950)	800 tons	40,000	1111 hectares	7577 hectares
1490-1494	5000 (+1000)	1000 tons	50,000	1389 hectares	9966 hectares
1495-1499	6000 (+1000)	1200 tons	60,000	1667 hectares	12,633 hectares
1500-1504	7500 (+1500)	1500 tons[322]	75,000 tons	2083 hectares	16,216 hectares
1505-1509	9500 (+2500)	1900 tons[323]	95,000 tons	2639 hectares	21,409 hectares

Sources: Cadamosto (1455); Pereira (1969 a, b, c, d); Rau (1964).

If true, these estimates strongly suggest that Madeira's sugar complex would quickly undercut its sylvan foundations. Recall the island's small size: 741 km^2, 150 km^2 of which today consists of old-growth forests. If 400 km^2 of forest were within reach of sugar, for conversion to arable or to extract fuelwood, this means that half the island's woodlands were cleared by sugar's appetites, after only a century of settlement. No wonder that Castro attributes the island's "collapse in sugar production due to lack of firewood" by the 1530s, stemming from "intensive economic exploitation … [based on]

[321] Equals AF(annual fuelwood in tons) *x* Y(number of years) / F(180 tons/hectare).
[322] Extrapolated from the rate of growth, 1472-94.
[323] Calculated from Pereira, 1969b: 454, from annual production figures for each year.

the demands of the external market" (2002: 105). The expansion had proceed so rapidly, they had tipped the forests "toward total degradation" (Castro, 2002: 105).

But are these estimates true? We cannot treat this question lightly. Let me say that I have begun by abstracting all other demands on the forest, and these were far from insignificant. As we have seen, Madeira began its life as an important timber colony. And it was home to no fewer than 800 people in the 1450s; a population that would grow to more than 15,000 by the early sixteenth century. Demands for firewood and construction timber, not least for the towns of Machico and Funchal, and the establishment of new mills, were considerable.

We can begin by considering the cultivation of sugar. Two big questions immediately present themselves. First, how much would a hectare, planted in cane, yield? Second, how much sugar could be extracted from a given mass of raw cane?

We begin with the passage from cane to sugar. The ecology of sugarcane mandates processing within 48 hours – the sooner the better. Raw cane could not be shipped off the island. There were of course many grades of sugar, and semi-refined sugar was commonly exported for additional processing to Lisbon, Antwerp, and Genoa. The crucial point concerns the rate of extraction, that is, the ratio through which a given weight of sugar is produced from raw cane. My bias here favors a highly efficient rate, which underestimates deforestation.[324]

There is no systematic study of the relation between technology and the rate of extraction in the development of the early modern sugar complex. So a crucial methodological task involves a certain extrapolation from other key moments in the sugar frontier's historical geography. On Barbados, the rate of extraction reached 3.1 percent in the 1840s, after a long period of experimentation (calculated from Simmonds, 1854: 138). By the later nineteenth century, in Brazil and Cuba, the sugar-to-cane ratio varied between 4:100 and 5.5:100; that is, between 4-5.5 pounds of sugar were extracted for every hundred pounds of raw cane (Eisenberg, 1974: 126; McCook, 2002: 80). At least in Cuba, the higher figure was obtained by deploying steam power and a three-roller mill, neither of which could be found on Madeira in the first sixteenth century. Even in the twentieth century, extraction rates rarely hit double-digits; Louisiana's was 8.6 percent in the 1950s (Humbert, 1968).

What, then, was Madeira's extraction rate? Any answer to the question begins with the prevailing technology. Warren Dean thinks a three percent extraction rate was standard in late seventeenth century Brazil, although this seems optimistic. Barbados, as we've seen, was scarcely more efficient in the 1850s (1995: 79; Simmonds, 1854). Without getting too far ahead of the story, the level of efficiency realized by the Brazilian *engenhos* was achieved by the vertical three-roller mill, an important technological innovation introduced during the 1610s (Barros de Castro, 1980). For our purposes, we can observe that the three-roller mill was at least two major steps ahead of Madeira in the fifteenth century. The vertical three-roller was not only a more efficient means of concentrating energy to extract the juice from the cane. The design of the new technology itself, in which the drive axle was positioned vertically rather than horizontally, was crucial:

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[324] The manufacture of high quality sugars, such as that used in pastries, would result in substantially more bulk reduction, by as much as one-third, and therefore a lower (less efficient) rate of extraction (Vieira, 2004).

> The vertical alignment allow[ed] the juice to flow away from the bagasse [the cane stalks] as it [was] expressed, giving potentially greater recovery. With horizontal mills [and earlier technology as well], the juice tends to be reabsorbed into the bagasse as it exits from the rollers (Daniels and Daniels, 1988: 522).

The conventional narrative places the two-roller mills on Madeira, from the 1450s. John and Christian Daniels, however, find little evidence to support this, preferring instead to locate the arrival of two-roller mills on Madeira in the 1520s. Even then, these were horizontal mills – and therefore susceptible to the re-absorption of cane juice into the bagasse – and remained uncommon until mid-century (Daniels and Daniels, 1988: 514). It is guesswork, but it seems unlikely that the two-roller mills exceeded a two percent extraction rate. Given the differences in design between the vertical and horizontal mills that Daniels and Daniels highlight, the actually existing rate was probably closer to 1.5 percent. (And even this may be too high.)

But if two-roller sugar mills did not appear on Madeira until the 1520s, what was the prevailing technology at the dawn of the island's sugar boom? On Madeira in the 1450s, the cutting edge of sugar mill technology was of the "edge runner" variety common to the medieval Mediterranean, including Cyprus and other sugar islands (Daniels and Daniels, 1988: 514). The edge runner was essentially a large, heavy wheel capable of crushing the raw cane, from which the juice would run into a basin. It could be powered by water or animals. Additional juice would then be extracted in presses similar to those used for olive oil. These had long been used to process sugar in the Mediterranean world. All of which means the extraction rate was exceedingly low. My guess is a cane-to sugar ratio of one percent, which gives the edge runner technology a very strong benefit of the doubt.

The sugar-to-cane ratio offers a starting point for the historical geometry of sugar's expansion. The next step is to consider how much raw cane could be harvested from a piece of land. Our best estimates derive from nineteenth century sources. Fresh land in Cuba during the 1870s yielded "as much as 119 tons of cane" per hectare (Eisenberg, 1974: 218). In the same decades, yields in Pernambuco (Brazil) "never exceeded" 60 tons, averaging about 40 tons per hectare (Eisenberg, 1974: 218, 126). Ure puts Jamaica production in the mid-19th century at 51.6 tons/ha (calculated from Ure, 1853: 758).[325] And Dean thinks 50 tons per hectare was standard for Pernambuco canefields in the seventeenth century (1995: 79). This latter is, indeed, the average for Pernambuco today; farther south in Sao Paulo, we're looking at cane harvests of 75 tons (Porter, Dabat, and de Souza, 2001: 833).

What, then, were the yields on canefields in fifteenth century Madeira? Here I would begin with Dean's estimate of 50 tons per hectare in seventeenth century Pernambuco. Northeastern Brazil had two great biophysical advantages over Madeira. First, it was warmer and wetter. (No irrigation works were necessary.) Second, its soils, especially the famed *massapé*, were more fertile. As Dean notes, the manuring practices so widespread in Madeira and São Tomé's sugar cycles, were unnecessary in Brazil (1995: 56). In this

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[325] Calculated from Ure's estimate of 7 hogsheads, of 16 cwt each (112 lbs/cwt), for 10 acres, assuming a three percent extraction rate (Ure, 1853: 758; also Simmonds, 1854).

light, I would be hesitant to place average yields in fifteenth century Madeira at greater than 40 tons/ha, which is the working estimate I've deployed in Table II.

We are accustomed to figures on land productivity, reckoned in annual cycles. But planted cane is not an annual crop. In early modern Brazil and the Caribbean, time to maturity varied between 14 and 18 months. In Madeira and the Canaries, Nicols puts the harvest cycle at closer to two years: "*good* Soil yields nine Crops in eighteen Years" (1560: 536, emphasis added). This means that a yield of 40 tons/ha translates to annual land productivity of 20 tons/ha. Now, it is true, replanting was not always necessary. After harvest, cane stalks left in the ground can be left to resprout, a process called ratooning. In Brazil and the Caribbean, ratoons matured faster, taking about twelve months, but characteristically with a lower yield than cane freshly planted; thus ratooning, in these estimates, does not alter the land productivity estimates – although ratoons most definitely commanded less labor (Schwartz, 1985: 109).[326]

In Table II, I have deliberately abstracted from sugar's well-known tendency towards soil exhaustion. This is a structural bias in the quantitative reckoning that minimizes the estimate of deforestation. But, of course, land productivity did not remain steady. The soil was progressively exhausted. (About which, we shall hear more presently.) The yield honeymoon of the early decades of cash-cropping had passed by the dawn of the sixteenth century. We have no reports of the precise *rate* of yield decline for Madeira. Fortunately, these are available for Barbados and Jamaica in the seventeenth and eighteenth centuries. In Barbados between 1649 and 1690, the volume of sugar produced on one acre fell by at least a third (Barrett, 1979: 22). But the aggregate figure obscures profound unevenness. Yields on plantations established in the 1640s had declined by as much as one-half by 1685 (Watts, 1987: 397). At the close of the seventeenth century "much of the most severely depleted landed had been taken out of cultivation" (Watts, 1987: 397).

The same thirty-year cycle is discernible for Jamaica. The island's Bybrook plantation, for example, saw output fall from more than one hundred hogsheads to just fifty over the last three decades of the seventeenth century. Bybrook, "not yet thirty years under cultivation… was nearly worn out and worth very little" (Dunn, 1972: 219-221). Charles Lesley observed in the 1730s, not more than a half-century after Jamaica's sugar boom commenced (Dunn, 1972: 149-187), that "Acres of Cane require almost Double the number of Hands they did formerly, while the Land retain'd its natural Vigour" (1740: 337).[327] Even Bahia's famed *massapé* soils could not sustain yields for "more than sixty years" (Silva Lisboa, 1781: 499). Madeira was surely no exception to the broader pattern of the sugar frontier.

Cultivation's advance into the forest paled next to the sugar frontier's greatest vector of deforestation, fuelwood exploitation. To say sugar is to say deforestation. This was an enduring ecogeographical structure of the modern world-system well into the early twentieth century. (Indeed, as the ethanol revolution gathers steam, one wonders if the formula ever disappeared.) Once the forests of Madeira, northeastern Brazil, and the Caribbean had been razed, the extension of the sugar commodity frontier to Mauritius,

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[326] In the favorable climate and soil of northeastern Brazil in the sixteenth and seventeenth centuries, ratoons were known to give comparable yields for the first and sometimes second ratoon crops (Schwartz, 1985 109).

[327] For declining labor productivity in Barbados, see Watts (1987: 268), and Chapter Six.

Australia, and the Philippines (Griggs, 2007; Tucker, 2000) among other places, would reproduce the same ecological devastations.[328] At the heart of early modern sugar's ecological vulnerability (*and* its economic dynamism) was the tendency to exploit forests beyond their capacity to renew. The exhaustion of the soil was important, and dovetailed with the energy regime in crucial ways, but it was not primary. The real downfall of sugar, like metallurgy, was not the exhaustion of the soil, but the evisceration of the forest.

Making sugar took an awful lot of woodfuel. Its closest counterpart in this era, both in volume and in aggregate fuel consumption, is ironmaking – the topic of considerable debate over fuel crises in eighteenth century England (Hammersley, 1973; Nef, 1932). The estimate that I've settled upon, for Table II, is a sugar-to-fuelwood ratio of 1:50. This requires some explanation.

I shall explain this estimate in two steps. First, this ratio is higher than the two estimates which have gained the widest circulation among environmental historians – Perlin (1989), who puts the ratio at 1:46, and Dean (1995: 80), who suggests 1:15. We can examine these in their respective turns. Perlin's guesswork has the virtue of drawing upon an eighteenth-century Brazilian source (Couto, c. 1757-59). The difficulty with Perlin's reliance on this source, which *does* after all yield a reasonable figure, is this. Couto's observation of sugar's fuel requirements, the weight equivalent of two cubic meters (3200 lbs), is phrased in relation to the sugar loaf or "form" (*pães*). The size of these loaves varied. In early colonial Brazil, the standard *pães* was 1-2 arrobas (15-30 kilograms); after the 1660s, this grew to 2-4 arrobas, which became standard in Bahia (Schwartz, 1985: 113). Between two and four arrobas, however, lay a world of difference. Two arrobas translates to sugar-to-fuelwood ratio of 1:50; three arrobas, to 1:33; four, to 1:25. The largest mills tended to produce the largest loaves, it is true, but these big mills became increasingly *un*representative in the century after 1627. This was a period characterized by the rapid growth of small mills. Output per mill fell by nearly half between 1627 and 1710. As for Dean, he offers no source for his estimate of extraordinarily high fuel efficiency (1:15). Possibly, he was drawing on Schwartz's magisterial study of colonial Brazil, which provides sugar-to-fuelwood ratios of between 1:10 and 1:20 (calculated from Schwartz, 1985: 112-113, 141).

If sugar manufacture demanded so much more fuel than the cautious estimates suggest, this ought to show up in the evidence drawn from multiple sites in the early modern sugar complex. Silva Lisboa, writing in Brazil at the end of the eighteenth century, suggested a ratio of 1 unit of wood for each unit of raw cane, which gives us a range between 1:33 and 1:50,[329] possibly much higher, if the cane-to-sugar extraction rate was under 2 percent (Silva Lisboa, 1786: 47-50 quoted in Padua, 2000: 269-270). Fraginals, drawing on early nineteenth century Cuban sources, offers data that indicates a range of 1:49 to 1:58 for technology that was, at worst, essentially the same as seventeenth century Brazil's, and almost certainly more fuel efficient than fifteenth

[328] The latest sugar revolution, pivoting on sugar cultivation for ethanol production, inverts the world-historical pattern only because the extension of cultivation has become the commodity's leading edge of deforestation.
[329] Respectively, at three percent and two percent extraction.

century Madeira (calculated from Fraginals, 1976: 74).[330] Barrett's evidence on sugar production and fuelwood consumption for the "sugar hacienda" of Marqueses del Valle, between 1580 and 1625, yields a ratio of 1:51 (calculated from Barrett, 1970: 72, and 130, Table 12). We find a similar figure for late seventeenth-century Brazi.[331]

Higher estimates are possible and not unreasonable. Indeed, Dean had previously offered a much higher estimate (1983), arguing that a metric ton of sugar consumed 100 cubic meters of wood. This translates to a sugar-to-fuel ratio of 1:73 (also, Williams, 2003: 216). But for present purposes, I simply wish to use these estimates to establish the plausibility for an ecohistorical explanation of Madeira's decline.

The final piece of this geometrical puzzle is the yield of the forest. This is at once a social and ecological question. Even a provisional answer hinges on the biophysical matrix of the forest itself, and the social and technical regime that takes shape around the latter's exploitation. Yield, in other words, is a historical question, one that interweaves the domains of net primary productivity and labor productivity; how much there was to extract, and how much could be extracted under definite historical conditions. Needless to say, even under optimal conditions the construction of yield estimates is challenging, and at best serves as a heuristic guide. To safeguard against overstating the extent of deforestation, I have abstracted other social demands on the forest. For instance, the 18,000 people living on Madeira at the dawn of the sixteenth century (Blackburn, 1997: 109) would have consumed no less than 18,000 cubic meters of fuelwood each year – about 80 hectares – *just for domestic purposes*! And while it is true that, given the opportunity, forests regenerate, Madeira's sugar revolution unfolded so rapidly that there was little opportunity to do so.

How much fuelwood could be won from a hectare of Madeira's forest? In Table II, I put average yields at 180 tons/225 m^3 of wood per hectare, assuming 1602.2 lbs per cubic meter of hardwood.[332] Making such estimates are hazardous by nature. To put matters simply, I've formulated a working estimate that draws on primary sources and forestry sources literature. In the first instance, our best documentary sources for fuelwood extraction are from nineteenth century North America, which give us a range of 15-50 cords/acre, or 134-447 m^3/ha for the northern U.S. from Minnesota to Maine (Marsh,

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[330] Fraginals offers the following data. The basic unit of timber volume was the "task," which was six cubic yards (4.59 cubic meters). If one cubic meter weighed 1602.2 lbs, then each "task" weighed 7354.1 lbs. One task was sufficient to produce between five and six Spanish arrobas of sugar (Fraginals, 1976: 74). Each arroba weighed 25 lbs (Ayala, 1995: 98). If so then, the sugar-to-fuel ratio for early nineteenth century Cuba, using the "Spanish train" in which each kettle was heated separately of the others, comes to 1:49 at the low end and 1:58 at the high end.

[331] Miller, in his pioneering study of sugar and deforestation in colonial Brazil (1994), believes Antonil (1711) is describing the famed engenho Sergipe de Conde in reporting that the mill consumed 2,500 cartloads of firewood each year (1994: 184 and 191, n.16). If the figure of 2,500 cartloads is correct, and if we side with Schwartz in estimating that each cartload weighed 1600 pounds, then the sugar-to-fuelwood ratio looks like this. We know that Antonil visited the Engenho Sergipe between 1693 and "at the latest" 1703 (Mansuy, 1968: 28). This was during a historic low point in Sergipe's production, averaging just 2442 arrobas (79,670 lbs at 32.625 lbs/arroba), between 1690 and 1700 (Schwartz, 1973: 195). If so, then 79,670 lbs of sugar were manufactured with just over four million lbs (4.006 million) of wood, which gives us a ratio of about 1:50.

[332] Premised on a working assumption of one hardwood standard cord at 5800 lbs.

1864: 151; Sargent, 1884: 497, 502, 552, 555, 559; also Whitney, 1994: 145, 213).[333] The middle range estimate of 225 m^3/ha – about 25 cords/acres – fits well with the working estimates among environmental historians (Dean, 1995: 80, 235; Williams, 2003: 532n). It also fits nicely with the forestry literature, which suggests a density – not to be confused with actual yields – closer to 300 m^3/ha for "old growth" temperate forests and 250 m^3/ha for their tropical counterparts (Holland, 1973: 972). Although an imperfect analogue to the hardwoods of fifteenth century Madeira, old growth Douglas fir stands in the American Pacific Northwest today offer a harvestable potential of 293 m^3/ha (Prudham, 2004: 61).[334] For coastal British Columbia, estimates fall in the same range, between 275 and 325 m^3/ha (British Columbia Ministry of Forests, 2007). European foresters have arrived at similar ballpark figure, identifying an upper limit of 287 m^3/ha (Nabuurs, et al., 2007: 396).[335]

There lies a rather wide gulf, however, between theoretical maximum and attainable yield.[336] For starters, woodcutting was extraordinarily dangerous work (1995: 182-183; also D. Watts, 1987: 185-186; Bridenbaugh and Bridenbaugh, 1972: 42-43, 268-271).[337] Beyond the inherent dangers of forestry, the technology was crude and not all timber was equally suitable for firewood. Large trees on Madeira would have been extraordinarily difficult to fell and then haul. It took dozens (yes, dozens) of oxen to move a single old-growth tree a maximum of 12.5 miles even in *twentieth* century Brazil (Zon, 1916: 21). If Madeira's hydrology changed enough during this period to limit river flows, as Grove (1995: 29) and Mason (1850: 162) suggest, transport of timber would have become even more costly. Beyond this, there was the labor of chopping the wood into parts small enough to generate sufficient heat – large, and worse unseasoned, parcels were useless (Antonil, 1711: 202-203; also Miller, 1994). This was a process that involved the bulk reduction of the wood, as a certain amount of wastage accompanied the labor of firewood preparation. (Never mind that batches of sugar were commonly lost during the boiling process, and these losses are structurally excluded from the estimates presented here.) All of which is to underscore the cautious nature of this estimate.

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[333] In an interesting evidentiary twist, the sources for late nineteenth century speak to extraction rates for various forest planting and coppicing schemes, rather than for wholesale forest clearance (Fernow, 1907, 1911).

[334] My calculation. These are from National Forests in the Pacific Northwest. The potential yield of these forests stands in contrast to the U.S. average of 67 m^3/ha (calculated from Prudham, 2004: 62). The inference that the National Forest timberlands are old growth is from Hermann and Lavender's reckoning of 174 m^3/ha for "naturally regenerated" coastal Douglas fir, after fifty years (1999: 58).

[335] Other European reports indicate a stocking rate (under managed conditions) of 300-450 m^3/ha for 130 year old oak and beech outside Vienna (Lewis, et al., 2004). The high-end figures, we should note, occur under highly managed conditions, and should not be regarded as typical.

[336] Extraction from woodlands in Europe, moreover, was significantly lower. Mulhall, looking at late nineteenth century Europe, suggests 1000 cubic feet per acre of forest "if cut down" rather than coppiced (1899: 297). Using his metric, which puts the weight of one cord (128 cubic feet or 3.62 m^3) at 5000 lbs rather than 5800, this translates to 2,470 cubic feet/ha or 48.24 tons/ha. This contrasts with our much higher figure of 120.16 tons/ha. It is on this basis that Dean's estimate of 200 tons of firewood per hectare of "secondary woodland" can be regarded as excessively high (Dean, 1995: 80).

[337] "Engenhos and lavradores often bought wood from the heavily forested region of the southern Recôncavo, both because they lack woodlands on their own property *and because the labor was hard and dangerous to their own slaves*" (Schwartz, 1985: 141, emphasis added). For present day indications of the dangers involved in forestry, see International Labour Office (2005); Frazier and Mullan (1983).

Working out such estimates can be tedious, and the numbers won from such efforts are subject to challenge from many directions. We are always on shaking ground in charting early modern deforestation and its multivariate feedbacks on the political ecology of accumulation. But for all its occasional tedium and precarity, the debate over the relations between world economic development, deforestation, and energy crises has persisted for nearly a century (see, *inter alia*, Allen, 2003; Sombart, 1921, vol. 2, ii: 1145-1148; Nef, 1932, 1950, 1964; Flinn, 1958, 1959; Cipolla, 1976; Clow and Clow, 1957; Hammersley, 1973; Malanima, 2006; Thomas, 1986; Williams, 2003; Warde, 2003, 2006; Wilkinson, 1973). It is a debate that will not go away, precisely because – like the debate over American silver – underpinning everything, it is a debate about modernity and about the nature of the crisis we are presently living through. (Does anyone now seriously question that civilisation is moving through a energy transition of the most far-reaching nature?) And yet I think it is safe to say that the eco-geometric estimates that are the basis of these debates have often been treated too casually (e.g. Hammersley, 1973).

Should we now return to Madeira at the dawn of modernity, it is reasonable to observe that the destruction of more than 20,000 hectares of forest on Madeira by 1510 – more than half the accessible timber, and much more than half of easily accessible supplies – would surely have represented a major problem for a fuel intensive industry such as sugar manufacture.

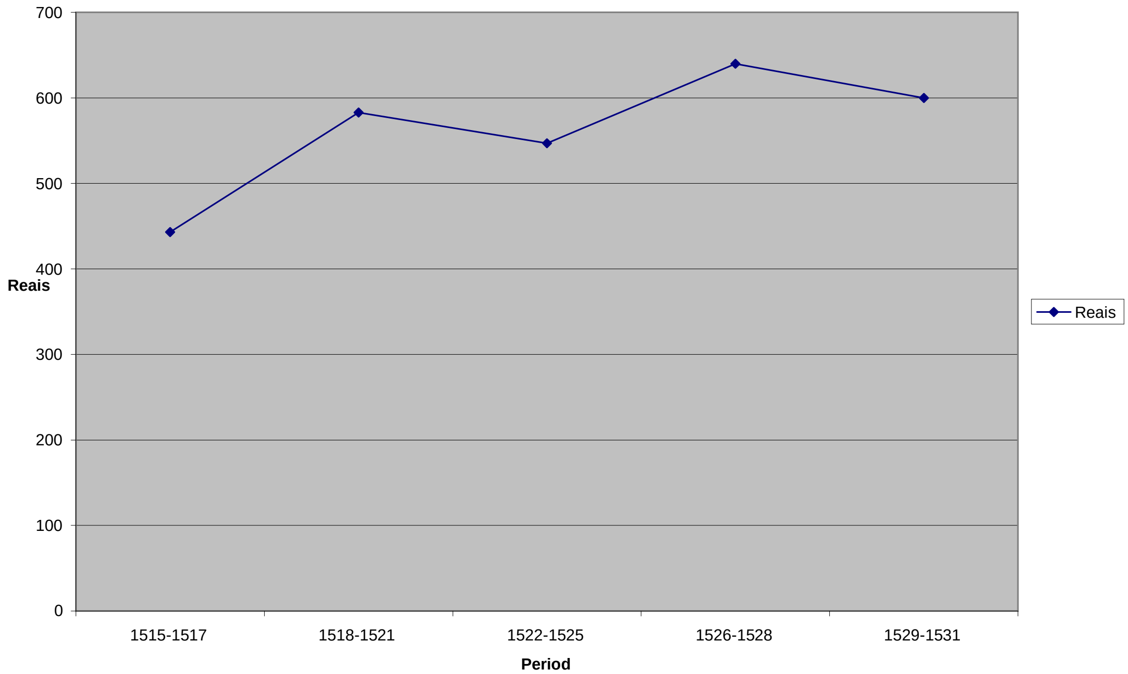
Ecology & the Path of Crisis: Explaining Madeira's Rapid Decline

So it is *plausible* that Madeira faced a mounting fuel crisis in the opening decades of the sixteenth century. But let me be clear that what we have at this point is more smoke than smoking gun. We know that the sugar economy declined quite rapidly after 1510. From an average of 1900 tons in 1505-09, annual output declined to 1073 tons in 1515-19, to 835 tons in 1520-24, to 549 tons in 1525-29, to barely 300 tons in the 1530s (calculated from Pereira, 1969d; also Schwartz, 1985). Production, peaking at 2480 tons in 1506, fell to 1180 tons in 1516, just 467 tons a decade later (Pereira, 1969d). In twenty years, production had collapsed. The island's output in 1525 was barely more than 20 percent of its 1506 peak. What is puzzling about this collapse is that it occurred in the midst of an improving market for Madeira's producers. (See Figure I.) The prices fetched for Madeira's best grades of sugar increased by one-quarter between 1515 and 1517; and by fifty percent between 1515 and 1520, a price level that held more-or-less steady throughout the decade (Pereira, 1969d).

Madeira's crisis coincided with massive deforestation. This much is certain. But correlation is not causation. It is not exactly news that sugar production and deforestation were intertwined. Yes, the geometrical representations we've just reviewed provide a with a working hypothesis. But they do not, in themselves, demonstrate anything conclusive about the rise and demise of Madeira' sugar complex. I do believe that fuelwood supplies constituted sugar's greatest vulnerability, on Madeira, to be sure, but not only on Madeira. It was a vulnerability common to the early modern sugar frontier in general. Nevertheless, to focus on this or that moment of environmental change may fall wide of the mark. For the era's commodity frontiers – Brazilian sugar, Peruvian silver, Norwegian timber – rose and fell on the strength of the totality of socio-ecological relations governing production, on the vitality of their *ecological regimes*. Thus, the crucial discussion, from our vantage point, is one of the exhaustion of the region's ecological regime, the erosion of that regime's capacity to compete effectively on the "vast but weak" world market of the times. All of which means the crucial variable is one of governing nature, rather than any particular vector of environmental change.[338]

Figure I

Sugar Prices: Madeira, 1515-1531



Source: Pereira, 1969d.

If our vantage point is that of sugar's ecological regime, it is probably most fruitful to begin with the geography of cultivation itself. If sugar faltered, it is plausible to direct our focus towards soil exhaustion, one of the enduring themes of sugar's historiography (Mintz, 1959, 1985; Edel, 1969; Dunn, 1972; Watts, 1987). While canefields diffused across the southern half of the island in the half-century after 1450, the *engenhos* did not. The mills remained geographically clustered around Funchal (Vieira, 2004: 57). There was consequently pressure to overexploit nearby forests. Demand for fuelwood was therefore not generalized equally across the 40,000 hectares or so of theoretically accessible forest. The fuelwood frontier inevitably took its toll on nearby forests, which meant that more and more labor became necessary to secure the same amount of energy. This was a logic of rising costs, but in a frontier zone – where we are dealing with a relatively unmonetized economy at the level of everyday life – rising costs manifested through rising labor demands, rather than any straightforward price movement. Among

[338] The rub, of course, is that only can see the governance of nature at work through these specific vectors; even as these vectors become historically meaningful only in terms of their relation to the broader ensemble of social and ecological relations.

the common traits shared by commodity frontiers throughout the early modern world-economy was a relation to the forest as a "free gift" for commodity production. It was not – and indeed, *could not* be marketized. (This was amongst the chief advantages of commodity *frontiers*, all of which depended upon access to free, or low-cost, forests.) As mills clustered geographically, they exhausted the woodlands nearby and close to waterways, and firewood had to be carted in from farther and farther away. True, Madeira is small, but carting was always an expensive proposition. All the more so given the island's steep topography.

We shall return to the fuelwood supply question presently. First, however, we might observe that deforestation was really a double contradiction for Madeira's sugar complex. It wasn't just that the forests supplied fuel for the boiling houses. Cane farmers depended on forest clearance, by means of organized (if not always contained) burns, to sustain land productivity. The creation of arable land from the forest greatly enriched the soil, thanks to fertility bestowed upon it by "the black ash of the forest" (Bryans, 1959: 23; Albuquerque and Vieira, 1988: 22, 27; Africanus, 1600: 56). And it was not simply black ash that the forest provided. It was also the "yield honeymoon," above all the temporary respite from the pests (rats especially) that emerged hand-in-hand with the monocultural regime. As all honeymoons must end so would this one, yields declined, and thence the renewed assault on the forests to restore fertility.

Quite distinct from the matter of fuel, then, forest clearance served as a crucial prop for the soil fertility that was a pillar of Madeira's sugar revolution. They were distinctive problems, but mutually reinforcing. It is clear that there were mounting ecological-feedbacks from the monocultural regime that began to materialize between 1510 and 1530. Leo Africanus, writing sometime between 1518 and 1526, drew a sharp contrast between the fertility of the early years of cereal agriculture and the decline of sugar. The sugar harvest "now… cometh not to the one halfe of that [earlier] reckoning" (1600: 56). This fits nicely with the experiences of Brazil, Barbados, and Jamaica, as we have seen. There was, at least in Africanus' view, a clear connection between the island's initial fertility, the sugar revolution, and its crisis in the years around 1520.

The soil crisis was enduring. Africanus' comments would echo, more than a century and a half later. In a 1689 travelogue, the English merchant Ovington observed that:

> The Fertility of this Island is much abated from what it was in the Time of its first Plantation; and the continual breaking up of the Ground has, in many Places, impoverished its Productions; so that they are obliged to let it lie fallow for three or four Years: After which Time, if there springs-up no Bloom, they conclude it is quite barren (Ovington, 1689: 563).

What role did declining land productivity play in Madeira's decline? Pereira, wrestling with the issue of Madeira's decline four decades ago, was struck by the paradox we have noted: rising prices, declining production. "We cannot discount the probable soil exhaustion resulting from intensive exploitation," contends Pereira (1969b: 484, 462). Elsewhere, he puts the matter more emphatically: Madeira's sugar complex faltered in great measure "due to the impoverishment of the soils, which given the limited area available for agriculture, inevitably reduced the productive capacity" (1969d: 158, also 220; also Birmingham, 2000: 13).

The political ecology of soil exhaustion was indeed a major factor. Monoculture achieved short-run gains by realizing surplus control of land and labor. Declining yields sooner or later set in, absent nutrient imports. But nutrient depletion was only one part of the story of declining land productivity. “Soil exhaustion” is a convenient scaffolding. But it is probably best if we don’t put too much weight on such a shaky trope. Over time, my guess is somewhere around thirty years across the breadth of the sugar commodity frontier, the radical simplifications effected by monoculture gave rise to the exact inverse of the yield honeymoon – an upward spiral of pestilence. In 1502 caterpillars ravaged canefields across the island. It was the first of many pest invasions (Koebel, 1909: 128; Mauro, 1983: 207; Duncan, 1972: 32; Rau, 1964: 5).[339] These invasions may be regarded as an effectively irreversible tendency – that is, a long run vector of downward pressure on land productivity – although new techniques could of course attenuate the worst effects.

It is probably best to situate such exhaustion from the standpoint of the broader ensemble of socio-ecological relations governing the island, and those obtaining within the Portuguese empire. This recasts the crucial variable as one of the profitability (broadly conceived) of the *ecological regime*, rather than the apparent “bigness” of this or that moment of environmental change – soil exhaustion, deforestation, pest invasions, and so forth. If we look at Pereira’s argument from this perspective (1969b, 1969d), we would expect to find the most dramatic expressions of crisis in the captaincy of Funchal, where cultivation began. And this is precisely what we see. Funchal’s output declined *sixty percent* between 1516 and 1537. This was in contrast to Machico’s much slower descent, a difference that Albuquerque and Vieira explain in terms of the relative soil fertility (1988: 29).

Land productivity is a measure of the earth’s productivity mixed with human labor. So one can hardly begin to think through the questions of relative fertility in the absence of the labor question. And here is a second paradox. To the paradox of rising prices and falling production, we can add the paradox of increasing slave imports and decreasing sugar output. From the outset, let us be clear that the evidence is not what one would wish. While there is some evidence on patterns of slaveholding (Vieira, 1996), we have neither good figures on annual slave arrivals or slave mortality.

We do, however, have some reliable estimates of Madeira’ slave imports over the period of its sugar revolution and subsequent crisis. When one works from a highly conservative reckoning of slave population – a bias that overstates slave productivity – the result is a curious sort of Kuznets-curve, one characterized by sharply rising, then rapidly declining, labor productivity. It is precisely what one would expect from a sugar

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[339] Mauro makes an interesting connection here: the caterpillar invasions that commence after 1502 “attacked [not only] the canes, [but also] the manpower” (1983: 206). It is not clear if this was metaphorical, in the sense that more labor power became necessary to sustain yields, or literal, in the sense that slave workers were invaded by parasites. Perhaps both? But caterpillars were not the only pests. There was also the “struggle against rats, against which the slaves were deployed with all their diligence” (Mauro, 1983: 207). This would become a recurrent feature of the sugar commodity frontier. In São Tomé just two decades later in the 1520s – and just three decades after sugar cultivation commenced on the island – rats had “mightily impaired the growth of this commodity,” for a time cutting export volume by 85 percent (Africanus 1600: 53). (Need we say that the “ship rat” common on São Tomé at this time was not indigenous [Dutton, 1994: 928]?)

revolution capitalizing on a yield honeymoon, then followed by a strong ecological pushback – as fields were exhausted or plagued with pests and weeds, as woodland receded, ever more labor was required to maintain output.

How much labor did it take to cultivate and process 1,000-2,000 tons of sugar? If we take Barrett and Schwartz's estimate of slave productivity for sixteenth century Brazil (1975: 542) – the middle range of which is .33 tons per labor-year (also Blackburn, 1997: 205) – then the 1680 tons Madeira produced in 1498 would have required the full-time labor of 5,040 unfree cultivators and technicians.[340] This is a very generous estimate for slave productivity, more than 25 percent higher than the prevailing average in 1680 Barbados.[341] Of course, Madeira was not a slave colony on the model of seventeenth century Barbados (Vieira, 1996, 2004). Vieira tends to minimize the role of slavery during Madeira's sugar cycle, but it is difficult to see how the island could have produced so much sugar otherwise. Blackburn thinks that some 2,000 slaves worked on the island at the end of the fifteenth century, "mostly" in sugar (1997: 109).[342] (This is almost certainly too low – as we shall see – even with low estimates of slave imports and high estimates of slave mortality.)

How many of these 2,000 slaves were directly implicated in the sugar complex is difficult to say. Certainly a large majority. If we were to assume that 1,500 slaves were directly involved in sugar – the rest working in other agricultural sectors, or as domestic servants – these workers would have produced 495 tons. If we assume that free workers were twice as productive (.67 tons/year), an additional 1,770 laborers were minimally involved, or nearly 3,300 for cultivation and processing as a whole for the late fifteenth century. When production peaked in 1506, at 2,480 tons, nearly 5,000 workers would be called for. An additional 1500 workers would have been necessary as woodcutters that year.[343]

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[340] There are two principal ways to measure slave productivity, at the level of the individual and at the level of the social economy. Thus, when Deerr (1949: 101) puts slave productivity for seventeenth century Brazil at 60 arrobas (1940.4 lbs), we are looking at the productivity within the cultivation process itself, hived off from processing, and also (no less crucially) from transport and distribution (see also Taylor, 1970). The measure of slave productivity that I am using seeks to illuminate Madeira's social economy as a whole.

[341] Whether or not labor productivity was substantially higher in the West Indies remains an open question. Looking at Antigua, St. Kitts, Montserrat, and Nevis in the 1770s – which together produced 21,158 tons (as much as Brazil in 1700) – Deerr's figures indicate a range of labor productivity between .198 tons/slave (Antigua) and .39 tons/slave (St. Kitts), with an average productivity of .26 tons/slave (for 82,270 slaves) (all calculated from Deerr, 1949: 174). This was roughly the same in Barbados c. 1680. The island produced about 10,000 tons of sugar (1683) with 38,782 slaves (1680), which yields (surprisingly in my view) a level of productivity *exactly* the same, .26 tons/slave (calculated from, respectively, Dunn, 1972: 203, and Galloway, 1989: 81). Schomburgck, drawing on contemporary reports, thinks the number of slaves was significantly higher, 46,602 in 1683-84 (1848: 82), which would have depressed labor productivity still further.

[342] "Most of the Islands inhabited by the Portugals, especially those of Saint Thomas and Madera, besides the Portugals themselves, containe a great multitude of Negro-slaves, brought thither out of Congo and Angola, who till the earth, water the sugar-canes, and serve both in the cities, and in the countrie," (Africanus, 1526/1600: 417).

[343] This is a deliberate underestimate. I've calculated that one woodcutter was necessary for every 1.62 tons of sugar. Calculated on the basis of the new arroba (32.34 lbs), from the number of woodcutters in Bahia in the 1750s (4000), and the region's sugar output in 1758 (400,000 arrobas) (Miller, 1994: 184; Schwartz, 1985: xxiii, 423).

Was the supply of slaves sufficient to sustain sugar's rising labor demands? Rawley and Behrendt, building from Elbl's recent estimates (1997) and Curtin's geographical distributions (1969), think that 17,500 African slaves were shipped into the northern Atlantic islands over the second half of the *fifteenth* century (2005: 20). This figure for the northern Atlantic islands is one that excludes São Tomé (3,500) and Europe (60,000). If we assume that 10,000 of these workers (60 percent) were destined for Madeira, and that most of them (90 percent) arrived after 1470, this put annual imports between 1470 and 1500 at 300. Klein is more cautious, estimating annual slave arrivals at 200 between 1476 and 1525 (Klein, 2004: 203). It is improbably that slave arrivals for any lower, given sugar's enormous labor demands, and the comparatively high number of slaves (155,800) shipped into Europe and the Atlantic islands between 1450 and 1521 (Elbl, 1997: 73). (Portugal alone was "extracting" 4,500 slaves a year from west Africa, by the early sixteenth century [Klein, 1999: 56].) Of these 156,000 slaves, some measure of these slaves would have gone to the Canaries, certainly, whose sugar mills churned out about half of Madeira's output (on a good day) at the dawn of the sixteenth century – about 1,000 tons (Birmingham, 2000: 18). The bulk of these slaves would have landed in Lisbon and then dispersed throughout Iberia and the Mediterranean; even so, not more than 6,000 African slaves were living in Lisbon in the 1520s (Russell-Wood, 1978).

At this point, we are again pushed back to a quantitative reckoning. Let us make three assumptions about the slave population on Madeira, all of which work against the notion that declining labor productivity was the order of the day: 1) very modest annual slave imports (200); 2) very high slave mortality (five percent);[344] and 3) the complete absence of slaves in 1475. From this standpoint, slave population increased very fast, to 2,054 by 1488, and to 3,000 by 1500. Productivity, through 1509, increased even faster, moving from .37 tons/slave to .57 tons in the two decades after 1489. Thereafter, as we can see in Table III, the trend is sharply downward. In the two decades after 1509, labor productivity fell from .57 tons to .15 tons/slave.

[344] Viewed from the longue duree of the sugar frontier, slave mortality was rarely higher than five percent, with a few gruesome exceptions to be found in the eighteenth century Caribbean – abstracting, of course, the horrific mortality of the Middle Passage itself.

Table III, Slave Productivity on Madeira, 1475-1529

	Slave Population	Sugar Output	Productivity
1479	905	405 tons	.45 tons/slave
1489	2151	800 tons	.37 tons/slave
1499	2892	1200 tons	.41 tons/slave
1504	3142	1500 tons	.47 tons/slave
1509	3337	1900 tons	.57 tons/slave
1519	3602	1073 tons	.3 tons/slave
1524	3692	835 tons	.23 tons/slave
1529	3762	549 tons	.15 tons/slave

Sources: Pereira, 1969d; Klein, 2004.

The point that I wish to underscore is the trend of rising labor inputs. More and more labor was required to extract wealth from external nature. The foregoing estimates bear only an indirect relation to the reality that seek to illuminate: many unfree workers were involved in other activities, including the vineyards that began to supplant canefields in a decisive way after 1520; free labor was mobilized widely; there were many small cultivators, with just one or two slaves; and so forth. And yet, we do know that more and more slaves were coming into Madeira after 1475. The trend was towards more, not fewer, slave arrivals: in the 1550s, some 300 slaves landed in Funchal every year (Mauro, 1983: 206). With so many slaves arriving, how was it that there could be a "labor shortage" on the island, dating from the 1520s (Vieira, 2004: 48)? There were at least 3,700 slaves on Madeira by 1525, when sugar output had to less than one-quarter of its 1506 peak. True, the economy was reorienting towards vines, and estate formation in viniculture could be labor intensive. But does this explain a situation of labor scarcity? Perhaps in part. At the same time, is it not rather more plausible to account for this tightening labor market *primarily* in terms of the political ecology of the situation? In the *conjoncture* of 1510-30, sugar planters were seeking to maintain output in an agro-ecological environment of dwindling fuel resources and declining soil fertility, and in a market environment of rising prices.

The squeeze on land and labor are compelling factors in accounting for Madeira's decline. But I don't think they explain the *speed* of the decline. Vieira unintentionally makes the point. Referring, almost in the same breathe, to the "rapid decline" of sugar on early sixteenth century Madeira, he refers to the "*gradual*" decline in Machico, the island's second ranking sugar district, as the "consequence of the progressive impoverishment of the soil and its growing unsuitability for the crop" (Albuquerque and Vieira, 1988: 29; Vieira, 2004: 48). The point? By themselves, soil exhaustion and the squeeze on labor power precipitated *gradual* rather than sharp decline, in the absence of massive capital flight and (or) a collapse of the market.

When viewed in comparative perspective, problems with declining fertility – barring catastrophic episodes of, say, soil erosion – were unlikely to issue such a sharp decline. There were certainly mechanisms to counteract the tendency towards declining land productivity. Madeira's soils were already manured, and more could be brought in; pest invasions could be catastrophic, but tended to produce sharp, *episodic*, production collapses; the evolution of weeds was a major problem, but one that could be addressed by putting more men on the job.

The only thing that could not really be fixed was the exhaustion of the forest. Fuelwood demands were simply too great, the island too small, the economics of transport too unfavorable. Timber, it is true, was an important item of trade in the sixteenth-century world-economy. *Timber* was. *Firewood* was not. And in any event, where would one find fuelwood? Recall that among the motivations of Madeira's initial colonization was the quest for timber, and that sixteenth-century Portugal was wracked by increasingly serious timber supply problems (Devy-Vareta, 1986; Barros, 2005).

Lack of fuelwood, in sum, would have compelled a sharp contraction of output in a very short span of time. Labor, capital, food, livestock – all could be shipped into Madeira as needed, so long as the economics of the situation allowed. Fuel was the one item that could not be easily secured from abroad.

The possibility of a fuelwood crisis gains real traction only if we can demonstrate, first, that the economics of the situation were in other respects favorable. Madeira's decline from sugar primacy is often chalked up to competition from Brazilian and São Tomé, even from the Canary Islands (e.g. Galloway, 1989; Klein, 1999: 14). But there's a problem with this kind of Smithian explanation. The timing just isn't right. Madeira's "rapid decline" spans 1516-1537 (Albuquerque and Vieira, 1988: 29). As we've seen, by the 1530s production declined to a level not seen since the 1470s (Vieira, 2004: 48; also Deer, 1949, I: 101). In 1529, São Tomé was producing not more than 80 tons of sugar. Brazil's sugar exports remained modest until the middle of the century.

If São Tomé or Brazil had been the culprit of this decline, we would expect to see major exports from these zones towards the beginning, not the end, of Madeira's crisis. But São Tomé came on line as a major producer only in the 1540s. In 1529, São Tomé was exporting just 80 tons a year, although this would increase thirty-fold by 1555 (Hodges and Newitt, 1988: 20; Garfield, 1992: 72). And in any event, Madeira and São Tomé sugar did not occupy the same market niche. Madeira's sugar was prized for its high quality, quality that was won, we should note, by additional phases of fuel-intensive processing (Vieira, 2004; Pereira, 1969d). In contrast, São Tomé's competitive edge was quantity, not quality (Garfield, 1992: 64-65; Harreld, 2003: 152-153). Indeed, São Tomé's sugar was of notoriously low quality (Garfield, 1992). As for Brazil, output matched São Tomé's by the 1560s, reaching 2,654 tons annually in that decade (Simonsen, 1957: 172-173; Hodges and Newitt, 1988: 20), but at best this extinguished an already collapsing Madeiran sugar sector.

Nor did the world market turn against Madeiran sugar. If anything, just the opposite (see Figure I). The paradox is that Madeira's boom played out in a period of falling sugar prices, while its crisis unfolded in an era of rising real prices. That is to say, the rising price of sugar was no artifact of the Price Revolution, with its origins in the European silver mining boom of the 1460s, accelerating strongly after 1520 (Braudel and Spooner, 1967; Munro, 2003). Thanks to the fruits of empire, Portuguese Crown, had been able to stabilize the *cruzado* in 1489, and for the next half-century it remained one of the most stable currencies in Europe (Godinho, 1969: 168). Thus, the relation between nominal and real price movements for Madeira's sugar in this era of crisis is a rather robust one.

What makes the political ecology explanation all the more compelling is yet one further paradox. Madeira's sugar revolution unfolded during an era of declining real prices. Virginia Rau, examining these movements' relation to Madeira's producers, traces a decline in price from an average of 725 *reais* per arroba in 1469 to 475 *reais* in 1496 (1964: 9; also Vieira, 2004: 62). Sugar prices in England declined 75 percent – and in France by a little more – over the course of the fifteenth century (Edel, 1969: 26; Taylor, 1978: 14). The nadir was the depression of 1497-99, a genuine overproduction crisis. But it was short-lived. Recovery and thence renewed expansion was quick (Albuquerque and Vieira, 1988). How was this possible? The sugar revolution's yield honeymoon depressed the costs of production faster than market prices fell.

After 1500, Madeira's sugar enjoyed steady or rising prices (Pereira, 1969d; also Garfield, 1992: 65). Measured in gold, the price of sugar increased 460 percent on the London market between 1501 and 1540 (Simonsen, 1957: 143). Demand for the island's sugar was also consistently high in Antwerp, where prices were rising through the first half of the sixteenth century (Harreld, 2003: 151). Indeed, sugar generally – in contrast to the spice trade – enjoyed steadily rising real prices in the sixteenth century, reaching .44 percent per annum until 1550, and .53 percent over the next half-century (O'Rourke and Williamson, 2002: 446-448).

If there was, by the early sixteenth century, a fuelwood crisis, there must be some evidence rapid deforestation over the previous decades. Looking at the biogeographical record, we find successive extinctions of endemic molluscs during the first two centuries after settlement (Goodfriend, Cameron, and Cook, 1994). The earliest extinction occurred in the beginning of the sixteenth century, another at the end, and another in the seventeenth century (1994: 315-318). The cause of these extinctions? Goodfriend and his colleagues conclude that:

> Habitat disturbance is mostly likely the cause of most or all of the extinctions… *With the coming of man to the island, there was a rapid and large-scale change in the habitat, from woodland to grassland*, with major effects on both species composition and relative abundances…. There was a loss of most of the woodland species, presumably mainly as a result of physiological stresses. There was also a relative increase in the grassland element (Goodfriend, Cameron, and Cook, 1994: 318, emphasis added).

Selective deforestation, in the terms that I've sketched, might however provide an explanation of rapid decline. Let us walk through several instructive pieces of evidence. First, it seems clear that Madeira's accessible forests did not regenerate for several centuries. Madeira was importing wood for wine casks and other purposes from New England by the mid-seventeenth century, an enduring trans-Atlantic division of labor that persisted into the nineteenth century and beyond (Duncan, 1972: 124, 153-155; Lyall, 1827: 361).

Such selective deforestation could be seen even during the boom decades of the late fifteenth century, as new centers of sugar refining began to emerge. While crude processing of cane had to take place on Madeira, further refining was increasingly relocated from Lisbon to Antwerp and northern Italy. By 1496, one-quarter to one-third of Madeira's sugar was marketed by Flemish capital, a volume of sugar six times greater than Portugal's sugar inflow (Furtado, 1963: 8; Birmingham, 2000: 13; Taylor, 1978: 16). Fuel-intensive clarification and refinement was increasingly relocated to northwestern Europe, Antwerp above all. Under conditions of formal colonialism, this might be explained through mercantile policies. But Madeira was part of Portugal, not a Flemish. The recentering of sugar refining suggests a situation of rising fuel costs not only on Madeira, but also in Portugal, relative to northwestern Europe. While the maritime Low Countries were sparsely forested, urban manufacturers such as sugar refiners could access abundant peat, and later, coal (de Zeeuw, 1978).[345]

But Lisbon had neither coal nor peat. To make matters worse, timber resources were limited in Portugal relative to the rest of Europe (Boxer 1969: 56; Wolf 1982: 111; Marques, 1972: 4). In 1559, the Crown prohibited sugar refining in Lisbon because its excessive fuel demands threatened the supply of shipbuilding timber (Mauro, 1983: 272). While sugar did not demand high-quality timber, in Portugal as throughout early modern Europe, such timber was widely used as low-quality fuelwood. The political ecology of Europe's forests was dominated by an endemic (and chaotic!) "battle for wood" amongst the widest range of commodity producers (Devy-Vareta, 1986; Goodman, 1997, 1998; Westermann, 1996). In 1565 the Crown imposed a "Law of Trees" and would initiate various tree planting schemes over the next few decades (Marques, 1972: 272). But with little success. "Forest resources continued to shrink until the eighteenth century" (Mendes, 2004: 83). Barros reports that "mentions of timber shortages [began to appear]… in Lisbon by the end of the sixteenth century" (2006).

It is no surprise, then, that the Crown's 1559 prohibition was issued at the very moment when the Crown was taking other measures to preserve forest resources, when Madeira's sugar complex was in a free-fall (thanks to deforestation), and when the Mediterranean world as a whole was in the midst of, if not a forest "crisis," then certainly a resource "crunch" characterized by rising fuel and timber costs (Cipolla, 1976: 228-230).

Was it merely coincidence that Madeira's timber had been exhausted at the turn of the "first" into the "second" sixteenth century? It seems unlikely. Signs of ecological stress on this front – Braudel thought the situation sufficiently grave to call it a "timber crisis" (1972: 143) and Cipolla agrees (1976: 228-230) – were apparent all across Mediterranean Europe. Indeed, Antonio dos Santos Pereira sees an exhaustion of Portugal's first imperial ecological regime in the 1520s (2006). Madeira's crisis was surely one contributing factor. If Portugal ran into trouble somewhat earlier than the rest of the Mediterranean, is this not explicable, at least in part, by its head start in overseas expansion? Not just Portuguese but Spanish shipbuilding was "in a state of crisis from the 1560s on" (Phillips, 1986: 22; also Goodman, 1997: ch. 2; Parry, 1966: 178). Philip III (Portugal's Felipe II) (r. 1598-1621) would be warned by a senior naval commander that

[345] Amsterdam's refineries would come to consume so much coal that the city government banned its use in 1614 on the grounds of excessive air pollution (Braudel, 1982: 193). This would be repealed by 1643, when the cost of firewood and peat had doubled since the ban was imposed (van der Woude, 2003: 70).

"those lands [within Portugal] that produce wood *should be guarded like the Potosi hills*" (quoted in Barros, 2005: 11, emphasis added).

The Mediterranean's timber crisis was intimately connected both with geographical expansion of the world-economy and its multilayered reconfigurations. The relocation of shipbuilding centers and the commodity frontiers – of sugar planting in this instance but of course, vitally, silver mining as well – were dialectically bound. On the one hand, the Mediterranean crisis allowed northwestern Europeans not only to capture the high-profit activities of the sugar complex (refining and marketing), but also the high-profit lines of shipbuilding. Shipbuilding was the basic industry – the production of the means of production, if you will – of the sixteenth-century world-economy. There are few better proxies of development (or underdevelopment) for the era. Whereas Southern Europe's share of European fleet capacity was 40 percent in 1500, by 1780 it had fallen to 15 percent (van Zanden and Horlings, 1999: 36; Unger, 1992: 260-261)). Of course the winners in all this were the Dutch and the British above all, not coincidentally the powers that occupied the commanding heights of world capitalism in the seventeenth and eighteenth centuries.

Conclusions

Baldly put, Madeira's sugar economy crashed because they cut down the forests. Not all the forests, to be sure. But a selective deforestation that reached critical mass so quickly that it compelled a radical contraction of output just a decade after its 1506 peak. No fuel, no sugar. Rising fuel costs intersected with Madeira's other cumulative woes: the exhaustion of the soil, pest invasions, rising labor costs. Market demand remained favorable in the sixteenth century, indeed more favorable than it had been during the boom years of the late fifteenth century. But not so favorable that Madeiran sugar could overcome the sylvan poverty of the Portuguese Atlantic. Given the slow regeneration of the forests, we would expect to see an industry dependent on massive and rapid forest exploitation to expand quickly and collapse precipitously. We might then expect to see periodic, but short-lived, revivals of that sector, given favorable price movements, once the forests enjoyed sufficient respite from overexploitation. And this is precisely what we see (Mauro, 1983). Madeira did indeed experience successive, short-lived sugar booms in the late sixteenth and seventeenth centuries. But it would never again scale the commanding heights of the world sugar economy. And this is after all the point. Early capitalism's boomtown regions were vast and varied, precisely because its ecological regime depended on the endless conquest of the earth to sustain modern economic growth.

What was the nature of this early modern ecological regime? The case of Madeira points us towards a new ecohistorical pattern that began to cohere after 1450, at the beginning of Braudel's "first" sixteenth century, and part and parcel of the rise of capitalism not only as world-economy, but as world-*ecology* (Braudel, 1953; Moore, 2003c). It was an unusual pattern indeed, and one that the sugar commodity frontier pioneered in decisive ways. To put it schematically, after 1450 across the spaces of the European economy, production centers were locked in a competitive struggle through which victory was achieved by maximizing and accelerating the extraction of wealth from land and labor. I am not convinced that this early modern ecological revolution was a narrowly Smithian phenomenon, as if the commercializing impulse had been stilled during the fourteenth century crisis, waiting to burst its medieval carapace. It is a perspective articulated by some of the most influential environmental historians (Merchant, 1980; Hughes, 2001; Richards, 2003). But is it perhaps more fruitful to situation commercialization as rather more than consequence than cause? (Without of course wishing to divest the latter of its causal power.) My preference is to situate the cascading ecological revolutions of the early modern era within a more expansive competitive dynamic specific to the conditions of Europe's emergence from the long ecological and social crisis of the fourteenth century – conditions that had as much to do with agrarian class structures and the Continent's state machineries as they did with concentrations of economic power. Over time (much less time than ever before), this emergent ecohistorical pattern, increasingly modern in its intensive and accelerating movements, led to *relative* exhaustion. Over the course of a half-century, the new dynamic undermined regional-scale profitability. Successive regional sugar complexes thereupon faltered as relative exhaustion undermined the human and ecological conditions of production. Thence renewed the search for new, more fertile zones of production – from Madeira we move to São Tomé, Brazil, the Caribbean.

The next phase of the sugar commodity frontier would play out in the Americas, where Brazil's seemingly inexhaustible forests and soil would give rise to the most expansive commodity revolution the world had yet seen.

CHAPTER SIX

'They treat the land not as masters but simply as exploiters'

Sugar, Ecology, and the Political Economy of Enclosure in the Western Atlantic, 1550-1750

At the zenith of Brazil's sugar cycle in 1627, the Franciscan Vicente do Salvador would lament the ecological thievery inscribed in the sugar frontier: "[N]o matter how attached to the land they become, or how rich they get," he argued, the planters "treat the land not as masters [*senhores*], but simply as usufruct exploiters [*usufructuários*], [who seek] only to enjoy use of it and leave it destroyed (1627: 16). Seventy-five years earlier,[346] Manuel da Nobrega had prefigured Salvador's lament, observing in the 1550s that among Portuguese settlers, "none has love for the land… All want to act in their own behalf, *even if it is at the cost of the land, because they expect to depart from it*" (quoted in Dean, 1995: 57, emphasis added).

As we have seen, what Nobrega and Salvador observed in sixteenth and seventeenth century Brazil was hardly limited to this time and place. Madeira's crisis, a century before Salvador's denunciation, had in the 1520s set the stage for multiple re-centerings of the world sugar economy. São Tomé would emerge as the leading sugar producer by 1550, only to be displaced by Brazil at the dawn of the seventeenth century. The tendency towards Salvador's "destructive exploitation" had neither begun, nor would it end, in Brazil. For it was a world-historical tendency that made for Brazil's ascent no less than its ensuing crisis. Brazil, as with Madeira and São Tome before it, scaled the heights of the world sugar economy not in spite of this destructive exploitation, but because of it. Such exploitation was not merely destructive; it was creative. Often breathtakingly so. Mere decades after Salvador penned his denunciation, the ecological overdraft he decried would play a decisive role in the crisis of Brazilian sugar and a re-centering of the world sugar economy in the Caribbean – at first to Barbados in the 1650s and thence to the Greater Antilles in the eighteenth century (Jamaica, St. Domingue, Cuba).

This chapter takes our two major story lines to the western shores of the Atlantic after 1550. The first story is about how and why the European world-economy expanded so rapidly to encompass most of the Atlantic world by the end of the eighteenth century. This was distinctive and epochal in itself. This is the story of how the European world-economy's voracious appetite for territorial expansion was driven forward by ecological overexploitation, Salvador's "destructive exploitation." And while there is no scarcity of explanation – typically concerning the world market, geopolitical rivalry and empire-building, technological innovation, and a range of socio-cultural factors – how these movements were materialized in an ecological sense has been rarely appreciated. The most pressing analytical task, then, is to illuminate the obscured ecological moment of commercialization, great power rivalries, technology, and the full range of modernity's world-historical movements. Simply adding an "ecological factor" to the laundry list of

[346] Indeed just a few years before Salvador was born in Bahia in 1564 (Castro, 1966: 71).

agencies in the making of the modern world has been an important contribution. The present world-historical conjuncture asks that we now take the next step.

From the standpoint of the big picture, the laundry list approach tends to obscure more than it illuminates. For such an approach leaves in the catbird seat the conventional approach to historical investigation. Here I have in mind, above all, the convention to begin with society and social agencies abstracted from the ecological relations that give life to both. Among the consequences of this social-reductionist reading of world history, the role played by territorial- and capitalist-led ecological transformation after 1450 in the geographical expansion of the world-economy has been underconceptualized. As a result, such transformation has also been minimized empirically. My intent is to highlight the ecological *moment* rather than simply to add environmental "factors" into the mix or to posit an environmentally driven theory of capitalist expansion. There is no need for such a theory because all social projects are ecological projects and vice-versa (Harvey, 1993).[347] The creation and expanded reproduction of the modern world market, empire-building, socio-technological innovations, all constituted a specific kind of world-ecological project.[348] This I have discussed in terms of early modern capitalism's ecological regime, one that privileged the geographically extensive accumulation of capital over the productivity-maximizing innovations that have come to be associated with capitalism in the wake of the Industrial Revolution.[349]

Our second story line is one of the rise and fall of regional production complexes. Our world-historical lens brings into focus such regional complexes as they moved to center stage in the world sugar economy. Neither epiphenomenal nor autonomous, neither wholly determined nor determining, these regional commodity centers were at once spaces created to resolve world-scale contradictions, only later to become powerful drivers of these contradictions, and in the systemwide crises that ensued.

If the colonial projects of Spain and Portugal (among others) were simultaneously imperial-territorial, economic, socio-cultural, *and* ecological initiatives, the story must be told not only in terms of capitalism's universalizing tendencies, but also in terms of the rise, development, and demise of successive regional divisions of labor. The story differs however from the emphasis within regional geography and environmental history. Taking

[347] Novais, writing in the late 1960s (1991), was among the first to realize the ecological antagonisms inscribed in the commodity-centered colonial projects of the early modern era: "[T]he colonial economy suffered from low productivity. As a consequence… it grew extensively, that is, through aggregation of new units composed of the same factors. But still, since it did not [*could not*] reinvest on an increasing scale, but simply replaced and aggregated – it depleted natural resources. *The mercantile-slave economy was a predatory economy*. [In contrast to what we might ask?]… Just as New World colonization began as a purely commercial activity involving natural products (dye-wood, furs), just so, although with the emergence of colonial production the system took on extraordinary complexity, *it kept on depredating natural resources*. *In this sense*, then, colonial expansion faced natural limits: the draining off of resources dilapidated by the colonial mode of production. Since, meanwhile, *this process developed within a larger context* and not just in a purely economic one in its strictest sense, long before any of those limits had been reached, tensions of every type began to appear. Thus, we begin to uncover the [social and ecological] contradictions within the system" (Novais, 1991: 48; also Prado, 1967).

[348] They were specific socio-ecological *projects* as well, although these can only be adequately comprehended from the standpoint of the geographically-extensive ecological regime of early modern capitalism.

[349] Which is not to say that productivity-maximizing innovations were absent, only that they were secondary.

a page from historical sociology, the rise and demise of successive production complexes is viewed in *their dialectical tension* with the dynamics of capital accumulation on a world scale. Thus the point of departure for this world-historical geography is neither an abstract "world-economy" nor an equally abstract (I would suggest) "region." It is, rather, the tensions and contradictions, *the relations*, that in fact constitute the essence of modernity's historical geography – the intertwining of local and global history. Neither the local nor the global is decisive in any *a priori* sense. The socio-spatial relations that constitute the local and global(izing) – and all manner of differentially-scaled places – are at the heart of the argument.

Such a relational approach to the making and remaking of the modern world-system's geographical configurations allows us, in the first instance, to cut through the Gordian knot of the transition debate within Latin America.[350] Was the taproot of such destructive exploitation the backwardness of colonial agriculture, a messy trans-Atlantic projection of European seigneurialism? Or was colonial agriculture among the vanguards of the commodity system's bottomless appetite for land, labor, and wealth? The longstanding debates around these questions have generated so much heat and so little light because they are, in the main, "non-debates," to borrow Arrighi's well-turned phrase (1998). Put simply, the pivot of disagreement is a Hobson's choice. Either the regional formation is privileged in containerized fashion – as in formal comparative inquiry – or the world-scale, typically viewed as world market, is emphasized. In both cases, the scales of region and world are treated as the locus of decisive causal mechanisms, the consequence of which is a tendency to treat the world-scale as "context" or the region as derivative. The debate offers an "either/or" choice to its audience. Needed is a perspective that allows for "both/and" – a dialectical synthesis of production and exchange, the accumulation of territorial power and monetary capital, social and ecological relations.

Enclosing Brazil, 1500-1560

The conquest of Brazil was a long-run affair. Pedro Alvares Cabral's India-bound fleet set ashore in 1500. The new land would be named after its timber, just as Madeira had been, nearly a century before. Among the "first acts" of the Portuguese sailors upon setting foot in the New World was "to cut down a tree" (Dean, 1995: 41). For the next three decades, Brazil's entry into modernity could be summarized with a single word: brazilwood. A factory was established in 1504. Yielding a red dye important to textile manufacture, some 100,000 metric tons of brazilwood made its way to Europe over the next three decades, the bulk of it procured through barter arrangements with locals (Costa, 1979: 49; Costa, 1983: 51; Mauro, 1983; Dean, 1995: 46-47). It was a lucrative trade, however, and the Portuguese soon found they were not alone. By 1530, French competition in the brazilwood trade had become intolerable. Castile was busy elsewhere and seems in any event to have respected the Tordesillas agreements (1494), giving to Portugal the landmass that today we call Brazil. France however had armed itself "with a more 'modern' concept of empire based on the secular law of nations" – a concept of

[350] Of the voluminous debates, see especially Frank (1967) and Laclau's critique (1971); Hall (1984); and Stern's (1988a, 1988b) exchange with Wallerstein (1988).

empire uniquely favorable to the pursuit of free trade, and to the disregard of Papal edicts (Johnson, 1987: 11).

The Portuguese Crown had a fateful choice. Colonize Brazil or let it go. It chose the first. France could not be stopped by sea. Its advances would have to be halted on the ground. And sugar would be at the center of Portugal's ground game, as a new colonial strategy was launched in the 1530s.[351] The difficulty was that sixteenth century Portugal was not seventeenth century England. The motherland offered precious little in the way of a relative surplus population. Only a settler colonialism shot through with seigneurialism and bourgeois acquisitiveness would do. The Crown launched the new colonial venture by "shifting the costs of such extensive colonization to private investors, many of whom had already expressed interest in taking up New World lordships with the aim of growing sugarcane" (Johnson, 1987: 12) By the next decade, enough was produced to load somewhere between forty and fifty ships for export to Europe (McAlister, 1984: 263).

Sugar was in play by the 1540s, but its efflorescence awaited. Necessary was a conjuncture of several developments, foremost amongst them the deepening crises of Atlantic sugar cultivation in the Atlantic Islands (Chapter Five). These crises signified the erosion of competitive barriers to the entry of new regional producers, and liberated essential technical expertise and capital.[352] The quantum leap in the volume of Brazilian production would in turn rest upon the indispensable infrastructures of the slave trade and the shipping-shipbuilding sector *powerfully stimulated by the Atlantic sugar islands and yet not dissolved in the wake of their crises*.

Brazil's take-off depended on a buoyant world market but cannot be explained by it. As we saw in the last chapter, real prices for sugar in Europe increased .44 percent annually until 1550, and then .53 percent until 1600. Brazil's moment in the sun as the vanguard sugar producer was in fact a period of *falling* prices on the world market (O'Rourke and Williamson, 2002: 446-448). In part, the rise of Brazil depended upon the decline of Atlantic producers. As Madeira and then São Tomé proved unable to meet rising European demand, Italian and especially Flemish capital — the decisive ingredient in Madeira's ascent — began to direct their attention to Brazil (Harreld, 2003: 153-154; Blackburn, 1997: 169; Castro 1966: 93; Fernandez-Armesto, 1982). This redirection of capital towards the south Atlantic would make possible the large-scale deployment of African slave labor in Brazil's sugar revolution.

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[351] It would be a mistake to explain the shift to sugar solely in terms of inter-imperialist rivalry. This was important, but it was not everything. The brazilwood regime imposed by the Portuguese was showing definite signs of exhaustion by the 1530s and 1540s. The Indians had reorganized themselves around the brazilwood trade, and had become increasingly astute in their bargaining strategies. Duarte Coelho, the donatory of Pernambuco, where Brazil's first sugar boom would begin, wrote to the King in (1545): "To get your brazil wood [the traders] importune the Indians so much… that my country is all in disorder. For it is not enough, Sire, to give them tools as was customary. To make the Indians fetch brazil wood is now necessary to give them beads from Bahia, and feather caps and coloured clothing that a man could not afford to buy to clothe himself and, what is worse, swords and arquebuses… For when the Indians were needed and wanted tools they used to come and, in return for what we gave them, they did the carrying and all the heavy work, and used to come and sell us food, which we needed rather badly. But now that they have plenty of tools they are becoming more useless than usual, are growing restless and proud, and are rebelling" (quoted in Blackburn, 1997: 163-164).

[352] Until the 1580s, Brazil's sugar sector was dramatically undercapitalized (Schwartz, 1978: 51).

If money capital was indispensable, it was not sufficient. The large-scale reworking of Brazil's social and ecological landscapes was an indispensable precondition. Brazil enjoyed some advantages that Madeira and São Tomé did not. In contrast to the island producers, the hydrologic cycle was not so easily disrupted, and large-scale irrigation works were for the moment unnecessary.[353] Brazil's northeastern bulge offered extraordinarily rich soils. Its *massapé* was a "rich, clayey soil which lies in a thick porous mantle over the Cretaceous clayey shales and calcareous rock" (Castro, 1966: 27). *Massapé* would help to make Pernambuco and then Bahia the world's greatest sugar producers in the first half of the seventeenth century. But environmental advantages went only so far. Successive and multiform enclosures – the colonial moment of Marx's primitive accumulation – were necessary to protect plantations from indigenous attack, to dragoon Indians into plantation labor, to organize and sustain the cultivation of basic foodstuffs, and to impose large-scale colonial territoriality and along with it, private property.

However much the extension of plantation societies may have resembled a kind of hyper-commercialized seigneurial order (e.g. Curtin, 1990; Genovese, 1969), the substance of the competitive relations in which Brazil's planters were enmeshed was quite different from what prevailed in medieval Europe. Planters were increasingly subject to, and dependent upon, specifically *capitalist* market relations through which their plantations reproduced themselves and according to whose logic they thrived or perished. Virtually all slave purchases were made on credit, owing to the chronic insufficiency of capital accumulated within the plantation (Mattoso, 1986: 67, 69; Koster, 1816: 355). Mauro is emphatic:

> The 'triumph' of the sugar cycle in the seventeenth century assumed the ascendance of the *senhores de engenho… But their profits remained limited*. The biggest winners were the merchants, the intermediaries with Europe (1972: 167, emphasis added; also, Mauro, 1983;Cardoso, 1983: 108-110; Mintz, 1985: 44-45; Braudel, 1982: 190-194).

To be sure, colonial planters would find greater "wiggle room" to effect relative and temporary withdrawals from globalizing market forces than, say, an urban manufacturer in the early twenty-first century.[354] That seigneurial relations *of a sort* did persist can hardly be denied. But *increasingly* – the secular trend is crucial – it was a seigneurialism dependent upon the dynamics of accumulation, and credit markets especially. Throughout the Lusitanian world especially, "successive Portuguese kings had gradually obtained control of the captaincies by sending out royal treasury officials, magistrates, and *corregedores* to supervise them" (McAlister, 1984: 253).

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[353] This led Sauer to remark that the "discovery that sugar could be grown well in the New World without irrigation made American cane plantations the prototype of virtually" all subsequent plantation systems the world over (1981: 49-50). This is something of an overgeneralization. Large-scale sugar cultivation on the mountainous Caribbean islands in the later eighteenth century – St. Domingue was the most significant – was dependent on the construction of expansive irrigation works.

[354] One could make a broad analogy to, *inter alia*, the haciendas of New Spain in the seventeenth century, which were perhaps more autonomous from global financial circuits, because they were not central to the world sugar economy, which is after all the point.

Here was an instance of the "articulation" of modes of production seldom attended to. It was precisely the increasingly capitalist dominance within such articulated relations that rendered the sugar commodity frontier especially voracious of human and extra-human nature. The competitive inter-state and inter-enterprise dynamics fueled each other. These manifested at the level of the production unit through escalating pressure to push land and labor beyond sustainable limits. Precapitalist regimes had worn down their environments too, but none responded by systematically exporting their regional ecological crunches through endless global expansion. Increasingly, planters found themselves in a position where they had to "sell to survive" – planters were typically heavily indebted and membership in the planter class was highly unstable[355] – and this predictably encouraged planters to overexploit land and labor in the middle-run to save to save their skin over the short-run.

This middle-run was about fifty years. Typically within the course of a half-century this dialectic undermined productivity, which drove the sugar frontier ever onwards to virgin soil,[356] which in turn required fresh supplies of capital and labor. A vicious circle indeed! American planters were yoked to a globalizing system of debt peonage reminiscent of seventeenth century eastern Europe and Norway (Malowist, 1959; Wallerstein, 121-22). The tendencies towards ecological overdraft, vigorously in play within northern Europe (Chapter Four), were even more powerful in the Americas. (Even as the strategic contributions of each zone were qualitatively similar.)

Italian, Dutch, and British financiers, not planters, were the primary beneficiaries of the sugar frontier (Braudel, 1982: 192-194). These financiers' accumulation, of course, depended upon successive waves of primitive accumulation on a continental scale in the Americas, in this instance the incorporation of Brazil's ecological wealth into the world capitalist system. Brazil's early settlers

> presumed upon the inexhaustible fertility of cattle, turtles, and birds, and upon the immeasurable resources of the forests: indeed, they seem to have gone berserk in the presence of so much edible wild life and a continent covered with firewood. In time, this waste went too far (Pares, 1960: 2; also Galloway, 1989: 63, 73; Miller, 1994).

Brazil's sugar revolution was impressive indeed. Just as the silver commodity frontier had earlier moved from central Europe to Peru during the 1540s, so the sugar commodity frontier by mid-century found its way to Brazil from the Atlantic islands, where (as we have just seen) the sugar monocultures had exhausted the soil and the slaves who worked it. Brazil's *engenhos* – these were sugar mills that serviced multiple plantations[357] – multiplied by a factor of *twenty-four* between 1550 and 1585 (Edel, 1969: 27). By 1620,

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[355] On this question see among others Dunn (1973), Lockhart and Schwartz (1983*:* 207), Pares, (1960); Sheridan (1973).

[356] By this I don't mean to suggest that the land upon which new sugar plantations were established had not been modified by previous human action. Indeed, there is a growing literature that speaks to the large-scale environmental transformations of pre-Columbian societies (e.g. Denevan, 1992).

[357] "Whilst, strictly speaking, the word *engenho* referred only to the mill for grinding the sugar cane, the term came to be applied to the whole economic unit: the mill itself, the associated buildings, the cane fields, pastures, slave quarters, estate house, etc. The term 'plantation' was never used by the Portuguese or Spanish of this period" (Johnson, 1987: 30).

the volume of sugar exports had expanded five and half times over (Blackburn, 1997: 172; Schwartz, 1987: 75).

A glance at parallel frontier movements on both sides of the Atlantic is instructive. If we were to look west from Bahia and Pernambuco in northeastern Brazil in the 1570s, we would see that this sugar revolution was no isolated phenomenon. The Brazilian sugar revolution and Potosí's silver revolution were astonishingly synchronous. The first phase of Peru's silver boom, based on surface deposits and Indian-controlled production, was simply a more lucrative analogue to the brazilwood trade (Chapter Three). Brazil's sugar exports and Potosí's silver output would skyrocket in the decades after 1570. (The nature of the teleconnections between the two regions remains an open question.[358]) And if we were to look far to the northeast from Brazil, we would also see that the extraordinary expansion of Dutch shipbuilding and the penetration of Dutch capital into southwestern Norway's timber regions also dates from the 1570s; so does the most vigorous expansion of Polish grain exports to Amsterdam (see Chapter Four).

How significant was Brazil's sugar revolution? From the standpoint of world accumulation, we can see that by 1600 Brazil's sugar exports amounted to nearly "double the total annual value of *all* exports from England to *all* of the world in that period" (Blaut, 1993: 191-192). Blaut reminds us further "that British exports in that period, principally of wool, are sometimes considered paradigmatic for the 'awakening,' indeed the 'rise,' of early-modern Europe" (1993: 191-192). By 1650 Brazil's "sugar shipments had reached the value of those of Spanish American silver in the mid-sixteenth century" (Blackburn, 1997: 173). This value, to be sure, was hardly accumulated by the planters alone. The merchant-wholesalers (as capital) and the empire (as revenue) took the lion's share of the surplus. The strategic significance for the Crown can hardly be underestimated. Sugar receipts constituted 40 percent of the Portuguese Crown's receipts in 1627 (Blackburn, 1997: 173).

The revolutionary character of Brazil's sugar commodity frontier turns on a threefold commodification – 1) the commodification of the sugarcane; 2) the commodification of the land; and 3) the commodification of labor power. The modern colonial endeavour pivoted on securing the necessary reservoirs of human nature *qua* labor power and the establishment of productive units capable of extracting ecological wealth from the soil in the interests of crystallizing it into monetized value, the lifeblood of capital accumulation. Of these three pivotal moments, by the late sixteenth century the commodification of sugar was no longer trailblazing. Even in medieval Europe sugar was an important item of commerce. Even so, the scale of all three moments would undergo a quantity-quality shift in seventeenth century Brazil. Since the expansion of sugar commodity production was in great measure dependent upon the revolutionary mobilization of labor, and the vast enclosure of land (by direct and indirect means), I will focus on these latter, shifting the narrative back and forth between these constitutive moments of primitive accumulation in the making of Brazil's sugar complex.

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[358] From the standpoint of economic history, however, Cross (1978) makes a strong case for the invasion of Portuguese merchants – alongside "Luso-Brazilian interlopers" (1978: 157) – into Peru during the union of the Portuguese and Spanish Crowns (1580-1640). This was a period, perhaps not coincidentally (?) as we have noted, of rapid accumulation in the Iberian *colonies*, even as the Iberian formations lapsed into stagnation and agro-ecological crisis. Among the questions raised by this Luso-Peruvian web of connections is the relationship between these capital flows and transformations of material life.

Colonial Primitive Accumulation, Part I: Indigenous Labor Power

Let us begin with labor power. First the simple stuff. Throughout the Americas, indigenous peoples were not especially inclined to work for wages. The necessary precondition for the large-scale mobilization of indigenous labor was therefore a colonial moment of Marx's primitive accumulation. The very scale of these enclosures and expropriations outstripped anything witnessed in contemporary Europe. Dean puts the zone of "effective occupation" (I would say conquest, but this is quibbling) at 16,000 square kilometers of Brazilian coastline by 1600 (1995: 64). Most of these 16,000 square kilometers were enclosed in the second half of sixteenth century, accelerating we might add at precisely the moment of cascading financial, fiscal, and agro-ecological crises within Europe. 1557 was not a European crisis nearly so much as it was a turning point in the transition to capitalism across the breadth of the Atlantic economy. Even this reckoning of enclosure may be too modest. For Dean's 16,000 square kilometers does not include the expansionary movements of ecological imperialism effected by European livestock, an important vector of expansion in Brazil.

These enclosure movements were as much about commanding space in militarized fashion as they were about organizing space into abstracted, interchangeable parcels. The effective occupation – should we say also the *creation*? – of Brazil rested on an admixture of enclosure by force of law and arms peculiar to Portugal's "monarchical capitalism" (Dean, 1995: 64; McNeill, 1984; Poppino, 1949; Prado, 1967; Subrahmanyam and Thomaz, 1991). And yet this was no mere replay of the *Reconquista*. The slave raiding expeditions (*saltos* and *entradas*) ranged ever farther into the interior because the commodity engines of the coastal plantations demanded it. The *Reconquista* had an end. The slaving frontier, like capitalism itself, was endless.

Indians may have made for poor workers, but this mattered little so long as supplies were plentiful. Plentiful but not necessarily pliant – the settler invasion that commenced in the 1530s quickly set in motion escalating Indian resistance. The high tide of this resistance inflicted "disastrous" consequences on settlements along the coast in the mid-1540s. Raids "wiped out the colonies of Bahia and São Tomé and severely crippled" two others (Johnson, 1987: 19; Deerr, 1949: 104). Nevertheless, the Crown's imposition of royal control in 1549 provided the muscle necessary to secure the sugar plantations and the labor power needed to work them. It was no accident that the new governor, Tomé de Sousa, set ashore in Bahia and promptly re-established Salvador da Bahia as the Brazilian capital, which it would remain until 1759 (Schwartz, 1969). With the assertion of royal control, the pacification of the countryside commenced. Throughout the 1550s successive military campaigns secured the Recôncavo for private property (Schwartz, 1978: 57). The explosion of Portuguese slave raiding (*saltos*) that followed was frowned upon by the Jesuits, and at least officially by the Crown, but with little effect (Schwartz, 1978: 57).

In this earliest phase of conquest, the interweaving of military and ideological power specific to the medieval *Reconquistas* found new life – and modern form – on the Brazilian frontier. Successive pacification campaigns coupled with Jesuit initiatives to create a European peasantry through forced resettlement. Bahia was at the center of this imperial coupling. The new villages were called *aldeias*, which we might put in the same broad category as the Peruvian *reducciones* (Chapter Three). Not by happenstance, the *aldeias* were sited on land inhospitable to sugar cultivation (Abreu, 2004: 370).

Organized in strict geometric fashion, these villages were amongst the earliest expressions of a thoroughly modern pacification strategy, one infamously crystallized during the Vietnam War as "strategic hamlets."[359]

These two moments combined to propel the demographic crisis to new heights. On the one hand, the military campaigns pushed coastal Indians into the *sertão*, the drought-prone interior (Andrade, 1980). Disease followed these refugees. On the other hand, in Bahia the Jesuits organized some 40,000 Indians into twelve *aldeias* during the 1550s and 1560s (Schwartz, 1978: 51). Not coincidentally, the sites for the *aldeias* were located away from the *massapé* soils best suited for sugar cultivation (Schwartz, 1978: 54). Flight from the *aldeias* was massive; indeed Indians sometimes preferred sugar's brutal labor regime to life in the hamlets (Schwartz, 1978: 52). Once established, the strategic hamlet strategy represented an epidemiological no-win situation for the Indians. To the extent the Indians were concentrated in the *aldeias*, Eurasian diseases could diffuse rapidly *within place*; to the extent that Indians fled, Eurasian diseases diffused rapidly *across space*. By 1590, only ten percent remained of the original 40,000 Indians concentrated into the camps (Schwartz, 1978: 51).

The escalation of Portuguese pacification measures in the 1550s were at once necessary to secure land and labor for the sugar plantations – and to protect *engenhos* from attack – and in the same breath constituted a crisis-producing strategy. At its core was the "deadly triad of warfare, disease, and famine" (Schwartz, 1978: 60). This crisis came to a head between 1560 and 1563. In Bahia's *aldeias*, one-third of the residents perished in 1563 alone. The mortality rate was if anything higher in the region's *engenhos* (Schwartz, 1978: 58).[360] Overall, 30,000 Indians died in just three months (Alden and Miller, 1987: 199). Sugar was in trouble.

The long-run response was a shift towards African labor power. But over the short run, this was impossible. Credit was in short supply and therefore costly. The same was true for African slaves. Both would become cheaper after 1580, as São Tomé confronted challenges of its own, and European demand continued to grow. But long-run tendencies did not obviate the need for short-run solutions. At the top of this list was a renewal of slave raiding. Together, rising demand for labor power from the *engenhos* and the decimation of the coast's indigenous population set the stage for a renewed phase of the slaving frontier after 1570. The Crown in that year formally proscribed Indian slavery,

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[359] Recall the grid-like pattern of Spanish-town building in the Peruvian *reducciones*. The same pattern held for the *aldeias*, "physically organized according to European norms, with a central plaza, a church, and rows of house units flanking the open space" (Schwartz, 1978: 52n). It is open to question, however, whether this urban vision can be chalked up to "European norms." Salvador da Bahia and other Portuguese cities were not organized according to this vision (Schwartz, 1969; Russell-Wood, 1977) – there is then a contrast between Spanish and Portuguese town building in terms of the organizing nodes of political and economic power, but a striking similarity in the spatial strategy of subordinating the colonized. "Company towns" are always more tightly structured than cities that take shape rather more anarchically around geographical and social conditions – there is certainly no scarcity of examples of this phenomenon in U.S. economic history.

[360] Nor would this be the end of the story. Over the next two decades, overwork and geographical concentration reproduced the favorable disease environment. Nine thousand Indians living around Salvador da Bahia perished in just one year (1581) (Metcalfe, 2005b: 379). On Bahian sugar plantations that year they died in "such great numbers… that the mills had to stop grinding the cane for lack of laborers" (Metcalfe, 2005b: 379).

but this merely registered the grim facts. The Crown's edict left room for a great many loopholes, foremost among them the doctrine of "just war." By 1574, the doctrine was so broadened that "just" wars became, well, *just war*. It was, in other words, business as usual – "almost anyone could go slave raiding with impunity" (Hemming, 1978: 151; also Abreu, 2004).

The proof was in the pudding. By the 1580s, the Jesuit Fernão Cardim (1583) thought 40,000 Indians had been captured from the *sertão* and brought to the sugar plantations of Bahia and Pernambuco in the previous quarter-century (cited in Metcalfe, 2005a: 189; also Hemming, 1978: 143). Another "Jesuit writer claims that 20,000 Indians had been brought just from the *sertão* of Arabo to Bahia" in only *two years* (1575-77) (Metcalfe, 2005a: 188). At the same time, a conjuncture of climate and Portuguese-led socio-ecological disruption created famine in the *sertões* of Pernambuco, which forced as many as 4,000 Indians into the coastal plantation zones during 1583 and 1584 (Schwartz, 1978: 59). Far from an isolated or climate-driven phenomenon, such famine was a structural feature of Portuguese advance in Brazil, undermining an indigenous mode of cultivation much more vulnerable than those found by the Spanish in the Andes and Mexico. The upshot was a dramatic enlargement, by direct and indirect means, of the relative surplus population accessible to the plantation economy. Relative to a white and mestizo population of between ten and twenty thousand at the dawn of the seventeenth century (Dean, 1995: 66; Schwartz, 1969: 635), these tens of thousands of Indian laborers marked a significant demographic surplus indeed.

Colonial Primitive Accumulation, Part II: Private Property in Land

The imposition of direct Crown control over the colony in 1549 aimed directly at the expansion of the sugar frontier. The Portuguese Crown was a revenue-maximizing machine and in colonial Brazil this necessarily entailed commodity production – in contrast to the Andes and New Spain, there was no peasantry for the Absolutist State to latch onto (Larson, 1988). Governor Tomé de Sousa was sent to Brazil with "specific directives" concerning sugar policy. Land would be distributed through *sesmarias*. Recall that the essence of the *sesmaria* was the compulsion to work the land. Ownership and alienability was conferred only after the land had been worked for several years.[361] So there is an evident continuity with fourteenth century Portugal and fifteenth century Madeira. In Brazil, however, the emphasis on the ground seems to have been much more commodity-centered:

> In Portugal the policy of royal land grants had been intended to stimulate peasant production for the supply of the towns; in Brazil it was bent to the purpose of encouraging the search for gold and gems, or failing their discovery, the production and export of sugar. Pretenders to *sesmaries* who, as evidence of their worthiness, at first emphasized loyal services to

[361] I don't wish to overstate the case. The sesmaries *were* implicated in the creation of a Brazilian peasantry, but also limited the possibilities for the emergence of capitalist yeomanry. The sesmarias "were quickly broken up into small holdings by absentee landowners who subdivided their domains among individual farmers and then appropriated the farmers' profits as rent, while they themselves remained apart from the actual production process" (Riegelhaupt and Forman, 1970: 104).

> the crown or their descent from the first settlers, *later came to emphasize their ownership of slaves to demonstrate their capacity to increase exports* (Dean, 1995: 72, emphasis added).

The precociously capitalist character of Portuguese colonialism was evident even before the establishment of direct royal control. Sixteen years earlier, in 1533, the Crown had carved up Brazil into fifteen *captanias donatarios*, granting these to twelve Portuguese noblemen (Schwartz, 1985: 17).[362] In certain respects, the donatory captains resembled medieval lords: "Within his jurisdiction, the captain had the legal right to do almost anything" (Curtin, 1990: 50). But in other ways the transition to capitalism was in full sight. The territories themselves had been imagined and then codified through the geometrically-informed, cartographic gaze of early modernity (Cosgrove, 1985). The boundaries of the captaincies were straight lines running from the coast to the Tordesillas boundary. No overlapping territoriality here! No less crucial, the *captanias* gave *carte blanche* to the donataries in the political realm (easily superseded as we've seen), but not in the economic sphere. The Crown reserved to itself "the economic advantages a merchant might normally want – not a king" (Curtin, 1990: 50; also Taylor, 1978: 17-18).

The new imperial geography was clear and in play. The Crown "denied that the natives retained any legitimate right to the spaces they occupied" and projected a "concept of the ownership of nature… [as] an abstract entity, *terra*," a concept that necessarily erased the "prior claims or even the presence of the indigenous inhabitants" (Dean, 1995: 62-63, order of quotations altered). As we have seen, this juridical attack was aided and abetted by relentless slave raiding. A half-century of slave raiding "netted, out of an original population of 150,000, perhaps 60,000 captives," half of whom were sold to sugar planters (Dean, 1995: 81). This labor demand/slave raiding nexus served as a recurrent impetus to the extension of the Europeans' free fire zone. The sugar commodity frontier set in motion its very own subsidiary dynamic of primitive accumulation whose core expression was slave raiding, depopulation, and thence to renewed slave raiding (Dean, 1994: 80-81; Metcalfe, 2005a: 157-193; 2005b).

Engenho as Carnivore:
The Slaving Frontier and the Transition to African Labor

It was capitalist Brazil's great fortune – and decidedly non-capitalist Africa's grim fate – that by the 1570s African slaves were increasingly available as substitutes to replace the withering supplies of indigenous labor power. Black slaves numbered just 3,000 in 1570. By the turn of the century, their numbers flushed to nearly 20,000 (Buescu, 1970: 84-85). About 4,000 arrived annually between 1580 and 1630. These were geographically concentrated in the sugar zones of the northeast, where two-thirds of all slaves worked at the dawn of the seventeenth century (Schwartz, 1987: 82; Blackburn, 1997: 168; Buescu, 1970: 85). The gruesome cocktail of territorialism and capitalism in the early modern commodity frontier fueled the appropriation of indigenous and African labor power alike. The expanded reproduction of the sugar complex demanded ever-

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[362] Although Curtin (1990: 50) argues that several of these donatory captains were of bourgeois extraction.

increasing supplies of human nature *qua* labor-power. Rising output was achieved through the plantation system's voracious appetite for human flesh.

Modern slavery was always relentlessly destructive of human dignity and well-being. Brazil's sugar frontier especially so. During the *safra*, the sugar harvest that typically began in late July and persisted into November, the typical slave rarely enjoyed more than four hours of sleep a night (Schwartz, 1970: 316). Small wonder that that the expression "sleepy as a slave" (*dorminhoco como negro de engenho*) became commonplace in colonial Brazil (Koster, 1816: 347). The ensuing fatigue rendered slaves vulnerable to all manner of hazards. The mills and boiling-houses were especially dangerous. "Drowsiness," Koster reported in 1816 at a time when neither technology nor labor process had much changed from two centuries previous,[363] rendered work in the mills extraordinarily dangerous:

> The negroes who thrust the cane in between the rollers have sometimes allowed [sic] their hands to go too far, and one or both of them having been caught, in some instances, before assistance could be given, the whole limb and even body has been crushed to pieces (1816: 348; also Cardoso, 1983: 96-97; John, 1988b).

So frequent were these accidents, it was common practice to keep next to the mills a "sharp machete with which to sever promptly the slave's hand or arm if necessary in order to save a life" (Cardoso, 1983: 97). (We may question how many lives were saved as a result.) "Even under the best conditions," Schwartz opines, working the fields and mills "could exact a heavy toll" (1970: 317). But the best conditions these were surely not. In "seventeenth- and eighteenth-century Brazil *the prevailing theory of slave management was to extract as much labor at as little cost as possible*" (Schwartz, 1970: 317).

And yet it was not only the severity of the regime of production that eviscerated the slave population. It was also the regime of socio-biological *re*production. (There is an instructive parallel here with contemporary developments in the Andes, as we saw in the discussion of populations within Potosí's orbit.) Slave diets were extraordinarily deficient (Schwartz, 1970). A crudely distilled brandy, in this instance the functional equivalent of coca for Andean mineworkers, "was used primarily as a stimulant to increase work capacity. The diet was not only poorly balanced, but it was also often insufficient" (Schwartz, 1970: 317).

At first glance, this seems a curious state of affairs. Planters may have viewed slaves, African or indigenous, as less than fully human. But these workers also represented considerable capital outlays. Africans especially. My sense is that the political ecology of sugar caught the planters in a structural bind. Planters found themselves locked into a debt-driven treadmill that compelled the maximization of surplus. Productivity-enhancing innovations were possible (as we shall see) but limited.

The upshot was relentless cost-cutting coupled with constant pressure to extend arable land. (And in some cases to relocate altogether.) On the one hand, cost-cutting tended to cut into the labor allocations and cash budgets for basic provisions. But production could not simply be scaled backed owing to the exigencies of the sugar harvest. Insufficient

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[363] See Eisenberg (1974: 41-42); and Barickman (1998).

labor power during the *safra* multiplied losses geometrically, not arithmetically. If planters wished to "save the harvest or the capital already invested" they were therefore compelled to secure slave labor through borrowing, apparently at very high rates of interest (30-48 percent annually) (Cardoso, 1983: 108; Taylor, 1978: 38).[364]

On the other hand, the pressure to extend arable land meant that even in expansive Brazil, sugar tended to drive out subsistence crops. Indeed the sugar monoculture evinced a "morbid hostility" not just to food crops, but toward all "other plant species" (Castro, 1966: 30).[365] In the last chapter, we saw how "sugar had killed wheat" on Madeira during the 1470s (Serrão, 1954: 341), initiating a cycle of displacement that held true across the early modern era. Of course, the agronomy and geography of this dialectic played out in distinct form in colonial Brazil. Wheat could not really be grown in northeastern Brazil (Brown, 1991: 318). And though wheat was imported – as time wore on the Brazil south became an important breadbasket – manioc would be the staple for Portuguese colonists no less than African slaves. Manioc's great virtue was its productivity. The perfect complement to sugar, it asked little of land, labor, or capital. It would also grow quite well on soils unfavorable to sugar cultivation.

While on balance the Brazilian northeast offered a more favorable sugar-growing climate relative to Madeira, there were new challenges too. To begin, there were two "northeasts." *At least two* (Andrade, 1980). One was a lush costal zone, home to thick forests. The other was the semi-arid interior known as the *sertão* (Castro, 1966: 22-25). Even on the coast, "drought alternated with torrential rains," opening the door to famine and soil erosion (Mattoso, 1986: 66; and Castro, 1966 *passim*).[366] In the abstract, climate represented a modest variable. In concert with sugar's tendency to displace food crops, however, this translated to a highly precarious food regime. The cultivation of manioc and legumes was forsaken for sugar. Manioc was pushed to the frontier. "Planters preferred to supply what was needed for immediate consumption by importing food from long distances" (Mattoso, 1986: 66; also Haskins, 1956: 68-70).

All of which was possible so long as food could be imported cheaply (or cheaply enough), and laborpower could be imported cheaply (or cheaply enough) to make good the losses ensuing from such a precarious food regime. While manioc extended the frontier on one side of the Atlantic, the slave trade necessitated a different sort of frontier on the other. The sugar-slave ecological regime was made possible by the organization of the African slave trade on precociously modern grounds, attaching abstract (and very low) value to human life itself. The sugar plantations remade their surrounding natures in exceedingly homogenizing and predatory ways through this coercive-intensive labor regime. Remarking on the 5-10 percent *annual* mortality rate of slave workers in Brazil's sugar sector, Schwartz dryly observes: "The *engenhos* consumed slaves and the slave trade replaced them" (1987: 83; also Mattoso, 1986: 104-105).

The waste of human life inscribed in this logic was possible because of the slave trade's economic calculus, which is widely acknowledged, and because of its ecological calculus, which is not. For the slaving regime delivered enormous ecological windfalls to

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[364] Cardoso's figures here may be read as exceptional rather than generalizable (see Schwartz, 1985: 202-241).

[365] An observation amply confirmed in biogeographical research (Watts, 1987; Goodfriend, Cameron, and Cook, 1994).

[366] As would become horrifically evident in the late nineteenth century (Davis, 2001).

Brazilian sugar regime. The unceasing impressment of Indian and African labor power into the service of capital accumulation represented not only an *economic* transfer from an "external arena" to the capitalist world-economy, but also (equally?) an *ecological* transfer. This was slavery's gruesome political ecology. Planters "bought slaves 'grown' in Africa on African food [or in the Americas on American food], applied their labor to the production of carbohydrates for export to Europe, and displayed little concern for their survival past the time when they could perform useful work" (Hugill, 1993: 61). Here was an ecological transfer, then, embedded in the combined and uneven articulations of an emergent capitalist system.[367]

We can take this uneven development perspective one step further. For the transfers of ecological wealth *motivated* the geographical expansion of the system no less than it created and reproduced new structures of inequality. These expansionary movements were evident on both sides of the Atlantic. In Africa, the historical geography of slave raiding and trading reveals a strong tendency towards some variant of Gadgil and Guha's sequential overexploitation (1992). European expansion was in other words driven by the dialectic of relative ecological exhaustion on the one hand, and the geographical extension of commodity exchange on the other. This is Miller's "slaving frontier" (1988: 140-169). For Miller, the bullionist dimension of the process is key. Slavery and the slave trade "allowed economic expansion without significant investments of specie," which is certainly true, and undeniably important (Miller, 1988: 686). But this may be an unduly narrow conception of "merchant capitalism" (ibid: 682-693). Once we include the eco-geographical flows underpinning the sugar-slave nexus and its contribution to world accumulation, it becomes possible to conceptualize (and empirically ground) the ecological moment of early modern capitalism as comprising more than the circulation of mobile capital and commodity exchange.

During the 1570s – note the synchroneity with the take-off of Brazil's sugar complex – we find the first stirrings of a decisive geographical shift in the African slave trade, from Senegambia towards the Congo and Angola, and from São Tomé to Luanda as the principal entrepot (Klein, 2004: 206, 209; Malowist, 1969: 27-28; Rawley and Behrendt, 2005: 20-21; Boxer, 1952: 224). (Luanda was established in 1575.) In Angola, by the end of seventeenth next century, "*the human resources of the coast were exhausted*" (Godinho, 2005: 320, emphasis added; also Boxer, 1962: 4). This set in motion the by-now familiar pattern of sequential overexploitation. The relative exhaustion of these "human resources" – relative exhaustion in terms of the semi-capitalist slaving complex – manifested in rising slave prices, which in turn precipitated the renewed "hunt for men" ever deeper into the interior (Godinho, 2005: 320; also Wolf, 1982: 195-231). Even in the early decades of the seventeenth century this slaving frontier penetrated quite far, with slaves arriving in Luanda "having marched sometimes hundreds of miles" (Boxer, 1952: 230).

The geography of this slaving frontier cannot be explained solely in terms of European market demand. On this matter Thornton is surely correct to argue for the relative primacy of internal politico-military dynamics relative to European military or

[367] Mandel ably captures the essence of this moment of combined and uneven development: "A capitalist world economy is an articulated system of capitalist, semi-capitalist, and pre-capitalist relations of production, linked to each by capitalist relations of exchange [not to mention territorialist power!] and dominated by the capitalist world market" (1975: 48).

economic power (1992). But was it coincidence that these dynamics began to generate a slaving frontier within Africa that looked an awful lot like the commodity frontiers of the slave-*consuming* zones? The slaving and sugar frontiers shared a geographical restlessness that privileged the external spatial fix, a shared emphasis that allowed for a stunning 15,000 slaves to be exported from Angola and the Congo every year in the century after 1580 (Boxer, 1952: 225). Of these, nearly 60 percent (8,500) were destined for Brazil It was not for nothing that a "slogan of the seventeenth century was 'without sugar there is no Brazil, without Angola there is no sugar'" (Anderson, 1962: 96). The slaving frontier enacted by African social formations would be increasingly subject to the gravitational pull of world accumulation after 1580. The strikingly modern pattern of geographical expansion in African slave raiding indicates that these territorialist dynamics were no longer wholly independent of the modern world market (Wolf, 1982: 195-231; Rodney, 1972).[368]

On the western shores of the Atlantic, the Amerindian variant of the slaving frontier was at work. As we have seen, Indian slave raiding was constitutive of Portuguese settler colonialism from the 1520s, and accelerated rapidly with the expansion of sugar mills in the 1540s (Metcalfe, 2005a: 174-175; 2005b). As in the earliest phases of the African slave trade, Portuguese slaving was limited to the coast. By the 1570s, that is at the very moment of the shift in the African slave trade towards Angola, the first phase of Brazil's slaving frontier had exhausted itself.

This exhaustion owed partly to Eurasians diseases. But there is more to the story. Disease was of course hardly an independent variable. It is probably best to regard epidemiological factors as proximate rather than primary in driving the shift from the first to the second slaving frontier within Brazil. The advance of Afro-Eurasian animals was, in Brazil differently but no less than in the Andes and New Spain, one major vector of disruption (Metcalfe, 2005: 153; Melville, 1994). Metcalfe sees an "ungulate irruption" of sheep, cattle, and horses in mid-sixteenth century Brazil. In this scheme of things, the introduction of new species into alien terrain offers the conditions for the exponential growth, and then rapid collapse, of populations (Melville, 1994). Drawing on Soares de Sousa's descriptions (1587), Metcalfe sees the accounts of degraded land characterized as "poor" and deemed suitable "only for cattle" around the Bahian hinterland as indicative of an earlier ungulate irruption (2005a: 154). Were these episodes perhaps linked not just to disease, but also to famine among Bahian Tupinamba in the 1560s (Hemming, 1978: 148; Dean, 1995: 75)? Viewed in this light, the synchroneity of famine and disease seems less than coincidental.

Domingos (2004) takes the argument one step further. He suggests that it was not simply the sugar frontier's demand for human labor that pushed the *entradas* ever deeper into the interior. Sugar's appetite for extra-human labor, oxen and cattle especially, set in motion large-scale stockraising, whose rapid expansion "on the open range was linear and rapid, and this required that the Indian tribes be exterminated" (Domingos, 2004:

[368] Wolf puts this well: "[T]he burgeoning slave trade had political repercussions in the areas of supply, especially since only in the rarest of instances did the Europeans engage in hunting slaves themselves. They relied instead, as the French factor Jean Barbot wrote in the late seventeenth century, on African 'kings, rich men, and prime merchants.' *African collaboration, in turn, strengthened existing states and spurred state formation in areas where no states had existed before European impact*" (1982: 206, emphasis added).

101; also Cleary, 2001: 84-85; Castro, 1966: 107-108; Buescu, 1970: 72-79). Linear? Or could we say perhaps that the trend line expresses the dialectical movement? For did not the expansion of Eurasian ungulates in themselves alter the fundamental conditions of socio-biological reproduction within the indigenous formations of the *sertões*?

Which leads us to slave raiding itself. The *entradas* certainly were implicated in the extermination of Indian peoples on the coast. Both in terms of direct capture, and in the destabilization of indigenous ecological formations. By the 1570s the coastal Indian populations were in "steep decline," but "their contemporaries in the *sertão* of the Bahia were plentiful" (Russell-Wood, 2005: 355). In Metcalfe's reading,

> Indian slaves were becoming harder and harder to obtain in the coastal regions where colonists lived. Mortality among coastal Indians had been extremely high since 1550, such that even Gondavo recognized that the coastal regions around the Portuguese colonies… had been left 'unpopulated by natives'… It would seem… that Africans would soon replace Indian slaves on the sugar plantations of Bahia and Pernambuco. *But, in fact, Indian slavery increased after 1570*…. Indian slavery did not end with the decline of the coastal population because *a new slave trade brought thousands of Indians to the coast from the* sertões, *the 'inland wilderness' frontiers* (2005a: 181, emphasis added).

Indian slavery increased it is true after 1570. But the scales had tipped decisively towards African slavery on the northeast's sugar plantations over the next decade (Russell-Wood, 2005: 358). The epicenter of indigenous slaving would subsequently shift towards the south (Dean, 1995: 57-58). In all cases, this large-scale mobilization of slave labor power enabled the rapid (over)exploitation and consequent degradation of the New World's ecological wealth.

Brazil's Sugar Frontier: A Short Economic History

'Whoever says Brazil says sugar and more sugar.'
– Municipal Council of Bahia, 1662
(quoted in Rawley, 1981: 33)

"The cane eats everything within its reach… [and as a consequence it] is self-devouring" (Castro, 1966: 28). This is the heart of the matter. It is often remarked these days that capitalism is a self-cannibalizing system (e.g. Harvey, 2003). In the early modern world, nowhere was this tendency in greater force than on the sugar commodity frontier. Sugar was the commodity frontier *sine qua non*, expanding faster than all other such frontiers. This was not simply because extraordinary profits beckoned. (Which they did.) It was equally because sugar "consumes the humus in the soil, annihilates competing crops and meanwhile destroys the very human capital on which it is ultimately based" (Castro, 1966: 28). Everyone knows that sugar moved from region to region, "gutting the land" at every stop, and "in every case, the colony which replaced its failing predecessor was land-rich at the start, land poor at the time of its eclipse" (Mintz, 1959: 273-274).

There is, then, widespread recognition that ecological factors played *some* role in the movement *between* sugar societies – that is, the movement from one leading zone to another in successive 50-75 year cycles. If the frontier movement between sugar colonies has been highlighted, the frontier movement *within* successive regimes has not. This is important, because it tells us something about the ecological contradictions through which regional sugar booms were created, how such expansions were sustained, and how they were, in a matter of decades, undermined. Geographical expansion, a mechanism of cutting costs and reviving productivity by creating access to fresh timber and fresh soil, would over time prove increasingly self-limiting. In what follows, we look at the ways that the sugar commodity frontier in colonial Brazil "gutted the land" and in so doing pushed relentlessly for renewed geographical expansion, at first from the perspective of political economy, and then from the higher synthesis of political ecology.

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We begin with sugar exports. These would make for 90 percent of all exports from the colony by the end of the sixteenth century (Buescu, 1970: 60). Unreliable in their precision, the extant figures nevertheless provide our best starting point for comprehending the geography of the sugar frontier. Simonsen provides one set of widely-cited figures (1957). Beginning in the mid-1560s, annual exports stood at 180,000 arrobas. This would nearly double by 1580 (to 350,000 arrobas), reaching two million arrobas, perhaps two and a half, by 1600 (Simonsen, 1957: fold-out chart; also Boxer, 1952: 179-180). Schwartz is more cautious. In his view, 1.5 million arrobas (24,470 tons) represents the theoretical – and "rarely reached" – maximum even in the 1620s (Schwartz, 2004: 164).[369] Mauro puts the high point of Brazil's seventeenth century output at two million arrobas in 1650 (1983: 516), a reasonable figure given the socio-technical innovations introduced after 1612 and buoyant world market demand until mid-century.

Chief amongst these technical innovations was the introduction of the vertical three-roller mill for pressing sugar (c. 1608-12) (Galloway, 1989: ch. 4; Daniels & Daniels, 1988; Schwartz, 2004; Barros de Castro, 1980). The new mills had three big advantages over the earlier two-roller mills, edge-runners, and presses. First, the technological apparatus improved the extraction of juice from the cane. Second, by eliminating the need for secondary presses, the new mills were cheaper to build (Schwartz, 2004: 163). Third, the "new arrangement simplified the mill's traction," rendering the three-rollers more easily powered by animals, especially oxen (Blackburn, 1997: 173; Poppino, 1949). This favored the dispersion of mills away from waterways, although on balance the friction of overland transport strictly limited the radius of dispersion; mills were rarely located more than a few kilometers from waterways. As long as the market continued to grow, these three advantages enabled a rapid expansion of the lower stratum of the *senhores de engenho*.

The *senhores de engenho* were those planters successful or fortunate enough to own mills. They planted cane, but their economic centrality stemmed from their ownership of the *engenhos*, the mills that ground, and then processed all cane. Colonial Brazil

369 My calculation on tonnage, assuming one arroba weighed 32.625 lbs (Deerr, 1949, I: 100). Schwartz (1985: 573) puts one arroba at 14.75 kg, which translates to 32.45 lbs (at 2.2 lbs/kg).

reproduced, on an incomparably greater scale, the two-tiered structure of Madeira's sugar regime. In contrast to the Caribbean sugar revolutions of the seventeenth and eighteenth centuries, the economic sociology of Brazilian sugar was one in which a few large-scale planters – known as *senhores de engenho* because they owned mills (*engenhos*) in addition to fields – presided over a much larger stratum of small- to middling-planters. A large *engenho* might process the cane of two dozen farmers, as was the case in the famed Sergipe Engenho in seventeenth century Bahia (Buescu, 1970: 110). These latter, the cane farmers, were the *lavradores de cana*, who relied on the millowners to process their cane. As a result, the *lavradores* found themselves in a doubly dependent position. On the one hand the *lavradores* were subordinated socially and economically to the *senhores*. On the other hand, the ecology of sugarcane required that the cane farmers secure access to a sugarmill within 48 hours, lest the cane sour and desiccate waiting in queue. The second moment decisively favored the first. Middling *lavradores* – whose farms averaged just 15-25 acres[370] – could not stockpile harvested cane. Unlike grain, farmers had no latitude to hold sugar until prices moved in their favor.

There was of course plenty of social conflict between these two groups (see esp. Schwartz, 1985: 295-312). (We shall return to this in due course.) There was, however, a built-in safety valve – a *lavrador* who was able to accumulate sufficient capital could establish a new mill on fresh land. The introduction of the three-roller mill after 1612 dramatically expanded this possibility. Cheaper, and more efficient in extracting juice from cane, the new mills "allowed smaller producers and marginal areas to enter the industry at lower cost" (Schwartz, 2004: 163).

The expansion after 1612 was remarkable. In the three decades before 1612, Brazil's sugar mills grew from 115 to 192, a sixty six percent increase or 2.2 percent annual growth.[371] Between 1612 and 1629, the number of mills multiplied from 192 to 350. Relative to the previous era, this more than doubled the annual rate of expansion to 4.8 percent (calculated from Blackburn, 1997: 173; also Mauro, 1983: 516). There was, then, a net increase of 168 mills between 1612 and 1629. Assuming that each *engenho* was established just ten kilometers away from any other *engenho* – a geometric assumption that fits uneasily with the historical-geographical record – each mill could expect to draw on a hinterland of at least 70 square kilometers, leaving 8.5 square kilometers for cultivation, pasture, rivers and lakes, etc.[372]

This geometric assumption overstates sylvan abundance for several reasons. For starters, mills often clustered geographically; the conditions for accessing forest resources were not evenly distributed. As we saw in Chapter Two, access to timber could be quite costly, even impossible, for all manner of social and topographical reasons. Forests might be rather thin, but labor plentiful and rivers widely dispersed; or quite thick forests might be home to indigenous formations uninterested in logging. Nevertheless, the simple geometric statement opens our eyes to the enormous possibilities for an external ecological fix that enabled Brazilian sugar's remarkable efflorescence. And this was in

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[370] Schwartz (2004: 187) believes the lower end of this range – six hectares (14.8 acres) – was "probably common." At the Sergipe engenho "the majority" of *lavradores* held less than six hectares and owned six or fewer slaves (2004: 186-187). About half this land would be planted in cane; the rest would be taken up with provision grounds and forest.

[371] Calculated as a simple rate of annual growth.

[372] Assuming a radius of 5 km, each new engenho would then enjoy access to a hinterland of 78.5 square kilometers ($r^2 = 25 \times 3.14 = 78.5$).

the period *after* 1600, when the best "caneland was no longer freely available," at least in the Bahian Recôncavo, which was in these years emerging as Brazil's leading sugar zone (Schwartz, 1985: 228). In this reckoning, 168 new mills just 10 kilometers apart would have created access, at least theoretically, to 11,760 square kilometers of forest. In other words, there ought to have been plenty of forest and therefore plenty fuel. This makes story of Brazilian sugar's eventual demise all the more compelling.

Start-up costs were still considerable. Partly because the *engenhos* took at least four years to build. Seven, even eight, years was common (Barickman, 1998: 37). Castro thinks the construction of large mill required the labor of between 150 and 200 workers, although these were unlikely employed full-time for the duration (1966: 103). The aspiring *senhor*, moreover, had to have credit to bridge the gap between clearing the land and eventual harvest. The expansion that commenced after 1612 was therefore a pivotal wedge for capital's penetration of colonial agriculture. If the evidence of new mill construction is any indicator, there seems to have been little in the way of serious constraints on credit flows – despite a generalized lack of specie (Schwartz, 1985: 203, 208). This expansion in the number of mills – which continued even after aggregate production volume stagnated – was therefore crucially dependent on the expansion of credit. And this of course was on offer from merchants. It was an instance of capital's preference for "unlimited flexibility" (Braudel, 1982: 433). "Merchant" capitalists happily moved beyond the limits of buying cheap and selling dear. Quite naturally this did not prevent them from using credit mechanisms – in Brazil for sugar no less than in Norway for timber or Poland for grain (Chapter Four) – to secure favorably low prices for sugar as payment for debt (Schwartz, 1985: 208).

Debt-financed expansion for new *engenhos* would have appeared as well worth the risk. Newly-cleared land promised high yields. Plentiful forests offered cheap construction timber and fuelwood. Slaves were expensive, but not unduly so, at least through 1670. They constituted about 20 percent of an *engenho*'s budget, and could be purchased on credit. Again the production figures suggest the dynamism of this movement. Brazil's sugar output grew from around 10,000 tons a year in the first two decades of the century, to 15,000 tons in the 1620s and '30s, to 30,000 tons or more between 1640 and 1670 (see Table 6.1).

Aggregate production figures, revealing strong growth through 1650 and then stagnation, are perhaps misleading. For the social composition of the *senhores de engenho* was undergoing an important shift, one with profound implications for the political ecology of the sugar frontier. The salient fact here is the continued growth of marginal *senhores de engenho*, even after the expansionary wave crested at mid-century. In 1612, there were 192 mills. In 1629, three hundred fifty. By 1670 there were five hundred and by 1710, nearly *six hundred* mills (Mauro, 1983: 516; Simonsen, 1957: 114-115). This was a 67 percent increase relative to 1629 (calculated from Edel, 1969: 42).[373]

Certainly this was a dramatic slowdown relative to the salad days of 1570-1630 (and especially 1612-29). But it is quite suggestive of ongoing geographical expansion as a response to stagnation. The number of mills increased, but the volume of sugar produced by each mill declined precipitously. If the average mill produced 62.9 tons of sugar in

[373] I've taken Simonsen's estimate of a range between 522 and 650 for 1710 and split it down the middle, to 586 (114-115). This is a fairly conservative estimate, moreover, because I have taken Blackburn's estimate of 350 mills in 1627 rather than Simonsen's much lower range of 120-200.

1627, the same mill made just 34.1 tons of sugar per *engenho* in 1710.[374] Bahia's mills tended to produce substantially above this average (51 tons), while Pernambuco's *engenhos* were substantially below it (26 tons) (Schwartz, 2004: 163). The expansion in the number of mills is usually explained in terms of the *lavradores*' desire for social mobility (Antonil, 1711: 84-85). True enough, but were not the *lavradores* of the previous century equally interested in social mobility?

What had changed? The crucial variable was the deepening profit squeeze within the Brazilian sugar economy after 1650. New mills would have offered the possibility for a short-run revival of profitability by relocating to zones with fresh soil, and more to the point – *untapped forests that lay atop fresh soil*. The ecological conditions of these frontier zones would have offered the promise of surplus profit in Marx's sense of the term (1967, II). This would have provided reasonable grounds for merchant capitalists to finance seemingly marginal engenhos, and would explain the "general result" across Bahia in the 1660s of "large number[s] of formerly successful *lavradores de cana* [becoming] heavily indebted as millowners" (Schwartz, 1985: 309).

Landscapes Found, Landscapes Conquered: An Ecohistorical Geography of the Northeast

Any account of frontier process must begin with two stories. The first is the story of the system or society that is expanding across space, and the forces driving this expansion. The second is the story of the landscape encountered. This is what historians of the American West have described as the tension between "process" and "place" (*inter alia* Cronon, Gitlin, and Miles, 1992a, 1992b). The second story is taken up by a vast literature, which accounts well for itself and need not detain us here. At the risk of ecohistorical naïveté, however, we might begin with the briefest survey of northeastern Brazil's geography. If we wish to understand the environmental history of the sugar frontier's movements across – and in the same breath its creation of – modern Brazil, it will be helpful to understand the rudiments of the landscapes that sugar would conquer.

We have just seen Brazilian sugar's extraordinary pace of expansion in the century after 1550. But so far, we have seen this largely from the vantage point of economic history. What is clear is that this extraordinary expansion was won at a terrific price, the destruction of the Atlantic forest. On this the social historians are in agreement with the environmental historians – by 1650 "the original forest cover around the Bay [the Bahian Recôncavo] had been destroyed" (Schwartz, 1985: 77; Dean, 1995).

How did this extraordinary transformation happen? The scale and speed of this devastation was incomprehensible by the standards of medieval Europe. It was a thoroughly modern event. And yet it cannot be explained solely by the dialectics inscribed in the first of our two stories. "Place" as well as "process" must be registered in the balance sheets of world history.

We might begin by looking at the topography of the Bahian Recôncavo. The Recôncavo was destined to become Brazil's leading sugar producer by the 1640s, in the wake of Pernambuco's occupation by the Dutch. Recall that sugar was an island crop *par excellence*. Islands offered many advantages to colonial agriculturalists. Above all, the

[374] My calculations. I have used Antonil's estimate of 20,000 tons for 1710 (1969 [1711]).

high ratio of coastline to land mass held to a minimum the expensive and risky tasks of overland transport. The frictions involved in the movement of the sugar frontier to a continental landmass (such as Brazil) should not be minimized.

Bahia, however, came as close to an island as any such landmass could be. The Recôncavo

> was lacerated with streams of various sizes ranging from the Paraguacu… and moderately large rivers like the Sergipe, Açu, Pericoara, and Subae to smaller streams like to Cotegipe, Jacarancaga, and Pitanga… Across the northern interior of the Recôncavo, another series of rivers like the Jacuipe, Joannes, and Pojuca ran eastward, emptying not into the Bay of All Saints but into the sea along the coast north of Salvador… The sugar plantations were, when at all possible, located on the margins of the bay or along the rivers which provided avenues of transportation and sometimes the power source as well (Schwartz, 1985: 77; also Hutchinson, 1957: 10).

Bahia was full of rivers and streams. And where there were rivers and streams, there were *engenhos*. At least in due time. Rivers promised the easy transit of sugar (out) and timber (in). The Recôncavo's thick forests were crucial, perhaps even more crucial than were its fertile soils. Sugar could be grown on poor soil but there was no sugar at all without woodfuel. In concert, the dense river network and the rich Atlantic forests offered propitious terrain indeed for sugar's rapid expansion. And yet, if the forests were in one sense a "free gift" to capital, they were a gift that could be secured only at a price. While the Recôncavo was well stocked with wood, these were hardwoods and the hardwoods didn't float easily (Miller, 1994: 187). Timber could not therefore be floated in gigantic "rafts" as was common practice on the Vistula or Rhine (Albion, 1926). Timber to be shipped on small boats. Antonil recommended in the early eighteenth century that a large engenho employ two such vessels to ensure a steady supply of fuel – as one arrived the other would collect more fuelwood upriver (1711). But river transport was expensive and a definite second option to felling nearby trees (Hutchinson, 1957).[375] An expensive option, and one from which there was no apparent escape. Sugarmaking was very much a continuous flow operation, and shutdowns owing to inadequate fuel were a serious and all-too-common phenomenon (Miller, 1994; Schwartz, 1985: 104).

The Recôncavo was a vast region of somewhere between ten and thirteen thousand square kilometers (Barickman, 1994: 653; Schwartz, 1985: 77). This was no tiny Madeira! (The Atlantic island occupied no more than 740 square kilometers). In seventeenth century Brazil, size matters quite a bit for conceptualizing the northeast's environmental history. We will have the opportunity to return to the issue momentarily. For present purposes, we may return to one of our constant refrains. The vastness of the environmental transformation of the Brazilian northeast is best considered in relative and

[375] "Every plantation, regardless of whether it was inland or on the coast, needed two things: the soil known as massapé, and woods as close as possible to the mill to supply firewood for boiling the sugar-cane juice. Firewood soon became a crucial problem, one which has haunted the sugar industry for centuries. Conservation never was a Brazilian practice, and the tropical forests of the Recôncavo were soon stripped to feed the hungry mouths of the furnaces. As time went on it became necessary to import firewood by boat from wherever it could be found, which added greatly to the costs of producing sugar. The steam mill came much later and added further to the problem" (Hutchinson, 1957: 34).

relational terms, rather than as absolute devastation. Twentieth century critics of Brazil's subordinate position in the world-economy would use scorched-earth language to characterize sugar's impact on the north. Galeano for instance, observing the Brazilian northeast, saw that "where everything had bloomed exuberantly, the destructive and all-dominating latifundio left sterile rock, wash-out soil, eroded lands" in its wake (1973: 74; also Castro, 1966; Prado, 1967). There is perhaps overstatement, but we dismiss such comments at our peril (e.g. Barickman, 1998) – not least because contemporary accounts, such as Salvador's with which we began this chapter, correspond with the logic if not the letter of more recent commentaries.

The chief difficulty perhaps is the vastness of New World space itself. The Recôncavo, although only a modest part of territorial Brazil today, is a good example. It was certainly a vast territory to the colonists of the sixteenth century. And the larger unit of Bahia was probably larger than contemporary France (Barickman, 1998: 98). Which means there was no certainly no possibility of *complete* deforestation in seventeenth century Bahia. Given the era's organizational, technological, and demographic constraints, this was flatly impossible. But the same constraints that limited *absolute* deforestation would create *relative* deforestation sufficient to affect the region's sugar complex. The constraints that limited aggregate deforestation were also those that limited the regime's capacity to achieve an ecological fix by finding new, more distant supplies of timber and fuelwood. The tyranny of distance was not easily overthrown.[376]

We can now move from lumber to land. Every introduction to colonial Brazil will share with the readers the marvels of *massapé*, a clayey marl, found throughout the northeast (Galloway, 1989: 72; Miller, 2000: 34; Prado, 1967: 155-56; Schwartz, 1987: 69-71; Haskins, 1956: ch. 2).[377] There is no question as to *massapé*'s extraordinary fertility. Indeed, it is common to read that *massapé* was virtually indestructible, the obverse overstatement to Galeano's lyrical denunciations (Barros de Castro, 1977: 6-7). Some *massapé* zones were floodplains, such Pernambuco's *Varzea*, which formed the immediate hinterland of Recife and Olinda (Boxer, 1952). These zones required relatively little effort to clear and prepare for cultivation (James, 1953: 314; Dutra, 1973: 433).[378] But in Bahia there were fewer such alluvial zones. Many of Bahia's *massapé* areas were forested and had to be cleared (Galloway, 1971: 596).

If there were abundant forests, it is not at all clear that *massapé* was abundant. Barros de Castro thinks *massapé* was sufficiently plentiful that any meaningful kind of soil crisis was off the table (1977: 7). In his view, only a small percent, perhaps 10 to 20 percent, had been cultivated. "If *massapé* were spoiled they [planters] could change and go on to the next soil" (Barros de Castro, 1977: 7). Others are more sceptical. Haskins sees the "Recôncavo as a whole" as a region of "only moderately fertile soil" (1956: 24). *Massapé* zones were indeed highly fertile, but limited to the northern perimeter of the Bay of All Saints. These were complemented by "zones of extreme infertility" (Haskins, 1957: 24). Barickman is prepared to go still further. He notes that "Bahian authors from the early colonial chroniclers on repeatedly classified, described, and ranked the types of soil

376 Braudel is very good on this (1981: 415-430).

377 Sugar planters throughout colonial Latin America preferred the calcium-rich marls and limestone soils (Harris, 1966: 88; Boyer, 1939: 313).

378 Even these, Taylor reports, were far from plentiful: "few engenhos possessed enough *varzea* to plant it exclusively" (1970: 273).

found in the Recôncavo. All agree that for sugarcane, the best soils were the heavy clays known as *massapé, which covered only a relatively small part of the region*" (Barickman, 1998: 105, emphasis added; also Mattoso, 1986: 66).

Even if we were to grant that soil exhaustion was only a minor variable – and I am far from certain that the evidence supports this – we have three issues to deal with immediately. First, the establishment of new engenhos was hardly a cost-free exercise. Even when credit was available, there were geographical constraints. A plantation could not be established just anywhere. Which suggests a second issue. Soil fertility was one of several vectors of productivity and relative costs. Perhaps it is more fruitful to think in terms of relative balance between timber and fuel supplies on the one hand, and soil conditions on the other.[379] Fertile soil would be worthless in the absence of cheap fuel to make sugar.

Finally, *massapé* was indeed highly fertile. But it was not immune to exhaustion. Silva Lisboa believed that *massapé* could sustain yields for "more than 60 years without [the soil] ever having been fertilized with manure; this is unheard of [elsewhere]" (1781: 499; also Schwartz, 1987: 69; Barros de Castro, 1977: 7). Alas, the Crown's forest inspector lamented, "it is true that the crop no longer has the same vitality as at first, nor does the land produce the same yields" (Silva Lisboa, 1781: 499). By the early nineteenth century, the *varzeas* of Pernambuco – often lumped in with the Recôncavo's *massapé* – continued to support sugar cultivation. But not *continuously*. Even the best soils now had to be rested periodically and supported no more than six ratoon crops (Galloway, 1968: 292), not the twenty or more as in an earlier era.

These ratoon crops were important. Among its many strengths, the *massapé* could sustain many ratoons. Freshly planted cane was a periodic event; cane stalks, once cut and left in the ground to resprout, were called ratoons. Left to sprout in the *massapé*, the cane could be left on its own for up to a decade – a practice called ratooning. The downside of ratooning was lower productivity. A ratoon crop would return about half the yield of a hectare newly planted (Barrett, 1979: 25; Dunn, 1972: 192; Schwartz, 1985: 114). Subsequent ratoons beyond the first yielded less and less, perhaps not more than 25 percent of planted cane. Sometimes not even this much (Craton and Walvin, 1970: 97-98). Still, the upside was considerable. Although ratoons offered a lower yields relative to newly planted cane, labor inputs were significantly lower. Moreover, they added a degree of flexibility to the planting schedule, since the ratoons matured quickly, cutting the harvest cycle from about fifteen months to just twelve (Schwartz, 2004: 159; 1985: 109).

While the soil chemistry of *massapé* has been universally ignored in the historiography of colonial Brazil, this much seems plausible.[380] In the first instance, *massapé*'s high calcium content would have raised soil pH to levels highly favorable to sugarcane.[381] In turn, higher alkalinity would have encouraged nitrification and discouraged weeds. Together, this would have sustained a long-run increase in free nitrogen (nitrification) and discouraged competitors for that free nitrogen. In the absence

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[379] Not to mention a host of other geographical issues, for instance transport costs to move the sugar to Recife or Salvador.

[380] My reasoning here draws upon Haskins (1956), Noble and Hurney (2000), Allen (2004), and Cornland, et al. (2001: esp. chapter 6).

[381] This helps to explain why massapé was wonderful for sugarcane but *not* preferred for manioc or tobacco.

of fertilizing the soil, those nitrogen stores accumulated over millennia would at some point become exhausted by recurrent cane plantings – six decades in this case. At which point it would have taken serious effort (and capital) to raise the exhausted fields from the dead, as it were. It was not for nothing that "once *massapé* lost its fertility the colonists considered it dead with little hope of resurrection" (S. Miller, 2000: 34).

Power, Capital, and Nature: The Political Ecology of the Sugar Frontier

It is at this point that our two stories – the story of modernity as global conquest and the story of the landscapes in the cross-hairs – begin to merge into a third. This third story follows the ways that the production of nature and the accumulation of capital intertwined in early colonial Brazil. In what follows, we look at the sugar commodity frontier's refashioning of Brazilian landscapes in ways that initially liberated, then undermined, the northeast's sugar regime. This would in turn set the stage for the rise of the West Indies to the commanding heights of Atlantic sugar production.

Our story begins with the forests. In 1500, Brazil's vast Atlantic rainforest hugged the coastline from the present-day states of Rio Grande do Sul in the south to Rio Grande do Norte (Brazil's easternmost tip).[382] This spanned some 4,000 kilometers, north to south, and as many as 1.5 million square kilometers (Ranta, et al., 1998: 386; Morellato and Haddad, 2000: 787). Today, somewhere between 20,000 and 100,000 square kilometers remain. Even the most generous estimate finds that a mere 7.6 percent of the original cover survives (Ranta, et al., 1998: 386; Morellato and Haddad, 2000: 786; Saatchi, et al, 2001: 2). Bad as they are, the abstract figures belie the extent of the devastation. The crucial geographical fact is the profound fragmentation the forest itself (Morellato and Haddad, 2000; Saatchi, et al., 2001). This to me suggests not the slow advance of settler colonialism, as in medieval Europe, but rather the search-and-destroy trajectory of the commodity frontier.

The Atlantic forest in the northeast was dense and rich when the Portuguese set ashore at the dawn of the sixteenth century. The extraction of brazilwood soon took its toll, although it is hard to tell how much forest was cleared as a result. Dean suggests that 6,000 square kilometers were "affected" by brazilwood by the early seventeenth century. This was far from wholesale transformation, however. Brazilwood was sparsely distributed, perhaps four trees per hectare (Dean, 1995: 47). In this respect, it was much closer to mast timber than it was to fuelwood. The exhaustion of brazilwood favored rapid geographical expansion but not a fundamental recomposition of the forest itself. This would await the sugar boom of the mid-sixteenth century.

Everyone agrees that Brazil's Atlantic forest has been eviscerated since the sixteenth century. The precise character of the environmental devastation in the northeast's sugar zones prior to 1750 is, however, very much an open debate. Dean offers one major

[382] Brannstrom (2002) argues that historical geographers would do best to decompose the category of Atlantic Forest into more specifiable components (for survey of debates over the boundaries of the forest, see Oliveira-Filho and Fontes, 2000). In Brannstrom's preferred order of things, Dean's concept of the "Atlantic forest" (1995) is an "overgeneralisation," one poorly suited for "historical-geographical analysis" (2002: 434, 432). Which I guess is Brannstrom's way of saying that one cannot step in the same river twice. Of course, it all depends on the geographical and temporal horizons of particular "historical-geographical analysis" in question!

account. Between 1550 and 1700, some 1,000 km^2 of forest was cleared for canefields, another 1,200 km^2 to feed the boilers (Dean, 1995: 80). Subsequently Barickman tried to situate this devastation relative to Bahia's vast forest resources (1998). Acknowledging widespread deforestation in the later eighteenth century, he reminds us that "the sugar industry, despite its voracious appetite for both firewood and land, never succeeded in entirely deforesting the Recôncavo or depleting the supply of uncultivated land… Woodlands survived everywhere" (Barickman, 1998: 100; also S. Miller, 2000).

There are really two big issues at stake here. One is conceptual. The other, empirical. In one sense, Barickman is of course entirely correct. Sugar and its ancillaries never succeeded in "entirely" wiping out Bahia's allotment of Atlantic forest. But then, deforestation is rarely total. The key conceptual issue, which Barickman recognizes but then sidesteps, is that of rising costs. Which is to say that we are dealing with the question of the tipping point. Sugar's renaissance in the late eighteenth century – which did not, alas, restore Brazil to world preeminence – "accelerated the deforestation… Shortages of firewood became more widespread… [and] planters began to search for ways to reduce their consumption of firewood without cutting back their output of sugar" (Barickman, 1998: 99-100). All clear indicators of rising costs, which despite buoyant market conditions were sure to limit Brazilian sugar's competitiveness. For the issue is not whether or not there were forests in Brazil. There were. Rather, as we've seen, the crux of the issue turned on whether or not the mills could *access* those forests. (And access them cheaply.) Miller ably cuts to the heart of the issue: "Trees any distance inland were as good as nonexistent" (1994: 187). Even Barickman's reference to woodlands is telling – woodlands do not a forest make. There was of course a large scale recomposition of forest zones once cut over; they did not simply regenerate the *status quo ante*. Rather, forests must be protected, and protection always carries a price tag. We shall return to the issue in due course.

If the conceptual issue turns on relative deforestation and production costs, the empirical issue remains. How much forest was consumed by the sugar regime in the period 1550 and 1750? Was it sufficient to undermine the competitiveness of Brazilian sugar on the world market? What I shall argue is that the extent of deforestation in this period outstrips Dean's estimates by an entire order of magnitude – not 1300 but 13,000 square kilometers were consumed by sugar in the two centuries after 1550. The destruction of the Atlantic forest marks a signal event in modern environmental history. Widespread deforestation had happened before, in earlier times and different places. But never so quickly. And never so geographically distant from the organizing centers of territorial and economic power.

It began with clearing the land for cultivation. Silva Lisboa described this process in the late eighteenth century:

> If the field is made on new land, the planting of cane begins with the cutting and felling of trees. When it is virgin forest, full of timber of enormous height and thickness, it is customary to saw the wood when possible, thus making use of it to fashion planks for boxes of sugar. Otherwise it is all reduced to ashes… The smaller, remaining firewood is piled into mounds called *covairas* and fire is set to them until all the wood is consumed (Silva Lisboa, 1781: 499).

Silva Lisboa rendered his observations at a time of growing concern over forest resources within Brazil (Padua, 2000; Webb, 1974: 90-91). In the sixteenth and seventeenth centuries, Costa suggests (1979), those clearing the land were less concerned with timber. As colonists moved into the forests, "the recourse to burning must have seemed such an obvious necessity that it did not even occur to them to try other methods of clearing the land. It seemed to them that the productivity of the soil cleared without the aid of fire was not large enough to be worth the work of clearing them by hand" (Costa, 1979: 52). The practice of burning as an effective means of forest clearance must have seemed common sense to the earliest planters, drawing as they did on the experience of Madeira and São Tomé before them. Even burning, it turns out, was insufficient to ready the land for cultivation. Silva Lisboa emphasizes the time and effort required *after* the burning to ready the land for planting (1781: 499; also Haskins, 1956: 68).

If clearing land for sugar cultivation was costly and deadly, the task of securing cheap – and more to the point, cheap and *reliable* – fuelwood was pivotal. At the outset, the two tasks can be distinguished. Clearing land for cultivation was usually performed by slave labor, at first indigenous, later African (Barickman, 1995: 329; Schwartz, 1985: 107). Fuelwood extraction could be carried out by slaves – this was the option favored by *engenhos* that moved inland during the seventeenth century – but millowners might also enter into contracts with outside suppliers. Here indigenous labor remained important (Schwartz, 1985: 528). The earlier phase of brazilwood extraction had drawn thousands of Indians into the practice of forest exploitation, preparing the ground for the sugar frontier (Dean, 1995: 46). It was therefore a strategy that, over time, promised rising costs on two fronts as the Indians died (to be replaced by more costly labor power), and the forests thinned.

Sugar, Fuelwood, and the Historical Geometry of Deforestation, 1550-1750

By far the most important driver of deforestation was sugar's appetite for fuelwood. The documentary basis for charting deforestation in sixteenth and seventeenth century Brazil is exceedingly thin, and for this reason we turn once again to a succession of geometric estimates. From these we will build up a historical geography of the Brazilian sugar frontier as a whole.

We can begin by assuming a *tabula rasa* of zero deforestation in 1550, just one year after the assertion of Crown rule. By the 1560s and 1570s, 180,000 arrobas were produced each year (Simonsen, 1957: 114-115). We may safely assume that, on average, sugar production in the 1550s amounted to somewhere around 60,000 arrobas annually. There were sixty mills in Brazil by 1560, fifty of which were in the northeast. Seventy five percent of these were found in Pernambuco and Bahia (Schwartz, 1985: 19). The very smallest mills produced nearly 1,000 arrobas (just over 15 tons) each year, but most, even in the sixteenth century, produced more (Schwartz, 1987: 75).[383] If these estimates hold, how much fuel can we say it took to produce this much sugar? From estimates of

[383] For the seventeenth century, Schwartz (1987: 74-75) posits a range of 3,000-4,000 arrobas (around 60 tons) to 10,000-12,000 arrobas for engenho capacity (also Deerr, 1949, I; Taylor, 1970, 1978).

fuelwood consumption we can move rather directly to estimates of forest exploitation, and thence to the geometry of deforestation.

The results are surprising (see Table 6.1). Holding production constant within each decade (therefore masking the accleration of production) for the period 1550-99, the cumulative deforestation for fuelwood alone comes to 56,650 hectares. Now, 566 square kilometers is not much relative to the *absolute* mass of the Atlantic forest in Pernambuco and Bahia. But recall Dean's widely accepted estimate for the sugar frontier's deforestation in Brazil for the period 1550-1700 – 1,200 km^2 of forest cleared (1995: 80). This comes to 8 km^2 a year. But it seems that deforestation, even at this early stage of the game, was moving even faster. For the period 1550-99 (Table 6.1), the tempo of deforestation moved more than 40 percent faster (11.33 km^2/year) than Dean's estimate.

These figures are impressive. But are they valid?

The peril of such exercises in historical geometry is that everything rests on figures that are necessarily abstract. The issue of generalizability resurfaces. Here again we return to the question, How much woodfuel was required to make one unit of sugar? Our working answer to the question, explained in some detail in the previous chapter, is a sugar-to-fuel ratio of 1:50 by weight. In my reading of the tea leaves, this is an optimistic guesstimate. It is improbably that fuel efficiency did improved significantly before the nineteenth century. Even a conservative geometric ratio lands us in the right neighborhood. It therefore "builds in" a bias against overstating the extent of deforestation. The intent, here and in what follows, is to build a series of middle-range estimates with a conservative bias. This means that even if the sugar-to-fuel ratio was ten, even twenty, percent higher or lower, the implications would be a matter of quantitative variation, not qualitative difference.

Estimates for the sugarmill's fuel consumption vary. We may offer here a concise reprise of earlier arguments (Chapters Two and Five). Dean argues for a 1:15 ratio in his study of the Atlantic forest (1995: 80).[384] Schwartz's estimate of 12,800 lbs of firewood to process one tarefa of cane (1985: 141) translates to something on the order of 1:10 for the 1650s. Elsewhere he suggests a ratio of eight cartloads of firewood for twenty of cane, which yields a ratio between 1:13 and 1:20, given a 2-3 percent extraction rate.[385]

These strike me as exceedingly low. It is likely that these low estimates refer to charcoal rather then fuelwood, a common enough misreading in early modern economic history (see Chapter Two). Silva Lisboa in the 1780s suggested a ratio of 1 unit of wood for each unit of *raw* cane, which gives us a range between 1:33 and 1:50,[386] possibly much higher if the cane-to-sugar extraction rate was under 2 percent (Lisboa, 1786: 47-50 quoted in Padua, 2000: 269-270). Moreno Fraginals, drawing on early nineteenth century

[384] Although Dean does not provide his source for this estimate, it is entirely possible that this ratio refers to charcoal rather than wood. An efficient conversion rate for wood to charcoal during this era would be 5:1. If this is the case, then Dean's estimate would be in line with the higher ratios discussed, below, include Dean's own earlier (1983) figure.

[385] Schwartz's production figures for various engenhos from 1584-1816 suggest an extraction rate in this range (1985: 112-113). But there is in these data a bi-modal structure, with one tier for watermills – *engenhos d'agua* – and one for the oxen-powered mills, the *trapiches*. For the former, the extraction rate was in the range of 2-3 percent; for the *trapiches* 1-2 percent. Hydraulic mills were capable of generating greater force and therefore achieved higher rates of extraction (Tomich, 1990).

[386] Respectively, at three percent and two percent extraction.

Cuban sources, offers data suggesting a range of 1:49 to 1:58 for technology that was, at worst, essentially the same as seventeenth century Brazil's (1976: 74).[387]

If Dean made the pitch for a highly efficient ratio in the early 1990s (1:15), a decade earlier he had earlier argued for a much higher ratio. In this earlier essay (1983), Dean tells us that one metric ton of sugar (2200 pounds) required 100 cubic meters of wood, *during the eighteenth century* – that is, when techniques were improved over an earlier era and at a time of was growing concern over forest resources (Padua, 2000).[388] If one cubic meter weighs 1602.2 lbs, Dean's earlier estimate moves the ratio much higher. (To 1:73.) Williams at one point is prepared to go higher still (2003: 216). (To 1:80). Among contemporaries, Antonil's data suggest a ratio of 1:50 (1976: 213 quoted in Miller, 1994: 184).[389]

The higher estimates of Williams and Dean are staggering. If true – and they certainly find support in Antonil's contemporary account (1711) – these would represent a scale and speed of deforestation 50-60 percent higher than the 1:50 ratio that I've proposed. Although I have opted for a more conservative estimate, the high range cannot be dismissed casually.

Indeed, the high estimate of the sugar-to-fuel ratio (1:70-1:80) holds up well under cross-examination. If we take the primary source figures provided by Miller and Schwartz, we find considerable support for the higher estimate. In Bahia during the 1750s (1758), Miller puts the *engenhos*' fuel consumption at 3348 cubic meters *every day*, or 750,000 cubic meters a year, assuming 224 milling days (1994: 184). If 200 milling days was closer to the mark – owing to the increasing frequency of shutdowns owing to fuelwood shortage[390] – then Bahia's annual consumption would come to

[387] Moreno Fraginals offers the following data. The basic unit of timber volume was the "task," which was six cubic yards (4.59 cubic meters). If one cubic meter weighed 1602.2 lbs (see Chapter Five), then each "task" weighed 7354.1 lbs. One task was sufficient to produce between five and six Spanish arrobas of sugar (Moreno Fraginals, 1976: 74). Each arroba weighed 25 lbs (Ayala, 1995: 98). If so then, the sugar-to-fuel ratio for early nineteenth century Cuba, using the "Spanish train" in which each kettle was heated separately of the others, comes to 1:49 at the low end and 1:58 at the high end.

[388] Williams also uses this figure, although with the English ton (2000 lbs) rather than the metric ton (2003: 216).

[389] Miller believes Antonil is describing the famed engenho Sergipe de Conde in reporting that the mill consumed 2,500 cartloads of firewood each year (1994: 184 and 191, n.16). I have been unable to find Antonil's reference to this figure, although at one point in the French edition (Mansuy, 1968) Antonil does report on Sergipe's firewood purchases, which ranged between 2,000 and 3,000 cruzados annually (1711: 202-205). If the figure of 2,500 cartloads is correct, and we side with Schwartz in estimating that each cartload weighed 1600 pounds (which I have converted to 1602.2 lbs, the standard weight for a cubic meter of wood), then the sugar-to-fuelwood ratio looks like this. We know that Antonil visited the Engenho Sergipe between 1693 and "at the latest" 1703 (Mansuy, 1968: 28). This was during a historic low point in Sergipe's production, averaging just 2442 arrobas (79,670 lbs at 32.625 lbs/arroba), between 1690 and 1700 (Schwartz, 1973: 195). If so, then 79,670 lbs of sugar were manufactured with just over four million lbs (4.006 million) of wood, which gives us a ratio of somewhere between 1:50 and 1:51. Incidentally, this is nearly identical to what I've calculated for the sugarmill in eighteenth century New Spain studied by Barrett (1970: 72, 130).

[390] "The adequate construction of reverberatory hearths would solve this problem,… of the immense quantity of wood wastefully employed[,]… which causes great losses to farmers and masters of mills, because those who do not possess large forests do not manufacture sugar and those who do have such forests in the future will let their mills go idle on account of lack of firewood, *because this is confirmed by experience*" (Silva Lisboa, 1786: 47-50, order of quotation slightly altered). Even in the absence of serious fuelwood problem, there were many days lost out of the theoretical maximum of 291. In the first half of the

669,900 cubic meters a year. (If fuelwood harvesting proceeded at a rate of 180 cubic meters/ha, the rate of effective deforestation was 2977 ha/year.) The nearly 670,000 cubic meters of wood translates to 536,657 tons, which become relevant in relation to the Schwartz's estimate of 400,000 arrobas (6525 tons) of sugar produced in Bahia during 1758 (1985: 423). This gives us a ratio of sugar-to-fuelwood of 1:85. If we assume that none of Bahia's mills shut down from lack of fuelwood and therefore a 224-day rather than 200-day year, this brings the ratio down to 1:80. (And it is doubtful that a 224-day work year was reached on a consistent basis.) Still, the figures are enormous and one is rightfully sceptical about them. We may cross-check these figures once more against contemporary accounts. Santos Vilhena (1969, I: 193 quoted in Schwartz, 1985: 524) estimated that a typical Bahian *engenho* in the 1750s burned twenty cartloads of wood daily – each of which Schwartz guesses was the equivalent of 1,600 lbs (1985: 142; also Dean, 1995: 196), or almost exactly our reckoning of one cubic meter. This reckoning leads to an equally high sugar-to-fuelwood ratio, 1:88.

Precisely how volume and weight measurements are rendered into geographical estimates of forest clearance is an open question. Estimates must be treated skeptically and with great care. Here we return again to matters of forest productivity (see Chapters Two and Five). Dean offers two such estimates for the North Atlantic Rainforest – 200 tons of woodfuel per hectare and 300 cubic meters per hectare (1995: 80, 235). Williams' estimate, for Europe, is close to Dean's: 250 cubic meters/ha for highly dense forest (2003: 532). What counts, in any event, is the volume of wood that could be harvested. Dean thinks 200 tons could be harvested from a single hectare (1995: 80), which fits with Williams' theoretical maximum of 250 tons/ha. This strikes me however as a very high estimate. The work was extraordinarily dangerous for one, as Dean, among others, recognizes (1995: 182-183; also D. Watts, 1987: 185-186).[391]

Beyond the inherent dangers of forestry, the technology was crude and not all timber was equally suitable for firewood. Large trees in the Atlantic forest would have been extraordinarily difficult to fell and then haul. It took dozens (yes, dozens) of oxen to move a single old-growth tree a maximum of 12.5 miles even in *twentieth* century Brazil (Zon, 1916: 21). Beyond this, there was the labor of chopping the wood into parts small enough to generate sufficient heat – large, and worse unseasoned, parcels were useless (Antonil, 1711: 202-203; also Miller, 1994). Necessarily, much as we saw in the case of shipbuilding timber (Chapter Four), there was a "cherry picking" effect. Those trees most suitable for fuelwood were selected. The remainders were left for another day. All of which leads me towards a modest, downward revision of Williams' and Dean's dovetailed estimates – from 250 cubic meters/ha and 200 tons/ha, to 225 cubic meters/ha and 180 tons/ha.[392]

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seventeenth century, the Engenho Sergipe lost 78 days (only five of them from woodfuel supply problems), bringing the number of production days to 211 (Schwartz, 1985: 101-102).

[391] "Engenhos and lavradores often bought wood from the heavily forested region of the southern Recôncavo, both because they lack woodlands on their own property *and because the labor was hard and dangerous to their own slaves*" (Schwartz, 1985: 141, emphasis added). For present day indications of the dangers involved in forestry, see International Labour Office (2005); Frazier and Mullan (1983).

[392] The figure 150 m^3/ha may seem arbitrarily low to some. I would say, first, that even with the higher Williams' estimate of 250 m^3/ha for "dense forest" there would be a loss in transport of 20-25 percent. This at least was the norm in early modern Europe and it is unlikely that things were more efficient in the New World (Sieferle, 2000: 58). Secondly, extraction from woodlands in Europe was *significantly* lower.

Table 6.1. The Progress of Deforestation, I: Fuelwood and Brazilian Sugar, Brazilian Sugar, 1550-1749

Date	Sugar output	Annual fuelwood use by weight & area[393]	Deforestation within era	Cumulative deforestation
1550-59	979 tons[394]	48,950 tons (272 ha)	2,720 ha (1550-59)	N.A.
1560-69	2372 tons	118,600 tons (659 ha)	6,590 ha	9,310 ha
1570-79	3500 tons	175,000 tons (927 ha)	9,270 ha	18,580 ha
1580-89	5850 tons	292,500 tons (1625 ha)	16,250 ha	34,830 ha
1590-99	7819 tons	390,950 tons (2172 ha)	21,720 ha	56,650 ha
1600-09	9700 tons	484,000 tons (2694 ha)	26,940 ha	83,590 ha
1610-19	11,000 tons	550,000 tons (3055.6 ha)	30,556 ha	114,146 ha
1620-29	13,500 tons	675,000 tons (3750 ha)	37,500 ha	151,646 ha
1630-39	16,700 tons	835,000 tons (4639 ha)	46,390 ha	198,036 ha
1640-49	28,390 tons	1,419,500 tons (7886 ha)	78,860 ha	276,896 ha
1650-69	34,256 tons	1,712,800 tons (9515.6 ha)	95,156 ha	372,052 ha
1660-69	34,256 tons	1,712,800 tons (9515.6 ha)	95,156 ha	467,208 ha
1670-79	32,625 ton	1,631,250 tons (9062.5 ha)	90,625 ha	557,833 ha
1680-89	25,000 tons	1,250,000 tons (6944 ha)	69440 ha	627,273 ha
1690-99	25,000 tons	1,250,000 tons (6944 ha)	69440 ha	696,713 ha
1700-09	19,000 tons	950,000 tons (5278 ha)	52780 ha	749,493 ha
1710-29	21,206 tons	1,060,300 tons (5890.5 ha)	117,810 ha	867,303 ha
1730-49	15,000 tons	750,000 tons (4167 ha)	83,340 ha	950,643 ha (1550-1749)
1750	10,000 tons			
1776	22,838 tons			

Mulhall, looking at late nineteenth century Europe, suggests 1000 cubic feet per acre of forest "if cut down" rather than coppiced (1899: 297). Using his metric, which puts the weight of one cord (128 cubic feet or 3.62 m^3) at 5000 lbs rather than 5800 lbs, this translates to 2,470 cubic feet/ha or 48.24 tons/ha. This contrasts with our much higher figure of 120.16 tons/ha (150 m3/ha X 1602.2 lbs/m^3). It is on this basis that Dean's estimate of 200 tons of firewood per hectare of "secondary woodland" must be regarded as excessively high (Dean, 1995: 80).

393 Assuming 150 m^3 of accessible fuelwood per forest hectare and a sugar-to-fuel ratio of 1:50; 150 m3 = 240,330 lbs (120 tons/ha). See Chapter Two for more details on the calculation of volume to weight.

394 60,000 arrobas is my estimate. 32.625 lbs per arroba (Deerr, 1949).

Sources: Mauro, 1983; Schwartz, 1985; Edel, 1969; Antonil, 1711; Dean, 1995.

The data in Table 6.1 indicate the rapidity of the advance into the forest – 950,000 hectares effectively cleared between 1550 and 1750. If we were to take a higher sugar-to-fuel ratio, say 1:75 instead of 1:50, the scale of deforestation would expand to nearly 1.5 million hectares. These estimates outstrip Dean's by nearly five-fold if we take the period 1550-1700 as our temporal frame; with a lower fuel efficiency, they would exceed Dean's guesswork more than ten times over.[395]

If we are to criticize Dean's guesswork, however, it is in the spirit of reconstruction rather than deconstruction. For we may extend Dean's essential insight regarding the epochal character of deforestation in early colonial Brazil. Indeed Dean's other major piece of guesswork is explicable only in terms of the reformulation that I've proposed. The first two centuries of Portuguese colonization saw the "neo-European" occupation of approximately 65,000 square kilometers, Dean argues. "*Most of this area*," he writes, "had been subtracted from the Atlantic forest" (1995: 90, emphasis added). And yet he accounts for only one-tenth of this subtraction. And though 65,000 square kilometers is not much by today's standards – and not much in relation to the one million or more square kilometers occupied by the pre-contact Atlantic forest – this was an unprecedented transformation in relation to the miniscule demographic forces involved. By way of situating just how massive was this undertaking, 65,000 square kilometers was larger than Portugal itself. Under the conditions of the time, such an audacious movement of "subtraction" could have been sustained only by the era's great commodity frontiers, interweaving as they did the mighty logics of empire and capital accumulation.

Sugar, Fuelwood, and the Historical Geography of Deforestation, 1550-1750

This geometric reformulation of the sugar frontier in colonial Brazil is suggestive. More is needed, however, to make a strong case for the gravity of the socio-ecological contradiction. Miller advances the sceptical view (2000; also Barickman, 1998). On the one hand, "deforestation was taking a toll that none could deny." On the other hand, "deforestation in colonial Brazil was never more than a localized event" (Miller, 2000: 40). We have encountered this argument before, among those charting forest exploitation in early modern Europe (see Chapters Two and Four; also Allen, 2003; Warde, 2006).

I would propose a modest and yet decisive geographical corrective to this line of argument: Deforestation is always local, and in the modern world-system it has been rarely local*ized*. The essence of modernity, above all on the commodity frontiers, was to consign "localized" events to the dustbin of history, to interweave such events into the fabric of world process. If this is the case, then the nature of the historical-geographical process under examination asks for a historical-geographical reconceptualization of the

[395] This calculation of deforestation abstracts a lot. For starters, trees continued to grow. On the other hand, there were a great many fuel-intensive and timber-intensive activities that are not considered. Of these latter, perhaps most important was fuelwood consumption by a rapidly growing population; the considerable demand for construction and shipbuilding timbers; and millions of wooden chests in which sugar was packed, and shipped. The extent of these demands on the forest overwhelmed the natural regeneration of the forests. My estimates are therefore biased towards minimizing the impact on the forest.

"nature" being deforested (or not). For it was not an abstract nature that the agents of colonial expansion confronted. Rather the abstract category of "nature," useful enough for some pursuits, is rendered much more heterogeneous in the analysis of early capitalism's territorial advance and environmental transformations. What counted in this process were the historically- and geographically-specific forms of nature that manifested on a local-scale,[396] and yet whose form was constituted not by local geological and ecological conditions alone. For ways of perceiving and modes of producing nature equally served to constitute these "local" natures, and the origins of these ideological and productive frames were to be found the multilayered contradictions of early modern Europe and its ongoing global expansion (Arnold, 1996). These were local natures no longer localized, transformed as they were both ideologically and materially into zones that could be exploited with the presumption of a geographically inexhaustible frontier of ecological bounty.

If the historical geometry of the previous section is to be sustained, it must find support in the historical geography of the colonial sugar regime. Here the evidence is persuasive indeed.

If all deforestation is local, some regional frame of reference must necessarily complement the broader expansionary movement. Here the Brazilian sugar frontier must surely be regarded as a succession of frontiers. For the task at hand, the decisive geographical shift is the re-centering of colonial production from Pernambuco to Bahia in the 1630s. Coincident upon the Dutch invasion and occupation, Pernambuco tumbled from its preeminent position in the Brazilian sugar complex. Responsible for 60 percent of Brazilian output in 1600, Pernambuco's share fell to under 20 percent in the 1640s (Schwartz, 1985: 178). Pernambuco's loss was Bahia's gain. Bahia's output expanded dramatically during the 1630s and 1640s. It would remain as "Brazil's leading producer" until the end of the eighteenth century (Schwartz, 1985: 178).

This output would be sustained for the next four decades (1640-1680). But the economic reality was one of stagnation and deepening crisis rather than the efflorescence. Between 1650 and 1668, sugar prices fell by 33 percent (Schwartz, 1979: 14). The increasingly marginal position of growing numbers of the region's planter class – a class continued to expand numerically even in face of stagnating output – expressed an increasingly serious profit squeeze after 1650. Squeeze turned definitively to crisis by 1670 (Schwartz, 1979: 14).

As we have seen, this was precisely the moment of the sugar frontier's most serious assault on the forest. Between 1640 and 1680, nearly 360,000 hectares (3600 square kilometers) of the Atlantic forest were stripped to provide fuel for the *engenhos*. This amounts to nearly 90 square kilometers annually, a rate of deforestation eleven-times faster than Dean's average for the period 1550-1700 and eight times faster than our estimate for period 1550-1590. If we presume that 40 percent of Brazilian sugar derived from Bahia in these decades (1640-1680), then some 1,440 square kilometers of Bahia's forest were sacrificed on the altar of sugar. This, still, would have been a far-from-total deforestation. But it would have been quite meaningful in terms of relative deforestation and its contribution the political ecology of crisis.

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[396] This is an argument that Noel Castree (2003) suggests, unfortunately with little reference to environmental history.

If annual output was sustained through the period 1640-1680 at a very high level – somewhere in the ballpark of 32,000 tons annually, if we are to believe Mauro's figures (1983; see Table 6.1) – and if much of this output was concentrated geographically in the Recôncavo, we would expect to see signs of stress in the socio-ecological regime within a generation. And this is exactly what we see. Beginning in the 1660s, we see in Bahia a series of juridical measures, social conflicts, and other developments indicating that access to cheap fuelwood had indeed become a serious issue in the region's economic life.

Beginning in the 1660s, there is a clear political ecology to the escalating tensions between the *senhores* and *lavradores*. An early instance appears in what Schwartz calls an "extraordinary letter" from the *senhores* and their allies on Salvador's municipal council (1985: 309). "The deplorable state of fuel resources in the Recôncavo threatened the very survival of the sugar industry," argued the *senhores* (Miller, 2000: 36). The letter petitioned the Crown for an injunction on the establishment of "new engenhos on the coast." New mills should be established, they urged (prefiguring later developments, as it turned out), "only toward the *sertão* [where] new mills [could] be set up without damaging the operations of those already in existence" (Schwartz, 1985: 309):

> The man behind this petition seems to have been Bernardo Vieira Ravasco, a *senhor de engenho* and the secretary of state of Brazil. In his own letter, he argued that the proliferation of mills caused shortages of cane and fuel and drove up prices. This resulted in a loss of production, so that an engenho *real* [a water-powered sugarmill] that had formerly produced 6,000 to 7,000 arrobas was reduced to an output of 4,000 to 5,000… Wages were rising, wood suppliers were 'inconstant,' and the *senhores* lived subject to [the suppliers'] 'whim' (Schwartz, 1985: 309; also Schwartz, 1973: 184).

There is a purely sociological way to read this statement. The *senhores* were concerned about overcompetition and therefore overstated the case.[397] This is surely true to some degree. But in an era of unprecedented sugar production and high fuelwood consumption, there would seem to be grounds for further investigation.

A decade after the *senhores*' petition to the Crown, "Salvador's city dwellers faced the same fuel scarcity and price increases as their rural neighbors" (Miller, 1994: 189). In the early 1670s, "city residents could not gather even a small bundle of firewood near the city because private parties owned all the nearby wooded land" (Miller, 1994: 189). The Crown would eventually grant a *sesmaria* to Salvador as a fuelwood reservoir, but at a location "inconvenient in relation to the city" (Miller, 1994: 192).

By 1680, Salvador's municipal council urged the Crown to forbid construction of new *engenhos* within a league of established mills. The economic conjuncture is decisive. Sugar prices, which had been moving upwards for nearly two decades, had begun a free fall during the 1670s. An arroba of sugar in 1680 fetched just two-thirds its 1670 price (Schwartz, 1973: 194). Making matters worse, the slave trade turned from a buyers' to a sellers' market at the end of the 1670s (Schwartz, 1973: 194). So it is no surprise that the

[397] Thus Miller stresses the *senhores*' "hyperbole in the description of colonial deforestation" in this instance (2000: 36).

senhores turned to the Crown to limit competition, which in this case offered the additional, crucial, advantage of keeping in check the price of firewood. The planters believed that "existing sugar mills… should have precedence over upstart neighbors in the exploitation of firewood" (Miller, 1994: 196). "It is more useful," the planters argued, "to conserve one [*engenho*] for many years than to lose two in a brief time" (quoted in Miller, 1994: 196). The next year the Crown's regent prohibited new plantations within a half-league of established mills (Mansuy, 1968a: 88).

Deforestation intruded in still other ways. With increasing frequency after 1650, the *senhores* began to make contracts with the *lavradores* requiring them to supply the fuelwood necessary to process their cane (Schwartz, 2004: 184). It was a double-edged sword – the *lavradores* could and did fight back by withholding firewood (Schwartz, 1973: 184). But this was exceptional. By 1690, *engenhos* were stealing firewood from one another (Schwartz, 1973: 170-171). And it was in this decade that Antonil, who typically regarded the Atlantic forest as inexhaustible (1711: 200-201), observed many millowners selling their land "because… they lack firewood" (1711: 92-93).

We might tease out yet another indication of relative deforestation from the geographical expansion of the sugarmills themselves. The expansion in the number of *engenhos* favored animal-powered mills (*trapiches*) over water mills (*engenhos reais*). This represented an important expansion of the sugar sector's geographical range of motion. Among other things, it enabled new mills to move to where fuelwood was cheaper. As we noted earlier, the combination of greater technical efficiency, lower start-up costs, and the possibility of substituting animal for waterpower freed mills from the locational imperative of immediate river access. Mills could move inland to some degree – we might imagine a theoretical maximum of eight miles although in practice probably much less – and this allowed *lavradores* to do the same (Schwartz, 1987: 78). Although the *engenhos reais* could handle greater output – in great measure because hydraulic power enabled the more efficient extraction of sugar from cane – it seems that the logic of an expansionary capitalism in this instance favored economies of scale only up to a point.

Economies of scale gave way to economies of space in the later seventeenth century, balancing returns to scale with returns to virgin territory. Even as late as the eighteenth century only five percent of Pernambuco's mills found their power source in rivers (Prado, 1967: 158). Was this figure higher in Bahia, given its dense river system? Perhaps, but probably not by much. By the end of the seventeenth century, that is in the midst of the rapid expansion in the number of mills but the stagnation of aggregate output, the *engenhos reais* were losing their competitive edge in the Recôncavo. Hutchinson suggests that the ecological situation played an important role in this, lending support to our contention that the quantitative expansion in the number of mills was also a qualitative shift in the frontier movement of the sugar regime. By the later seventeenth century in Bahia, a century of breakneck expansion "had pretty well stripped the littoral of the firewood necessary for continued high production" (Hutchinson, 1957: 29). The coastal regions had long since been occupied. The alternative was to turn inland, where new planters "found an abundance of the rich *massapé* lands and sufficient firewood for the needs of many plantations… [S]oon the number of inland sugar mills surpassed that of the coast" (Hutchinson, 1957: 29).

And not by ecological accident. New mills on the frontiers suffered many hardships (Schwartz, 1985: 115), but expensive fuelwood was not amongst them. "We learn from the testimonies of the period," reports Prado, "that lack of fuel was one of the most common causes for the abandonment of *engenhos*" (1967: 156). Mansuy concurs. The "multiplication of *engenhos*" underpinned a profound disequilibrium in the relation between the sugarmills and the forest. "In effect," Mansuy argues, by 1680

> the consumption of firewood involved in the manufacture of sugar became too great, the exhausted forests could not meet the needs of plantations that had grown up too close to one another; and for want of combustibles to make sugar, the harvests were lost, as a consequence provoking the ruin of many *senhores* ['maitres d'habitation'] (Mansuy, 1968a: 88; also Prado, 1967: 156).

The geographical consequences were predictable. For those *engenhos* with the wherewithal to do so, firewood was purchased. This entailed rising fuel costs as woodcutters ventured farther and farther afield (Prado, 1967: 156; Miller, 2003: 232). "Even before the 1670s, many mills at the [Recôncavo's] shoreline depended on fuel sources far from their base of operations" (Miller, 1994: 183). During the 1670s, producers from the *massapé*-rich zones of the northern Recôncavo were "harvesting mangrove fuel 70 [kilometers] south on Itaparica island" (Miller, 2003: 231). Even if wages did not rise, growing numbers of workers would have been necessary to secure the necessary – and necessarily reliable – fuelwood supplies. Nearly a century later in the 1750s, when Bahia's production was one-third to one-half its 1640-1680 zenith, the timber harvest mobilized some 4,000 workers (Miller, 1994: 184). It is possible the figure was not much higher in the seventeenth century; it certainly was not lower. Furtado observes that sugar's "devastation of the forests" on the coast required not only more men, but also more animals "to haul firewood from ever-greater distances" (1963: 62). These oxen, too, must be figured into the broader picture of rising costs for the Brazilian sugar complex. (Not to mentioned the broader expansion of the sugar-centered division of labor.)

The vulnerability of these relatively distant supply zones was already apparent in the 1650s and 1660s, with Indian raids on Portuguese settlements in southern Bahia (Schwartz, 1979: 9, 11). As a result, Sierra observed (1676: 43), the "northern part [of the Recôncavo] lacked the necessary items for the sugar mills such as wood… Because of this the mills had to close. With production halted, commerce ceased." While pacification campaigns were launched, more crucial over the long run was the governor's 1660 decision to build a "royal highway to serve for wagons… [to move] through the entangled forest" (Sierra, 1676: 43). This surely was conducive to securing the fuelwood hinterland of the Recôncavo.

That Brazil's sugar complex, in Antonil's fiery turn of phrase, "devoured the forests" is not in question (1711: 196-197). Nor is there any need to overstate deforestation. The scorched earth realities of late capitalism, through which forests are laid waste in the blink of the eye, is no metric by which to gauge the significance of early modern deforestation. For in an "organic economy" (Wrigley, 1988) *selective* deforestation weighed much more heavily on the calculus of world accumulation, and regional competitiveness, than does *total* deforestation today.

The Sugar Frontier and the Social Basis of Soil Exhaustion

Soil exhaustion usually enjoys pride of place among ecological factors in the history of slavery. So far, however, in this story the decisive ecological relation in the emergence of the sugar-slavery nexus has been the balance between arable land and the forest. In this sense, sugar is distinctive from other soil-exhausting monocultures, such as cotton or tobacco. The fuel-intensive character of sugar as a factory in the field (or should we say factory in the forest?) sets it apart from these other commodity frontiers. In the early modern era, the closest relative to the sugar commodity frontier was not agriculture, but mining and metallurgy.

That the sugar complex was a mode of extraction, as well as a mode of cultivation, was no secret to contemporaries. Writing at the very moment when Brazil's sugar boom was in full flower, the Franciscan Vicente do Salvador criticized Portuguese agricultural practices in Brazil along these very lines. "[N]o matter how attached to the land they become, or how rich they get," argued Salvador

> they still intend to take everything to Portugal. If the farms and goods they possess could speak, they would teach them to talk like the parrots, to whom the first thing they teach is: 'royal parrots go to Portugal'… and this is true not only of those who came [to Brazil as colonists], but also to those who were born there – they both treat the land not as masters (*senhores*), but simply as usufruct exploiters [*usufructuários*], [who seek] only to enjoy use of it and leave it destroyed (1627: 16).

The mythic status of *massapé* has obscured the dialectics of soil exhaustion in colonial Brazil. There is, to be sure, more than kernel of truth in the pedological homage. *Massapé* was indeed fertile.[398] And in contrast to what we will see in the West Indies, *massapé*'s thick, clayey nature meant that soil erosion was minimized. Three facts however must be reckoned with. First, as we've noted, *massapé* was plentiful but not universal. In the Recôncavo, the *massapé* region comprised the northern third of the Bay's shoreline (Haskins, 1956). Second, *massapé* was durable but not exempt from the laws of soil chemistry. It could be exhausted.

The first and second facts imply a third. Given the far-from-universal geography of *massapé* and its tendency towards relative (if gradual) exhaustion, sugar cultivation necessarily expanded into other pedological zones. Alongside forest exploitation for fuelwood, the extension of arable land paled in comparison. Dean puts cultivation's share

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[398] Barros de Castro thinks soil exhaustion was inconsequential: "[T]here is no evidence at all of massapé exhaustion through cane" (1977: 6). And yet later in the same paragraph makes precisely the argument that we've advanced: "The fact is that we know places used for sugar cane for sixty… years, without changing the same soil, with no evidence of putting down productivity" (1977: 7).

of deforestation at 1,000 square kilometers between 1550 and 1700 (1995: 80), a figure that is essentially correct.[399]

Even if cultivation ranked second to fuelwood in forest exploitation, the analytics of soil exhaustion cannot be reduced to geometry. The crucial question is this. What is the *causal role* of such exhaustion in large-scale economic and geographical shifts, especially but only for the period before the Caribbean sugar revolutions of the seventeenth and eighteenth centuries?[400] Brazilian sugar in its heyday is arguably the strongest case *against* any kind of soil exhaustion argument. But to abstract such pedological concerns is to elide the ways in which small (and increasing) differences in soil fertility intersected with other regional-ecological and world-economic conjunctures. All crises are in some sense the outcome of mounting cumulative woes. Under conditions of impending crisis, small quantitative shifts may come to play large, qualitative roles.

Just how quickly yields declined is uncertain. We can look at this question from the vantage point of labor, and then in terms of the land productivity. In terms of labor productivity, Brazilian sugar planters were caught in a double-squeeze. On the one hand, the terms of trade became increasingly unfavorable by 1680. The prices of slaves was going up, the price of sugar, going down (Schwartz, 1973). Thus a Brazilian slave could produce enough sugar to meet replacement costs in just over eight months in 1608; this replacement break-even point nearly doubled by century's end (Schwartz, 1987: 82-83, 94-95; 2004: 170-171; Taylor, 1978: 38).

The economic crunch was reinforced by an ecological squeeze. Declining land productivity necessitated rising labor inputs. Edel's figures suggest one trajectory for seventeenth century Brazil. In his view, Brazil's sugar output increased by just over 50 percent between 1600 and 1640, but its slave population increased by over 120 percent (Edel, 1969: 42). Where one slave produced just over one ton of sugar in 1600, the rate of productivity would fall sharply over the next century – to .74 tons per slave in the 1640s and to just .4 tons by 1710 (calculated from Edel, 1969: 42).[401] Edel gets the dynamic mostly right but the numbers mostly wrong. A more reliable contrast would begin with Blackburn's estimate 55,000 African slaves in 1630 and Goulart's estimate of 100,000 in 1670 (Blackburn, 1997: 174; Goulart, 1950: 106 cited in McAlister, 1984: 342). By this reckoning, each slave produced .28 tons in 1630 and .33 tons in 1670.[402] By 1820, each

[399] Dean underestimates the yield per hectare, at 50 tons/ha, and overestimates the rate of exhaustion (every 15 years) (1995: 80). His estimate of a three percent rate of extraction for the period 1550-1700 is entirely too optimistic.

[400] We opened this chapter with the comments of contemporary observers Manuel do Nobrega and Vicente do Salvador, writing in the 1560s and 1620s respectively. Among Brazilians, the early colonial critiques of this predatory political ecology would continue – indeed the resurgence of Brazilian sugar production and then coffee would be implicated in another such wave of ecological critique, beginning in the late eighteenth century (Padua, 2000). Another line of ecological critique would take shape again after World War II (Prado, 1967; Novais, 1989; Buarque de Holanda, 1956).

[401] I have used Antonil's estimate of 20,000 tons for 1710. Edel is somewhat more generous at 21,800 tons. This latter changes the productivity estimate to .43 tons of sugar per slave. 77

[402] Here I have taken the production figures for 1630 and 1670 from Table 6.1. I've made no effort to recalculate labor productivity on the basis of the sugar's sector share of the slave labor force, since in these years the overwhelming majority would have been employed in sugar. In the late seventeenth century, Blackburn thinks no less than 25 percent of the slave population was deployed outside sugar (1997: 205). Nevertheless his estimate of labor productivity coincides (quite independent of my calculations) with mine for 1670, a third of a ton of sugar annually (Blackburn, 1997: 205). Whether or not labor productivity was

slave in Bahia produced .19 tons each year.[403] It was a 38 percent decline in productivity relative to seventeenth century average.[404] This is an inexact measure to be sure, but one that accords well with the evidence for land productivity.

Soil exhaustion is often discounted in the study of the Brazilian sugar frontier. But this may be premature. Schwartz offers four cases between 1624 and 1752 indicating a decline in yield per acre from 2,083 lbs to 1228 lbs (1985: 114).[405] Yields would revive by the 1780s (Schwartz, 1985: 114) – which makes sense given the bottoming-out of the sugar cycle by mid-century. (Therefore offering some relief to the land, allowing it to regenerate.)

Our next step is to turn these figures into yields. In the first instance, we can acknowledge that declining yields are, on the one hand, a structural feature of all sugar zones in the absence of significant fertilizer additions. On the other hand, it is clear that yields may decline for all manner of reasons. During an era of protracted difficulties, and by the mid-eighteenth century this was certainly the case, colonial planters would redirect slave labor towards the "natural economy" (Brandão, 1979), and where feasible, towards more remunerative activities. In such cases, labor once devoted to cultivation would be minimized. Ratoons would be favored over replanting. And yields would fall.

Translating sugar production per acre into cane yields turns on the industrial efficiency of extracting sugar from cane. In methodological terms, industrial efficiency is also crucial because, under conditions of rapid technological innovation, rising output can be sustained on the basis of declining yields. The extraction rate varied according to the power source. Oxen-power mills, the *trapiches*, were about half as efficient as the water-powered mills, the *engenhos reais* (Schwartz, 1985: 112) – 1.5-2 percent relative to 2.5-3 percent. For northeastern Brazil (1624-1752), Schwartz estimates an average output of

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substantially higher in the West Indies remains an open question. Looking at Antigua, St. Kitts, Montserrat, and Nevis in the 1770s – which together produced 21,158 tons (as much as Brazil in 1700) – Deerr's numbers indicate that labor productivity varied between .198 tons/slave (Antigua) and .39 tons/slave (St. Kitts), with an average productivity of .26 tons/slave (for 82,270 slaves) (all calculated from Deerr, 1949: 174). This was roughly the same in Barbados c. 1680. The island produced about 10,000 tons of sugar (1683) with 38,782 slaves (1680), which yields (surprisingly in my view) a level of productivity *exactly* the same, .26 tons/slave (calculated from, respectively, Dunn, 1972: 203, and Galloway, 1989: 81). Schomburgck, drawing on contemporary reports, thinks the number of slaves was significantly higher, 46,602 in 1683-84 (1848: 82).

[403] This estimate proceeds from two pieces of evidence. First, Schwartz puts Bahia's slave population at 147,000 for 1819 (1982b: 57). Second, there were 500 mills in Bahia in 1820, with an average production of 1500 arrobas per mill (Schwartz, 1985: 423-424). This amounts to 750,000 arrobas or 12,234 tons (32.625 lbs/arroba). If 45 percent of Bahia's 147,000 slaves were involved in the sugar sector, that comes to 66,150 slaves, or .185 tons/slave. What is important in this estimate is the productivity figure rather than the precise translation of economic demography. In estimating 45 percent of the slave population engaged in the sugar sector, I am not arguing that all these workers were employed by the *senhores* and *lavradores*. That said, my estimate is on the low side of a more expansive definition of this sector. For taking the mills and canefields by themselves, Schwartz's reckoning of 500 mills for Bahia in 1820 and 100 slaves per "reconstructed" unit of engenhos plus lavradores yields a figure of 50,000 slaves (1982b: 72-73; see also Barrett and Schwartz, 1975: 552, for a ratio of mills to slaves in the Recôncavo). The additional twenty percent would include slave labor deployed in, say, Salvador's sugar trade (40,000 slaves lived in 1820 Salvador), or in manioc cultivation to feed sugar workers (Schwartz, 1982b: 57).

[404] I have average the seventeenth century figures from 1630 and 1670.

[405] Schwartz's last two cases are from 1751 and 1752, which I've averaged, to give the benefit of the doubt to soil fertility and strategies to sustain yields through rotating cultivation.

2541 lbs/ha for the *trapiches* and 5870 lbs/ha for the *engenhos reais* (1985: 112).[406] This yields agricultural productivity of 63.5-84.7 tons/ha for the *trapiches*, and 97.8-117.4 tons/ha for the water-powered mills.

If these figures hold, then the Brazilian sugar frontier enjoyed a marvelous fertility windfall indeed! The high figures are not unrealistic. The highest estimate of 117.4 tons/ha is comparable to the very highest yields obtained in nineteenth century Cuba. Moreno Fraginals reports that "first plantings of a dead forest commonly produced well over 120,000 arrobas of cane per caballeria" (1976: 76, also 170), or 112 tons/ha.[407] If *massapé* offered the bounty that its celebrants proclaim, then such high yields may indeed have been possible. It would explain not only the efflorescence of the Brazilian sugar complex in the seventeenth century but also the slow pace of its decline in terms of aggregate output. Dean is however less optimistic. He (1995: 79) seems unwilling to concede much to *massapé*, estimating agricultural productivity between 1550 and 1700 at 50 tons/ha.

But we might do better to give *massapé* the benefit of the doubt. My reading of the tea leaves suggests that Dean's estimate fits the end of the colonial era in Brazil rather than the beginning. In the 1870s, yields in Pernambuco "never exceeded" 60 tons/*safra*, averaging about 40/ha annually (Eisenberg, 1974: 218, 126-127). The majority of producers in the northeast during the 1930s would produce cane yields of just 30 tons per hectare, and in 1990 average yield was 47 tons/ha (James, 1953: 314; Moore, 2006: 1745). This accords favorably with Cuba (c. 1860-81), were average productivity oscillated between 60-70 tons/ha (calculated from Moreno Fraginals, 1976: 170; Ayala, 1995: 106).[408] By 1913, newly founded plantations in Cuba enjoyed average yields of just 58.7 tons/ha. Among plantations founded before 1880, yields were 22 percent lower than those of plantations established in the next decade (Ayala, 1995: 106). Productivity for the island as a whole had declined to 43 tons/ha by the eve of the First World War (Food and Agriculture Organization, 1961: 33). Relative to 70 tons/ha a half-century earlier, this represents a 46 percent decline in land productivity. This accords well with Schwartz's findings of very high yields in the early seventeenth century (1624), giving way to lower yields in the eighteenth century. Although we must do so very gingerly, there is a good fit in terms of the secular trends. If we take Schwartz's 1624 figure of 2,083 lbs/acre and the 1751-52 average of 1228 lbs/acre, this represents a decline of 41 percent.

The longer time frame of soil exhaustion in Brazil, relative to the later Cuban frontier, may be readily explained. First, the Brazilian sugar commodity frontier was a succession of frontiers. This was true for Cuba as well, but in more limited fashion. We have mentioned the shift from Pernambuco to Bahia in the 1640s, but this merely scratches the surface. The Recôncavo itself – never mind the rest of Bahia and the northeast – was at a minimum two sugar frontiers. In the Recôncavo an initial frontier movement established production on the north-central edge of the Bay, followed by southwesterly expansion towards Iguapé and the Rio Paraguacu (Barrett and Schwartz, 1975: 535). Second, Cuba's sugar revolution, which unfortunately is outside the bounds of the present study,

[406] Calculated on the basis of 1.07 acres per tarefa, or 2.31 tarefas per hectare.

[407] Calculated on the basis of 13.4 ha/cabelleria and 25 lbs/arroba (see also Ayala, 1995).

[408] Cuban sugar's competitiveness in the mid-nineteenth century therefore found its source in higher industrial rather than agricultural yields (Ayala, 1995; also Tomich, 2004). Javanese production similarly average 55 tons/ha in the 1880s before its fertilizer-led sugar revolution occurred (Knight, 2006: 60).

embodied the dynamics of industrial capitalism in a way that Brazilian sugar could only prefigure (Moreno Fraginals, 1978; Tomich, 2004).[409] Capitalism not only gets bigger in successive phases of world development, it gets faster.

Finally, Brazil's soil crisis was attenuated because of the unusual freedom of movement enjoyed by planters. By 1600, most of the best caneland in the northern perimeter of the Recôncavo had been occupied (Schwartz, 1985: 228). Once this occurred, planters quickly found their way onto *salão* soils. The distinction was sufficiently important that Antonil regarded knowledge of these different soil types as essential for anyone who wished to buy caneland (1711: 90-91). If sugarcane could be planted in *massapé* and left to ratoon up to twenty times on its own before replanting, *salão* "tended to become exhausted much more quickly" (Schwartz, 1985: 107). Replanting on *salões* (rather than ratooning) was typically necessary after three, or at most four, *safras* (calculated from Edel, 1969: 42). This meant not only a tendency towards geographical expansion as a response to declining yields. It also entailed rising labor costs relative to *massapé* zones. Ratoon crops minimized labor demands; planting maximized them.

The movement onto *salões* was sometimes better and sometimes worse. On the one hand, its lower clay content meant that *salão* had an advantage over *massapé* during very wet years. *Salão* retained less moisture during these years and therefore produced better crops (Schwartz, 1985: 107). Transport in these zones was also easier in these years, when *massapé* zones became "effectively impassable" and oxen (with their carts) would get stuck and perish (Schwartz, 2004: 159).[410] On the other hand, in addition to lower aggregate fertility, its sandier quality rendered *salão* zones vulnerable to erosion.

Nonetheless, by 1600 and especially after the 1620s, such zones offered high yields relative to areas of established cultivation, and cheap fuelwood in the surrounding forest. This accelerated still further sugar's overexploitation-expansion dynamic:

> The perception of the [*salão*] soils' limited fertility and an unwillingness to enhance them caused planters to view land as they would any capital good, fully expecting its value to decline to almost nothing through depreciation. This, and the fact that new cleared soils were extremely fertile, *were incentives to range further in the pristine forest and make a completely new start* (Miller, 2000: 34, emphasis added; also Prado, 1967: 155).

I am not suggesting that this process fit neatly into a Ricardian logic of sorts. The best soils were not always brought into cultivation first. Surely planters found *massapé* as well as *salão* soils in the second phase of Brazil's sugar revolution after 1600 (Hutchinson, 1957). Yet, it seems that *salão* were encountered were increasing frequency over the next century. This movement onto *salão* soils doubly favored relocation over improvement – hence the "migratory nature of sugar agriculture" in the eighteenth relative to the seventeenth century (Schwartz, 1973: 170).

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[409] Not least because of steam-power *usinas* and railroads.

[410] Even in the 1930s, tractors could not operate in *massapé* located on even very modest slopes (James, 1953: 327).

It is indeed questionable whether this was a *new* logic of relocation at all. Perhaps it was a case of the underlying tendency becoming more conspicuous after 1650. "As a rule," Buarque de Holanda observes, "farmers would search for new land in the forest, and thus rarely did two generations pass without the same farm changing sites or owners… As it did not occur to anyone to reinvigorate exhausted soil through fertilization, the soil lacked improvements of any kind" (1956: 47; also Costa, 1979: 52). The timing is important. Two generations translates almost exactly to the 50-60 year cycle that we've identified earlier on Madeira – not to mention along the mining and forest product frontiers.

Buarque de Holanda is prepared to go even further. He wondered if one could even

> apply the term 'agriculture' to the processes of [environmental] exploitation that the sugar cane plantations introduced… European techniques served only to make the rudimentary cultivation methods used by the indigenes all the more devastating… The truth is that large-scale agriculture, as it was and as it continues to be practiced in Brazil, constitutes by its wasteful nature almost as much of mining as it does of agriculture. Without enslaved labor and superabundant land to use up and ruin… it would be unrealizable (Buarque de Holanda, 1956: 43-44).

Three socio-ecological pillars supported this soil mining regime. Two of these we have encountered already – the grand enclosures of colonial occupation that dwarfed those of contemporary northern Europe, and the concept of nature as "abstract entity" (Dean, 1995). The third was a legal regime that instanciated the *extensive* character of early capitalism's ecological regime. In stark contrast to the English model, which compensated tenant farmers for improvements (Duncan, 1992),[411] in seventeenth century Brazil "all improvements made to the land [by the *lavradores*] became the property of the *engenho*… at the end of the tenure" (Schwartz, 2004: 184; also Taylor, 1978: 32; Andrade, 1980). As in England, the tenants did go down without a fight, offering both legal and "physical" resistance (Schwartz, 2004: 184-185).[412]

The contracts between the *senhores de engenho* and the *lavradores* further intensified the ecological squeeze. Many of these contracts began to specify that *bagasse* – the term of cane stalks after the juice had been extracted – would remain in the hands of the *senhores* (Deerr, 1949, I: 109). While bagasse is commonly regarded as a primarily a fuel source – although apparently not used for this purpose in Brazil until 1695 (Barros de Castro, 1977)[413] – the ashes that resulted were equally "valuable" as a source of soil fertility (Deer, 1949, I: 108).

So when Miller argues that the era's planters were "unwilling" to improve the soil, my sense is that the roots of this unwillingness are to be found in the social relations that emerged through the frontier realities of cheap land for the taking. I am sceptical that the

[411] A model that would not achieve global currency until the long nineteenth century (Thompson, 1991).

[412] "When *lavradores* were forced to surrender the lands that they had work and improved for years they often objected and resisted either physically or in the courts" (Schwartz, 2004: 184-185; for England, see Overton, 1996).

[413] Other sources put the first use of bagasse much later. Prado believes it was not used until 1809 (Prado, 1967: 455)

planters "view[ed] land *as they would any capital good*, fully expecting its value to decline to almost nothing through depreciation" (Miller, 2000: 34, emphasis added). In the early modern era, capitalized nature was *not* expected to be exhausted. Indeed quite the contrary! For the basic problem in colonial Brazil was that arable land was *not* a "capital good" and yet articulated with – and *dominated by* – the territorialist and business agencies of an emergent capitalism.

Under the conditions of a capitalist world-economy in creation, nature was, in Marx's turn of phrase, a "free gift… to capital" (1967, III: 745). There were, then, constant efforts in the context of early capitalism's extensive ecological regime to reduce the capital requirements of production, and to maximize output at the expense of pedological sustainability and human well-being. A much different logic prevailed in those regions characterized by the first *modern* "agricultural revolutions" – in England and the maritime Low Countries. In these regions, land was progressively drawn into the circuit of capital, and there were correspondingly greater efforts to *augment* land productivity (de Vries and van der Woude, 1997; Brenner, 1985a, 2001). Capitalized nature for sure entrains a specific set of ecological antagonisms, but these are quite distinct from those of undercapitalized cultivation in the first great wave of European expansion. To call one capitalist and the other not may however obscure their interrelations. These two geographical movements of agrarian transformation – one path capital-intensive, the other land-intensive – constituted a dynamic whole.

Thus the centrality of free land in the commodity frontiers. Along the sugar commodity frontier, free land tended to favor world accumulation. World accumulation, but not accumulation within the Brazilian "home market" – precisely because this was an era when the maximization of the ecological surplus on a systemwide level was achieved largely by *extensive* means.[414] In Marx's classic account, free land was the "anti-capitalist cancer of the ["free"] colonies" (1977: 938). So long as the colonial state did not strive to set an "artificial price" on land, and so long as the bulk of the population employed family labor rather than wage- or slave-labor, the possibilities for capitalist development existed on "too limited a scale" (1977: 938, 935). But, as Marx realized, the situation was substantially different in the slave colonies. In the first place, seventeenth century Brazilian sugar planters depended on the world market not only to sell their goods, but also to finance their social reproduction, at the level of the household, and as a class. The Brazilian planter was *not* analogous to the Mexican hacendado. (Or at least the idealized representations of the latter.)

It is for this reason that Barrett wishes to counterpose the "efficient" plantation to the "inefficient" hacienda (1979). The language of economic rationality is surely misplaced, but the dichotomy succeeds in identifying the differential penetration of capital into the reproduction of these idealized economic forms. The *engenho* enjoyed greater geographical mobility as we have seen. Slaves and mills could move. Mobility was purchased on credit. Debt obligations met with the dynamics of slave mobilization to produce a situation whereby production had to be maximized, costs minimized, and as a

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[414] This is not to say that intensive, productivity-maximizing innovations were unimportant. Quite the contrary. The Dutch and English agricultural revolutions were very important. But there were definite limits to how far these productivity-maximizing revolutions – capitalist intensive revolutions rather than capitalist *ex*tensive revolutions – could proceed.

consequence the ecological bases of profitability undermined. "Bahian planters," Schwartz observes,

> like all sugar producers, were captives of their own system of captivity. Agricultural units dependent on a permanent slave labor force had to be housed, clothed, and fed the year round, in crop time or slack season, whether sugar was produced or not… *Then, too, most of the senhores de engenho were indebted, and the servicing of these loans and mortgages called for an annual harvest*. Planters might have sought another staple, but the coastal zone of the Northeast did not lend itself to many alternatives… The *engenhos* were tied to slavery and sugar in a complex web of culture and economics that constrained and limited their actions. Whether sugar prices were high or low, planters tended to maximize the output of their laborers (Schwartz, 1985: 194, emphasis added).

At an enterprise-level, while the very largest *engenhos* were highly durable, ownership was not (Schwartz, 1987: 89). And *engenhos* could and did shut down rather than change hands. More than a quarter of Bahia's 146 mills, forty in all, closed down between 1700 and 1724 (Barrett and Schwartz, 1975: 560). The long-run response, within the region, was in the direction of many new mills – there would be 500 by 1820 – each producing about half as much in 1820 as they did a century earlier (Schwartz, 1985: 423-424). There was, then, constant pressure to establish new mills on a shoestring in frontier territory, whereby diseconomies of scale would be offset against the advantages of fertile soil and abundant fuel. Hence the long run tendency towards many *smaller* mills, in contrast to the Caribbean experience (Schwartz, 1982b).

If the *lavradores* were indebted to the *senhores*, the *senhores* found themselves at the mercy of merchant capital. The big planters found themselves locked into an "international system of debt peonage" (Wallerstein, 1974) from which there were few avenues of escape. The result was profound instability within both strata. From the first decade of the seventeenth century, the *senhores* were at odds with the merchant financiers over the terms of this debt regime. Appealing to Lisbon, the planters sought and won legislation in 1612, limiting creditors from collecting more than half an *engenho's* annual production. (Two-thirds for *lavradores*.) Like forest regulations, this is surely evidence of more serious problems. The protective legislation was in any event rescinded by the Crown in 1614, under pressure from Lisbon's bourgeoisie. More serious problems emerged in the 1620s, and by 1632 "*another* series of enclosures" swept across Bahia (Schwartz, 1985: 195, emphasis added). By 1636, Bahia's governor issued a mild reprieve. As long as the planters owed *less* than the total value of the *engenho*, there would be no foreclosure. Piecemeal foreclosures of land, slaves, or equipment were ruled out. The effectiveness of the legislation, however, is doubtful. It was re-issued in 1663, 1673, 1681, 1686, 1690, and 1700 in Bahia alone (Schwartz, 1985: 195-196).

The social basis of the metabolic extroversion instanciated by the sugar complex was, then, the economic extroversion of a debt-driven export economy. In Buescu's view, this debt regime deprived the *engenhos* of "indispensable turnover capital" (1970: 71). Once an *engenho's* debt obligations reached critical mass, high interest rates rendered the mill's economic viability highly precarious, given minimal disturbances. Under these conditions, a seemingly normal "situation could rapidly worsen, particularly from the moment that the sugar cycle entered the period of descent" (Buescu, 1970: 71).

The *senhores* naturally sought to devolve these burdens onto the *lavradores*. This intertwining of ecology and political economy contributed mightily to the "*inconsistency and precariousness of the agricultural sector*, even within the privileged sugar sector," and especially among the *lavradores* (Buescu, 1970: 112). For the eighteen safras between 1622 and 1650 at the Sergipe do Conde *engenho*, 128 *lavradores* brought cane to the mill; they returned for an average of 3.4 years, or just barely more than two harvests. Of these 128 planters, two-fifths (41.4 percent) appeared in the mill's books for just one *safra*. Fewer than one-fifth (18.8 percent) appeared for more than five (Buescu, 1970: 112; also Schwartz, 1973).

Such instability, coupled as we've seen with tenurial arrangements specifically aimed at discouraging the accumulation of Blaikie and Brookfield's "*landesque* capital" (1987: 9-10),[415] favored extracting as much from the soil as quickly as possible. "From the earliest moments of colonization," Buarque de Holanda observes, there was one "guiding principle [of colonial agriculture:]… everyone wanted to extract extreme benefits from the soil without significant sacrifices" (1956: 50).

The tendency towards soil exhaustion was reproduced not only through the class relations that emerged in the sugar complex, but also through the broader inter-regional divisions of labor that the frontier set into play. Among these latter, sugar's tendency to displace other species deprived it of the nutrients necessary for middle-run sustainability. There was, simply put, little room for agro-pastoral linkages within the plantation unit itself. Here the geography of *extra-human* labor power enters the story. Oxen were most crucial. "As early as 1521 sugar had been planted in Brazil, but it was never profitable until oxen were available as power," probably in the 1530s (Poppino, 1949: 220). From where did these oxen originate? As it turns out, the first cattle to arrive in Brazil were raised on Madeira. (Surely not from Madeira itself but on the smaller islands of Desertas and Porto Santo.) For the rest of century, "nearly all" livestock imports were drawn from the Azores, the Cape Verdes, and the Madeiras (Poppino, 1949: 220) The Atlantic islands would remain an important supplier of livestock for the British Caribbean in the sugar frontier's next great era after 1640 (Watts, 1987: 408).[416]

Although oxen-driven mills were common – these were the *trapiches* enabled by the new vertical three-rollers – there seems to have been little in the way of manuring (Galloway, 1989: 73). Far from a narrowly enterprise-level failure, there emerged in early colonial Brazil's interregional division of labor "a complete and drastic [geographical] separation" of cattle raising and sugar cultivation (Prado, 1967: 215). To be sure, they were mutually interdependent (Crosby, 1972: 90-91). Oxen were crucial sources of power for the mills, and the mills were the crucial consumers of these animals (Buescu,

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[415] By this Blaikie and Brookfield refer to "any investment in land with an anticipated life well beyond that of the present crop, or crop cycle. The creation of landesque capital involves substantial 'saving' of labour, and other inputs for future production" (1987: 9).

[416] Why were oxen available for export from, among other places, Madeira? Precisely because the sugar sector was by the 1530s in decline, increasingly displaced by vineyards (Vieira, 2004). And among the chief advantages of the vineyards was its relatively fuel-thrifty processing. No great boiling houses were needed to transform grape into wine. Thus livestock exports were possible precisely because the Atlantic islands were no longer major sugar producers, shifting to (or still growing) wine, wheat, and other crops with a less voracious appetite for animal power.

1970: 80; also Galloway, 1975: 27). But the ecological relations of production and exchange were such that we can see an early form of modernity's tendency towards "radical simplification," (Worster, 1990) through the rupture in the metabolic interchanges internal to this agrarian (should we say *agro-pastoral*?) zone. In the first instance, this metabolic rupture "rob[bed] the cultivated land of its only readily available fertilizer" (Prado, 1967: 215). This favored soil exhaustion and thence geographical restlessness on the part of cultivators. And yet it was the sugar complex's very land hunger that squeezed out cattle ranching in the first place. Thus, this spatial separation between stockraising and cultivation – a colonial and multilayered moment of the Foster's "metabolic rift" – constituted a mutually reinforcing cycle of expansion and exhaustion (Prado, 1967: 215-16; also Dean, 1995: 75-76).[417]

The Crisis of Brazilian Sugar, 1670-1750

We have so far pointed to signs of regional crisis, and identified its underlying sources. But we have yet to trace the unfolding of the crisis itself. If stagnation and therefore relative decline characterized the Brazilian sugar regime in the second half of the seventeenth century, absolute decline set in after 1700. Exporting 20,000 tons a year in the early eighteenth century, Brazil's exports sunk to just 10,000 tons annually by the 1750s (Dean, 1995: 173). By the 1730s, Brazil's share of the world market had fallen to 25 percent, to just 10 percent in 1776, and eight percent in 1791 (Schwartz, 1985: 422; Tomich, 1990: 15). The crisis of the northeast was such that Bahia and Pernambuco, together once the greatest sugar production region in the Atlantic world, were by 1875 not even the leading producers within Brazil. Rio de Janeiro and São Paulo were by this point the top two producers: "The Recôncavo struggled to maintain even a poor fourth position" (Haskins, 1957: 80-81).

Production declined from just over 34,000 tons a year to about 25,000 tons in the second half of the seventeenth century (Table 6.1). Aggregate revenues may have declined even more sharply, perhaps by as much as 75 percent owing to "the depreciation of Portuguese currency in relation to gold" (Furtado, 1963: 17). There is no doubt that the deteriorating world position of Brazilian sugar producers after 1650 cannot be tied narrowly to ecological factors. Narrowly conceived, the ecological contradictions we've surveyed may not have been sufficient, *in themselves*, either to compel Brazil's relative decline, or to drive a relocation in the sugar frontier's center of gravity after 1650. But then, ecological contradictions, abstractly conceived, existed no more than political factors or market forces abstractly conceived. These (and not these only) constituted a dynamic whole. As in any crisis, we dealing with a situation of crises within crises, layers within layers. The movements of political economy were so tightly interwoven with ecological transformations and ecological relations that it is impossible to identify a facet of imperial power, or capital accumulation, independent from socialized nature.

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[417] Or perhaps we should say, expansion, extermination, and exhaustion as Domingos puts it: "Driving the frontier of settlement deeper into the outback was originally in the interest of the sugar industry, which needed the Indian slaves, protection against the wild [sic] Indians, live oxen (for traction), and cheap beef and leather. *The growth of cattle ranching on the open range was linear and rapid, and this required that the Indian tribes be exterminated*" (2004: 101, emphasis added; also Cleary, 2001: 84-85).

Even if one were to retain a conventional environmental history focus on local conditions, one would have to acknowledge that these were a big part of the story. For these local conditions were overlaid with global pressures. Three stand out. First, there was war. The Dutch invasion of, and temporary hegemony over, the great sugar region of Pernambuco (c. 1630-54) caused widespread devastation (Schwartz, 1987; Boxer, 1952). Protection costs – and therefore transport costs – skyrocketed (Schwartz, 2004: 164). Of special import in this regard was the imposition of the convoy system after 1649 in order to protect the sugar fleets from the Dutch. Under this system, planters could no longer arrange individually to send their sugar to Europe. They were compelled to wait for the fleet's arrival. And this was unpredictable. The semi-refined sugar might be stranded on the wharfs of Recife or Salvador da Bahia, awaiting the fleet. Waiting for as long as two years in extreme cases (Boxer, 1952: 184; also Schwartz, 1985). "[T]he convoy system may be useful and may be valid for gold and silver, but certainly not for a bulky commodity like sugar, where you have a small galley for a great tonnage and a product that spoils with humidity" (Barros de Castro, 1977: 7). At the same time, the colonial state imposed new taxes on sugar planters to pay for the war, heavy enough to put them at a competitive disadvantage with emergent production centers by the middle of the seventeenth century (Schwartz, 2004: 166; Steensgaard, 1990: 138).

Perhaps most decisively, the war led Dutch merchants to ship a growing surplus of slaves northwards to Barbados, pushing down the price of slaves in the Caribbean relative to Brazil (Green, 1988). By mid-century slave labor power was fully twice as costly in Brazil as it was in Barbados (Edel, 1969: 42). This, coupled with the flight of Dutch capital away from its insecure investments – for instance contracting credit to Brazil producers – provided favorable conditions for a Barbados sugar revolution. Regardless of the precise role of the Dutch in subsequent developments, it is in any event clear that credit in the English colonies was becoming more favorable (Menard, 2006), while it was becoming worse for the northeast's planter class (Hutchinson, 1957: 38-39).[418]

A second major global development concerns the increasingly aggressive mercantilist policies of the French under Colbert, and the British by virtue of the Navigation Acts (Godinho, 2005: 319). In 1630, 80 percent of the sugar on the London market derived from Brazilian sources. By 1690 this had fallen to 10 percent (Schwartz, 2004: 170; Green, 1988; Batie, 1991; Edel, 1969). But the blame for Brazilian's sugar decline cannot be laid entirely on mercantilism's doorstep. Brazil lost its market share not only in France and England, but also in relatively open Italian markets, where Barbados sugar had won out by the 1670s (Barros de Castro, 1977: 5).

Finally, the climate turned unfavorable. Although the effects on northeastern Brazil were less catastrophic than they would be in the late nineteenth century (Davis, 2001), ENSO[419] seems to have aggravated the sugar complex's underlying structural problems. El Nino occurrences seem to be implicated in a series of ecological woes in the region, reinforcing those socio-ecological contradictions we've just surveyed. The serious droughts of the mid-1660s, lasting five years, gravely undermined productivity at a time when the Caribbean enjoyed a century-and-a-half lull in hurricanes (c. 1600-1750)

[418] The dissolution of the Portuguese and Spanish Union in 1640 "caused a monetary crisis in Brazil," (Schwartz, 1973: 185) depriving the already cash-poor region of precious specie, which would have raised interest rates.
[419] ENSO – El Nino-Southern Oscillation.

(Schwartz, 1985: 184; Garcia Herrara, et al., 2003: 1031; Caviedes, 1991). Serious droughts would strike again in 1671 and 1673 (Schwartz, 1985: 184), again strongly correlated with ENSO (Prieto, Herrara, and Dussel, 1999).[420] (Were these correlated also with what Schwartz calls a "series of bad harvests" in Bahia during the 1670s [Schwartz, 1982: 8]?)

These droughts were perhaps not unrelated to the 1665-66 smallpox epidemic that hit slave populations quite hard (Schwartz, 1985: 184), leaving "many plantation owners without laborers" in the Recôncavo (Hutchinson, 1957: 38). It is surely no coincidence that London was "decimated" by plague that very summer (1665) (Fagan, 1999: 167). (The next summer was one of the warmest in London since the fourteenth century – and surely contributed to the Great Fire of 1666 – notwithstanding cool temperatures during seventeenth century as a whole, cool even by the standards of the Little Ice Age.) Storms in 1667 were sufficiently intense to delay the fleet's arrival in Salvador da Bahia, adding insult to the convoy system's injury, further depressing prices (received by planters) as sugar wasted on the wharfs (Schwartz, 1985: 184). Finally, yellow fever "decimated" slave populations in Bahia and Pernambuco (but not elsewhere) between 1686 and 1691 (Schwartz, 1985: 188) – possibly aggravated by an apparently chronic situation of "near famine" in these years (Hutchinson, 1957: 38). And although the connection between yellow fever and Brazilian environmental conditions is not clear, we do know that yellow fever in the West Indies was strongly linked to deforestation and the expansion of canefields. Receding forests undermined the bird populations that preyed on fever-carrying mosquitoes, who found the expansion of marshland at the expense of forest a favorable breeding ground (McNeill, 1999).

The Luso-Brazilian sugar complex was embattled on all fronts.

The Sugar Revolution Systematically Combined: Barbados, 1640-1750

The rise of the Caribbean sugar complex to global primacy in the seventeenth century is well-traveled terrain. While Brazil's export growth stagnated by 1650 and declined by 1680 – not to revive until the end of the next century – the Caribbean entered the era of the Sugar Revolution proper. Like all revolutions, its revolutionary character has been subject to endless debate (Menard, 2006). Nevertheless, any other term seems exceedingly cautious. The expansion of American sugar exports from about 30,000 tons to 187,000 tons between 1650 and 1750 surely represented a decisive extension of capitalist power throughout the Americas.[421]

The revolution would be launched from shores of Barbados. A small island, it would come to pack a continental wallop. Barbados is properly regarded not so much as a region unto itself, but as the pivot on which the extended Caribbean of the seventeenth and eighteenth centuries emerged. No sugar, no slaves, no trade. Sugar would *directly* account for about half the value of Europe's imports from the New World by the mid-eighteenth century (Findlay & O'Rourke, 2001: 10). Thus, no trade, no accumulation, no industrial revolution (Blackburn, 1997).

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[420] Bradley and Jones (1992: 635) see drought and El Nino in northeastern Brazil "related to each other 70% of the times."

[421] Figures from Table 6.1 above, and Steensgaard's estimate of 170,000 metric tons (187,000 tons) in 1750 (Steensgaard, 1995: 12).

In what follows, we move seemingly against the grain of historical capitalism's geography – from big to small, from the vastness of Brazil to the finitude of Barbados. Even more so than Brazil, Caribbean sugar represented not one but many frontiers. We shall focus on Barbados because it came first, but not only because it came first. The Barbados model crystallized the logic of the early modern sugar commodity frontier in its purest form. In the span of mere decades, the whole of Barbados would be remade in the image of sugar, its monocultures prefiguring the radical disruption of nutrient cycling characteristic of late capitalism's last days (Magdoff and Foster, 2000). By century's end, "Barbados was probably exporting more relative to its size and population than any other polity of its time, or indeed any other time up to that point" (Eltis, 2000: 198). Already in 1680, no less than forty percent of Barbados' 431 square kilometers was enclosed by about two hundred sugar magnates (Dunn, 1972: 67).[422] From a dead stop in 1640, Barbados would produce 10,000 tons of sugar by 1683, and 15,583 tons by 1698 (Dunn, 1972: 203).

At the core of this agro-ecological revolution was an organizational revolution.[423] Where distinct actors in the Atlantic islands and Brazil organized processing and cultivation, the hallmark of Barbados' famous sugar revolution was its systematic combination of the two (Higman, 2000). It was, in Menard's scheme of things, a transition from the "dispersed" to the "integrated" plantation model (2006: 83, 95). It was *not* a revolution in the scale of the field-mill complex, which could not in any event be extended much beyond 200 acres owing to the agro-ecology of sugar and the capacity of mills (Pares, 1960: 25).[424] The island's 350 sugarworks in 1683 produced on average 28.6 tons a year,[425] significantly lower than the average for Bahia (51 tons) and Brazil as a

[422] Galloway thinks eighty percent was planted by 1680 (1989: 81). This seems high. Curtin, unfortunately without citing his sources, thinks that 45 percent of the island was planted in cane by 1645, and only in 1767 would this figure reach 80 percent (1990: 83).

[423] A "remarkable feature in the development of the sugar trade is its competitive character and the need for innovative ingenuity in the business. The global increase in sugar production in the second half of the seventeenth century took place under conditions of a long-term fall in prices. The Brazilians apparently never recovered their dominant status in the world market or even the prewar level of production, being hampered not only by a high level of taxation but also by more traditional and less efficient methods of marketing than those employed by their new rivals. *In the West Indies only the planters were able to consolidate their estates and who followed a conscious policy in production and marketing were able to survive and continue the profitable expansion*" (Steensgaard, 1990: 138).

[424] The scale of production would increase yet again in eighteenth century Jamaica, but even here plantations could not move much beyond 300 acres of cane (Galloway, 1985: 343; Pares, 1960: 25). This was probably very close to the biological limit of profitable sugar cultivation within the ecological regime of early modern capitalism. If left unfilled after harvest, the cane would desiccate quickly; if milled, the juice would have to be boiled quickly or else it would sour (Pares, 1960: 25). Theoretically, planters could locate nearby mills with excess capacity; but this was an option fraught with high levels of ecologically mandated risk and high transport costs (Pares, 1960: 25). If too much cane ripened at the same time, exceeding mill capacity, it would go to waste. It would take a new global ensemble of production and exchange relations – pivoting technologically on steam power and light railways – to transform this early modern limit. It would also take another geographical shift, this time to Cuba in the "first" nineteenth century (c. 1763-1865), where the new socio-ecological regime would materialize yet another quantum leap in the scale production: Cuban sugar plantations grew from an average size of 300-400 acres in 1763 to 1,432 acres in 1860 (Tomich, 2004: 85).

[425] Sheridan (1970: 29) provides data on the number of mills in seventeenth and eighteenth century Barbados. Schomburgck puts the number of mills in 1683 at 358, which would modestly reduce output per mill (1848: 82).

whole (36 tons) in 1700 (Barrett and Schwartz, 1975: 552). Smaller size was however compensated by a significant downward revision of transaction costs. The integrated plantation allowed for centralized planning of cultivation and milling schedules, such that planting and harvesting could be effectively staggered, and the volume of cane wasted in queue for the mills therefore minimized. The upper tier of plantations, owned by those 74 families who held over two-thirds of the island's 91,000 acres of arable land in 1680, operated two or three mills on contiguous properties (Sheridan, 1973: 137; Dunn, 1972: 95-97; Schomburgck, 1848: 82).

But it is far from clear how much of this land was planted in sugar. Dunn thinks that, at least up to 1680, an acre of cane yielded a ton of sugar (1972: 192). If so, this would mean a minimum of 10,000 acres of canefields. This would be a very high yield. One ton/acre translates to 2.47 tons/ha. Assuming a 15 month harvest cycle and a three percent extraction rate – the cycle would extend to 18 months by 1667 as soil exhaustion set in (Watts, 1987: 399-400) – this would mean yields of 103 tons/ha of raw cane. This may be regarded as the average for the period 1640-80. Yields would have been higher – perhaps, as Barrett suggests (1979: 23), closer to the 120 tons/ha that Moreno Fraginals identifies in eighteenth and nineteenth century Cuba – in the 1640s, declining thereafter.

Thanks to high yields and superior organization, the new system worked. Barbados sugar was at the center of an enormous expansion of world demand, and the British market in particular. West Indies' sugar exports to England – two-thirds of which came from Barbados and a third of which was reexported (Dunn, 1969: 4) – jumped by about 150 percent between the 1660s and 1700. Much as Madeiran sugar had done to its Mediterranean competitors some two centuries earlier, now Barbadian sugar drove Brazilian sugar from northern European markets by way of England's booming re-export trade (Davis, 1954: 152): "Heretofore we had all our Sugars from *Portugall*," Barbados planter Edgar Littleton wrote in 1689,

> and it is computed, that they cost us yearly about four hundred thousand pounds. Now that great Leak is stopp'd: and we hardly buy any *Portugall* or *Brasile* Sugars… But moreover; beside what we use ourselves, we export as much Sugar to other Countries, as brings us in yearly near the same summe (Littleton, 1689: 33).

The secret of success was partly organizational, partly a quantum leap in ecogeographical specialization. But first the ecological barriers would have to be overcome. And chief amongst these were woodlands. When English colonials first encountered the island, Ligon reported, "the Woods were so thick, and most of the Trees so large and massie, as that they were not to be faln by so few hands" (1657: 24; also Schomburgck, 1848: 141). As the slave trade enabled few hands to become many, Barbados (like Madeira two centuries earlier) was virtually deforested in the thirty years after initial settlement in the 1630s. The work was arduous, and it was slow. Clearing the forest was, moreover, an endeavor that demanded skill and experience. But such skill and experience was in short supply amongst a British settler population whose motherland had been substantially deforested over the long sixteenth century (Perlin, 1989: 163-245). Land clearance was, as a consequence, "an incredibly slow process." Converting forest to grassland involved one year of slave labor for every acre. Even then sugar could not be planted until the third year (Bridenbaugh and Bridenbaugh, 1972: 42-43, 271). And still, "for many years the settlers' fields [would be] encumbered with rotting stumps and logs" (Dunn, 1973: 52). Clearing was also deadly work. The work of forest clearance, like so many extractive activities, seems to have killed workers at a much higher clip than the "normal" annual slave mortality of six percent (Littleton, 1689: 18; Ligon, 1657: 97):

> Customarily, newly arrived slaves from Africa were set directly and immediately onto the task of land clearance wherever this was required…. No seasoning into the new environment was tolerated. Coupled with a frequently deficient food intake, this ensured that… this phase of estate development was characterised by very high slave death rates (Watts, 1987: 394; also Bridenbaugh and Bridenbaugh, 1972: 268).

How much higher? Watts suggests a 25 percent annual mortality might not be excessive (1987: 394). His reasoning turns on the political economy of the heavily capitalized Barbadian sugar revolution:

> It was only from monies on such a scale that the expense involved in forest clearance could rapidly be recouped… The implications of this for the… labour force were profound, for there seems no doubt that [slave laborers were] worked much more intensively…, *and even to the point of death in many instances*, in the accomplishment of this task (1987: 185-186, emphasis added).[426]

Littleton (1689) seems to support this estimate. While not referring directly to forest clearance, Littleton indicates that a Barbadian planter with his newly-purchased slaves should "take all the care he can, [lest] he shall lose a full third part of them, *before they ever come to do him service*" (1689: 19, emphasis added). Linda Newson arrives at the same figure as Littleton in her study of colonial Trinidad, whose sugar revolution unfolded nearly a century later: one-third of the slaves employed in clearing the land did not survive to work it (Newson, 1976: 185). This wave of forest clearance was, in David Watts' helpful turn of phrase, the first step towards making a "virtual biological wasteland" of Barbados (1995: 274). It was also a first step towards turning the island into a graveyard – one filled with the bodies of 339,000 slaves between 1651 and 1775 (Richards, 2003: 424).

Where Brazil's cane farmers, at least in principle, had aimed for timber self-sufficiency, this strategy was quickly rendered impossible in Barbados. So much were the woodlands thinned –perhaps more to the point, *enclosed* – that by 1656 that the island's General-Assembly was moved to legislate against what it called growing "encroach[ment] upon their Neighbor's Line": "Many persons… have encroached up their Neighbor's Line, and made use of great parcels of their Lands, and fallen and cut

[426] Watts is almost certainly mistaken when he attributes overwork in itself as the primary cause of higher slave mortality in forest clearance. The decisive variable was probably the dangers associated with cutting trees – and this hardly a phenomenon limited to the colonial era. Even today, logging remains one of the most dangerous industrial (or extractive) occupations in world, especially but not only in the global South (see International Labour Office, 2005; Frazier and Mullan, 1983).

down many of their marked and timber trees, of a good value" (reproduced in Hall, 1764: 25).

In the grips of a sugar revolution that was in equal measure social and ecological, it seems likely that such legislation indicated two intertwined phenomena. First, the forests *were* being mowed down. "By the 1650s there was a timber shortage, and by the 1660s [just fifteen years after the first serious sugar exports commenced] Barbados had less woodland than most districts of England... [C]olonists were complaining of a timber shortage" (Dunn, 1973: 67, 27). By 1665, "all but the most isolated patches of forest" were gone (Watts, 1987: 186).

But timber scarcity was also an expression of the changing class structure that was part and parcel of the Barbadian commodity revolution. Between 1643 and 1680, sugar planters engrossed about 80 percent of the island's arable land (Beckles and Downes, 1987: 226). The smallholders who had grown tobacco and cotton in the colony's early years were squeezed out, and not by Smithian means alone, as Blackburn observes:

> The construction of plantations thus involved a process of concentration of land management and landownership. The planters had money to buy out the numerous smallholders or leaseholders dating from the early days of colonization; *but the smallholder or tenant, satisfied with his position and with the rewards of a second staple, might be unwilling to sell*. The larger planters held office as vestrymen in the parish councils, posts which they used to impose taxes and levies on the land. Smallholders were encouraged to sell both by the cost of landholding and by rocketing land prices. *Between 1648 and 1656 a local statute enable the Church vestries to confiscate and sell the land of any smallholder who had failed to pay the parish levies* (Blackburn, 1997: 231, emphasis added; also Puckrein, 1984: 62).

It was these smallholders, in addition to perhaps a few adventurous and marginal planters,[427] who were likely the chief culprits identified in the General-Assembly's 1656 Act against timber poaching. The sugar revolution by its nature imposed a structural squeeze on the island's smallholders, and those who managed to survive undoubtedly resorted to illicit forays into the woodlands as a way to make ends meet.[428]

If the social problem of smallholder agriculture and their encroachments was easily dispensed with, not so the ecological issue. Forest products, for timber and fuel especially, were necessary (and often urgently so) to the life of sugar society.[429] And so Barbadian planters resorted to the first, best ecological fix strategy of early modern capitalism: expand the hinterland. As woodlands were thinning, Barbadians traveled to

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[427] "For the 'middling' and 'small' planters, life was of course a good deal more meagre than [that of ruling plantocracy], many living in poor conditions with only a bare subsistence diet, except when sugar prices were high" (Watts, 1987: 357).

[428] There is a clear parallel with England here, and not just with England to be sure (Thompson, 1976).

[429] Insert discussion on "Jamaica train" and fuel efficiency. Moreno Fraginals thinks the Jamaica Train reduced fuel inputs by 50 percent. Furthermore, it could use bagasse, the dried cane stalks as fuel. The problem on Barbados was that at least some meaningful share of the bagasse was being used as feedstock for animals in order to supply manure for the fields (Littleton, 1689: 18). On origins of Jamaica Train in Barbados, see Galloway, 1985, Watts, 1987: 399. Also Tomich (1990: 165-166) on bagasse.

Tobago and St. Lucia to extract construction timber, especially for the cedar rollers need to press the cane (Bridenbaugh and Bridenbaugh, 1972: 269). So prized was St. Lucia for its dense forests that Barbadian planters sought to colonize the island in 1664. Nor was St. Lucia the only external source. During the 1660s, Barbadians imported so much timber from Antigua that in 1669, the latter's governor "forbade exports in order to preserve wood for [the island's] inhabitants" (Bridenbaugh and Bridenbaugh, 1972: 207-208, 269). Shut out of Antigua, Barbados, and then Jamaica and the West Indies as a whole, applied to Guiana and especially the Carolinas. The bulk of timber leaving such major ports as Charleston was destined for the sugar isles by the mid-eighteenth century (Silver, 1992: 117-118; Hobhouse, 1999: 75). The hinterland was expanded, moreover, not just horizontally but also *vertically*, in the form of coal. By the 1660s, a contemporary observer would report that "at the Barbados all the trees are destroyed, so that wanting wood to boyle their sugar, they are forc'd to send for coales from England" (quoted in Watts, 1987: 186). And Newcastle coal was indeed used in the island's boiling houses, where just ten years previous it was nowhere to be found on Barbados (Hobhouse, 1999: 175; Ligon, 1657: 67; Sheridan, 1974: 115; Bridenbaugh and Bridenbaugh, 1972: 269).[430]

The rapid pace of deforestation – especially the clearance of patches of woodland between estates – eliminated the ecological advantage of retaining forest land within and between sugar estates. This had formerly protected against soil erosion (Watts, 1987: 186-87). Their removal eventuated in mounting problems of soil erosion by the later seventeenth century. "Rivers began to silt up and in some cases went completely dry, estuarine habitats were destroyed by siltation and estuarine animals disappeared; and with the loss of the dense tree cover the whole hydrology, and thus the whole climate, of the area was slowly altered, at considerable cost to both land and water species" (Sale, 1990: 165; also Hughes, 1750: 21). Soil eroded from nearby cane fields began to clog Bridgetown harbour in the early 1660s, after just two decades of sugar cultivation (Watts, 1987: 222).

Planters responded in two major ways. Having cut down the stands of forest between estates, the planters sought to fix mounting erosion problems by "mak[ing] high and strong Walls… to stop the Mould that washes from our Grounds" (Littleton, 1689: 18). This was costly – it ranked high amongst Littleton's litany of cost pressures facing the island's planters. And it was not very effective. Thence arose the second strategy. By shifting towards cane-holing in the place of erosion-friendly trench planting, planters did succeed in reducing erosion, but at a high cost in labor-power. We will revisit this second strategy momentarily.

Problems of soil erosion compounded the rising challenge of soil exhaustion. By the closing decades of the seventeenth century, Barbadian planters "complained endlessly of declining crop yields, insect and vermin plagues, drought, barren soil, and rising costs" (Dunn, 1972: 203-204; Deerr, 1949: 166). Between 1649 and 1690, the volume of sugar produced on one acre fell by a third, and yields on many sugar estates declined by as much as one-half (Barrett 1979: 23; Watts, 1987: 397). Declining soil fertility also signaled sharply falling yields for "ratoon" crops, where the cane root is left in the ground to produce a second (or even third and fourth) crop. By 1680, and definitively by 1700, the island's planters had forsaken ratooning. The soil was too depleted (Dunn, 1972: 192;

[430] It is perhaps not coincidental that England too was in the grips of a serious energy crisis at this very moment (Thomas, 1986).

Dalby, 1690: 15; Pares, 1960: 42). Just as the island's planters sought to annex St. Lucia for its timber, by 1769 some now looked to import fertile soil itself, this time from British Guiana (Schomburgck, 1848: 165).[431]

Such exhaustion played a key role in the eighteenth century shift of sugar production from Barbados to the larger islands of Jamaica and St. Domingue, which "had sufficient land to be able to abandon overworked sugar plantations and replant on virgin soil" (Davis, 1973: 254; also Dunn, 1973: 205; Ponting, 1991: 206). Already by the 1670s the contrast between Jamaica and Barbados had become so striking it led one contemporary to observe that "a sugar work with 60 negroes [in Jamaica] will make more profit than one with 100 in any of the Caribbees, the soil being new, and well shaded with goodly woods" (quoted in Sheridan, 1970: 42).

The deepening crisis of the soil demanded ever-greater inputs of fertilizer and labor. As we saw with Brazil, in Barbados too the metabolic contradictions *within* the countryside were consequently sharpened as producers became increasingly specialized. The challenge of declining soil productivity was met, in part, by importing animals to supply fertilizer. This option was, however, a limited one in the smaller islands such as Barbados, and at all turns led to more deforestation for pasture, which resulted in yet more soil erosion, and still greater demand for fertilizer. And yet there was little space available for the expansion of stockraising sufficient to counteract the deepening fertility crisis. In fact, Barbados was importing most of its cattle from, of all places, the Madeiras and Cape Verdes (Watts, 1987: 197)![432] By the mid-seventeenth century, fertilizer costs in Barbados had increased to the point where smallholders began to raise livestock not for meat or hides, but as a source of manure (Watts, 1987: 222-223; Batie, 1991: 50). This spatially concentrated animal population — especially horses, the power source for many sugar mills — provided a favorable disease climate. In 1655 and 1656 "a virulent epidemic almost destroyed the horse population in Barbados." This development threw the sugar mills into crisis – without animal power no cane could be milled – and induced a shift to wind-power, which was now possible because the island had been so thoroughly deforested (Watts, 1987: 193, 198). But this in turn reduced relative supplies of fertilizer by dispensing with some share of the island's need for animal traction (Menard, 2006: 78).

As soil fertility declined, more labor was required — and slaves were the most costly part of the production process (Dunn, 1972: 197). During the late seventeenth century, slaves in Barbados were put to work carrying soil that had washed to the bottom of cultivated hillsides back to the cane fields. It was a "mighty labor" indeed (Littleton, 1689: 19)! Labor costs rose dramatically. Among the more innovative responses to the emerging crisis of the soil was a shift away from trench planting – which encouraged "massive" water and wind erosion – in favor of hole planting by the early eighteenth century (Watts, 1987: 402-405). Cane-hole planting was reasonably effective, but highly

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[431] The soil itself in this case was forest soil: "One of the strangest importations from Guiana [which regularly supplied Barbados with firewood and other forest products] was in 1769, the rich soil of that fertile tract, which in some places in the virgin forests forms a stratum of manure to a depth of twelve inches, but the wood-ants committed such ravages in the vessel, that the attempt was never repeated" (Schomburgck, 1848: 166).

[432] Indeed Jamaica's comparably vast expanses proved favorable for various forms of stockraising, and leant its sugar sector an increasingly important competitive edge in combating fertility problems (Ormrod, 1979).

costly in terms of the labor involved (Dalby, 1690: 16). This was "tedious, labor-demanding work to which planters resorted only when environmental constraints combined with market opportunities to make it a rational strategy" (Galloway, 1985: 345). Declining soil fertility and rising labor inputs: this was order of the day. By 1717, an acre planted with sugar in Barbados required five times as many slaves, "and many more head of cattle and horses," relative to the more expansive (and therefore more fertile) French sugar islands (Williams, 1944: 113; also Pares, 1960: 41). Even on much larger Jamaica, during the 1730s Charles Lesley observed that

> When Sugar was first planted in this Island, one Acre of Canes yielded more than now, for four, five, six or seven Years together without any further planting or dunging; the same Root would shoot forth new Branches, and those be fuller of Sap than the Canes are at this Time; when the Sugar being of so great a Substance, and containing such Quantity of rich Juices, and the Planters pressing it so often with the same Plant, and never letting it lay still, the soil is so impoverished, that they are now forced to dung and plant every Year; insomuch, that 100 Acres of Cane require almost Double the Number of Hands they did formerly, while the land retained its natural Vigour, which also then, did not only bring forth certain Crops, but fewer Weeds too, the Weeds having been increased by frequent Dunging (1740: 337).

Over the next half-century, Barbados' slave population increased by "about 30 percent" while sugar output declined by "more than 20 percent" (Pares, 1960: 41). It is no surprise that profitability fluctuated sharply according to soil conditions (Williams, 1944: 113-114). Where the average rate of profit for Jamaican planters in the 1770s was around 10 percent, it was only 2-4 percent in Antigua and Barbados (Williams, 1970: 125-126), islands that were not only smaller, but with a longer history of sugar cultivation.

The degradation of the soil not only demanded more workers. It demanded more *out of* the workers. When the planter purchased more slaves to compensate for declining yields, pressures to exploit the soil and the slaves were accordingly intensified – above and beyond the chronic pressures of indebtedness and downward price movements. Thus the "terrible depreciation allowance" of slave mortality (Pares, 1960: 39-40). "The sugar plantations on which over three-quarters of all Caribbean slaves worked consumed the lives of slaves almost as voraciously as the mills ground the mounds of cut cane" (Blackburn, 1997: 339). What is intriguing, in a specially gruesome way, is how this slave mortality was linked not only to the radical simplification of extra-human nature, but also to the simplification of the slave body itself. Much as a meatpacker today demands a "standard hog" from suppliers, so the slave market of the seventeenth century Caribbean was measured in terms of the standard slave: male, 30-35 years old, nearly six foot tall. This standard slave was "a piece of the Indies," in the language of the day. Those who did not measure up were reduced to some fraction, reduced to "pieces of Indies" (Williams, 1970: 139) It was a small step to move from considering nature in terms of equivalents and interchangeability, to considering human beings in the same fashion.

Slave mortality could therefore be calculated. It could be recast ideologically as a "terrible depreciation allowance." Estimates of this terrible depreciation in the seventeenth century West Indies vary, but one trend seems clear. Economic growth and slave mortality were closely linked (Curtin, 1968). Comparatively low mortality in the early years of the sugar revolution (after forest clearance) gave way to escalating mortality in later years. As Barbados' sugar exports to London surged 300-400 percent in the second half of the seventeenth century, annual slave mortality — 3.5 percent in 1627-1650 — increased some 40 percent (to 4.9 percent) by 1700 (Sheridan, 1972: 299; Dunn, 1973: 203). Almost unbelievably, this gruesome figure increased still further in the eighteenth century. Between 1708 and 1735, Barbados imported about 3,150 slaves a year. Its slave population during the same period increased from 42,000 to 46,000, which translates into a net increase of 148 additional slaves each year. If accurate, this suggests a slave mortality rate fully twice (7.1 percent) the still-grisly pace of a century previous (calculated from Dunn, 1973: 314; also Williams, 1970: 145).

Might this have something to do with available land, and therefore relative soil fertility? One answer is suggested by way of comparison with Jamaica. Slave mortality in Jamaica, an island that could accommodate *30* islands the size of Barbados (Mintz, 1985), was initially lower (2.8 percent) during the establishment of the plantation regime in the 1650s, and increased much less dramatically (about 25 percent) in the ensuing 75 years (Sheridan, 1972: 299).

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Barbados had launched the Caribbean phase of the sugar frontier. In time, it would be displaced in its world centrality by progressively larger islands, in successive turns – by Jamaica in the 1720s and St. Domingue by mid-century (Sheridan, 1973: 418; 1970: 22-23). Cuba would emerge as the leading sugar producer by the early decades of the nineteenth century (Tomich, 1994; 1990: 15). But Cuban sugar belongs to a different era of historical capitalism, one marked by the primacy of industrial capital. With Barbados and the Caribbean sugar revolutions of the long *seventeenth* century, the full flowering of early capitalism's ecological regime was realized. The ecological contradictions emerged even more rapidly than they had in Brazil and the Atlantic islands. They were attenuated by a multiplicity of islands and the proximity of the North American mainland, from which flowed food and timber above all. Nevertheless, the long-run squeeze on profitability remained in force, despite the possibilities for geographical expansion, and also because of these possibilities. There was room for expansion, and this meant, given the relative balance of power between Britain and France, there was room for competition. But in an age of protected national markets, overcompetition was unlikely to serve as the prime mover of a falling rate of profit. Average profitability in the West Indies sugar plantations fell from 20 percent between 1650 and 1700, to 10 percent between 1750 and 1775, to 7.5 percent at century's end (Craton, 1974: 139). Was it coincidence that the progressive exhaustion of sugar's political economy unfolded, in the middle decades of the eighteenth century, at precisely the moment when agricultural stagnation emerged as a flashpoint of systemwide crisis throughout Europe, not least in England (Pomeranz, 2000)? By this point, one thing was clear. Sugar's days as a leading accumulation sector in the world-economy were numbered. Sugar would remain important, but it would no longer decide the fate of continents.

By way of conclusion

If American silver was a means of consolidating emergent global inequalities in the early modern era, the sugar plantation was perhaps the chief means of pioneering them outside Europe. Around sugar, first in the Atlantic islands and later in Brazil and the Caribbean, developed a "plantation complex" (Curtin, 1990) whose great innovation was to combine a new means of organizing labor (modern slavery) with a new means of organizing the land (monoculture). Far from accidental, the modern plantation's combination of a brutal labor regime with an ecologically destructive agricultural regime reflected the logic of an emergent capitalism. Slavery and monoculture were not somehow incidental to each other. Quite the contrary, they were two sides of the same (world-historical) coin.

These paired innovations had two things in common. First, slavery and monoculture reflected capital's tendency to radically simplify land and labor. Although slaves performed skilled labor, by and large the slave system functioned best when assigned to relatively simple tasks. In the case of the plantation system, the labor process could be simplified largely to the extent that the land was simplified. Diversified agriculture tended to require more complex tasks and therefore posed a greater labor control problem relative to monoculture. Second, slavery and monoculture embodied an alienated relation between the direct producers and the land. While not fully proletarian, modern slavery, like the modern working class, presupposed the domination of the land by capital and its intermediaries. Capital's increasing domination of the earth — "severing...any direct connection between the mass of the population and the earth" (Foster, 2000: 170) — was the necessary precondition for capital's exploitation of wage-labor in a system of (progressively) generalized commodity production. The production of monocultural regimes in fifteenth century Madeira (and its many successors) was the flip side of this process. The original settlers, who had grown wheat, were displaced by the sugar planters, who then purchased foodstuffs from abroad. This dual expropriation of the direct producers from the land — the laborer (the slave) and the displaced settlers — tended to reproduce such alienated relations by stimulating cash-crop production abroad. (Madeira, once sufficient in grain, switched to sugar and began importing wheat from the Azores — a pattern that would repeat itself, on a vastly larger scale, in the Americas.)

The unity of monoculture and slavery was possible in large part because ongoing transformations of Europe's division of labor stimulated growing demand for sugar. Sugar, like wood, was one of early capitalism's few continuing "growth crops" (Wallerstein, 1980: 161). Far from merely responding to market demand, however, the plantation regime at once extended capitalism's geographical reach and through its contribution to trans-Atlantic commodity flows — including various incarnations of the so-called "triangular trade" — contributed mightily to the accumulation of capital. Even if we leave open the question of the "contribution of the periphery" (O'Brien, 1982; Wallerstein, 1983) in strictly economic terms, we can still identify as considerable indeed the sugar commodity frontier's contribution to spearheading new divisions of labor, driving forward the commodification of land and labor on a world scale.

Early capitalism's socio-ecological contradictions were especially dramatic in the New World. I am not certain that the environmental transformations of the Americas were any more, or any less, strategic than the remaking of European environments. But they were certainly more dramatic, given the relative weakness of effective opposition to the commodity regime in the New World. It is however clear that the system's demand for fresh supplies of land and labor was greatest in the Americas, which provided hospitable terrain to meet such demand because: 1) there were vast tracts of land for the taking, owing to weak indigenous resistance; and 2) there were ample labor supplies, owing to the success of the African slave trade. In sum, the Americas were not only economically central to the consolidation of capitalism in the early modern era; they were *ecologically* central. In other words, the Americas were economically central to the extent that colonized landscapes favored the rapid accumulation of capital. The unequal ecological exchange signified by a globalizing metabolic rift between American peripheries and European cores — and between the country and the city at multiple scales — meant not only that the American environment was laid waste, necessitating further widening of the division of labor. Each new stage of such world capitalist widening involved simultaneously (if unevenly) both more intensive *and* more extensive commodity agriculture, each phase effecting a new and more serious break in the nutrient cycling of local ecosystems — in Europe no less than the Americas.

The flow of American agricultural products — above all, sugar — meant that the town-country division of labor within core states could be deepened beyond the capacity of any single "national" economy. Robert Brenner (1977, 1985a, 1985b) may be right that the social transformation of English agriculture — which made possible long-run productivity advances — made possible the emergence of a vast reserve army of labor which could be put to work in the satanic mills. But there is more to the story than this. The profits that resulted both directly through the closely-linked sugar and slave trades, and indirectly through the reduced costs for reproducing the English working class, or the profitable activities of shipping and shipbuilding, contributed to an accumulation fund that made possible the further expansion and intensification of the world capitalist division of labor. African slavery, for example, represented not only an *economic* transfer from an external arena to the capitalist world-economy, but also an *ecological* transfer. "National" development within Europe was fed with the fruits of slavery's global political ecology.

All of which permitted, and indeed compelled, a widening metabolic rift between core and periphery, between town and country, and within the countryside itself. In equal measure, the capacity of ecosystems to reproduce themselves within the capitalist division of labor was radically and *progressively* undermined. Or perhaps we should say that these capacities were reshaped, such that the reproduction of local ecologies was subordinated to the gravitational pull of the capitalist world-economy? The trend line seems certain. The accumulation of capital is the simplification and overexploitation of nature. The endless accumulation of capital is the infinite conquest of a finite world. This has been the secret of its success. It is an important clue to its present crisis, one that promises not only the unraveling of the modern world-system, but threatens the basis for human civilization as we know it.

CONCLUSION
Ecological Crises and Economic Crises in Historical Capitalism

Or, How Do We Know an Ecological Crisis When We See One?

In one sense, economic crises are by definition ecological crises. If in the modern world the pivotal form of wealth is capital, if capital is "value in motion," if value is abstract social labour, and if the "original sources of all wealth" include land as well as labor (Marx, 1977: 638), it is clear that capital – for all its outward appearances – achieves its liberation from ecological process always in form, never in substance. Accumulation crises are by definition ecological crises.

This may well be true. But it doesn't tell us much.

I have run this syllogistic reasoning to its conclusion for a simple reason. Since Marx, the outpouring of accumulation crisis theories has been nearly as endless as the accumulation crises themselves. It is evident that such crises are implicated in the sometimes dramatic, at other times gradual, refashioning of material life. But there has been little effort to constitute, analytically, capitalism's combined and uneven ecological antagonisms into an active force in accumulation crises of any scale or durée. Even among those who would argue for an ecologically-informed political economy, there persists a curious lacuna between the theory of accumulation crisis and the theory of ecological crisis.

We may begin with an elementary contrast. There is a longstanding distinction in political economy between general crises and partial crises.[433] While there is debate over precisely what counts as a general crisis, there is agreement that such crises represent a fundamental breakdown in the capacity of the existing accumulation regime to revive profitability, and resume accumulation. Partial crises range from sharp downturns in the business cycle, to those more sustained moments of stagnating or falling profitability, but which do not, yet, signify fundamental tears in the fabric of accumulation. The "first" Great Depression of 1873-96 represents one such general crisis; the post-World War II recession in the United States qualifies as a partial crisis.

Despite the enormous literature that takes up the political economy of the environment as its central concern, the place of ecological contradictions in the theory of accumulation crisis remains a vexing problem. Two decades after O'Connor penned his seminal essays on uneven development, ecological crisis, and the "second contradiction" (1989, 1998)[434] – a span of time wracked by devastating (if technically partial) accumulation crises, and an ongoing slowdown of world accumulation – the question of the political ecology of accumulation crisis is, curiously in my view, barely on the agenda. This is unfortunate, because (and I will put it schematically) the relation between the political economy of accumulation and the political *ecology* of accumulation is

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[433] Shaikh's (1978) outline is instructive on this.

[434] O'Connor did not of course construct these arguments from whole cloth. Important predecessors would include Enzensberger (1974), Harvey (1974), Schnaiberg (1980), Commoner (1971: esp. 249-291), and above all Polanyi (1957).

central to this study, and because the ecological crisis tendencies of capitalism have become central, in the most immediate and pressing fashion, to all those of who live on Planet Earth in the twenty first century.

We might begin with O'Connor's notion of a "second contradiction" (1998). O'Connor's innovation was to attempt a synthesis of the capital-labor antagonism (a "first contradiction" of overproduction) and the capital-nature antagonism (a "second contradiction" of environmental degradation, broadly conceived). O'Connor argues that rising costs arising from the degradation of the conditions of production has, since the 1970s, set in motion a dynamic that will fetter accumulation from the supply-side, reinforcing difficulties the system already faces on the demand side, that is, in realizing surplus value. What I wish to underscore is the effort to bring ecological degradation into the theory of accumulation crisis. Whatever the pitfalls of this innovation,[435] the act of bringing "political ecology" and "political economy" together into a holistic theory of accumulation crisis is precisely the kind of theoretical innovation needed if we are to come to grips with the specificities of ecological crisis today.

Of course, the difficulty with crisis theory is the Crystal Ball problem. Crisis theories are fundamentally predictive enterprises. They build up and out from the historical development of previous crises, seeking to discern the underlying forces that have not generated crisis, but will do so if they continue, all things being equal. O'Connor has seen the day of reckoning coming, but the theory of the second contradiction cannot tell us just when that day might arrive. Foster criticizes O'Connor on precisely these grounds, acknowledging that rising costs from ecological degradation may have some purchase on regional developments, but that in itself, the theory of the second contradiction cannot account for the progressive stagnation of the world-economy since the 1970s (2002b). Fair enough. The global ecological crisis threatens humanity but is not, Foster seems to be arguing, implicated in the ripening of accumulation crisis. But if O'Connor is tracking the emergence of a new crisis tendency within late capitalism – perhaps new, in light of the arguments in this study, primarily in terms of its global reach and depth – and if we are dealing with a crisis tendency that drives towards biospheric overshoot, then one would expect the accumulation crises emerging from the second contradiction to be slow in building, rapid and catastrophic in their detonation. Shades of Madeira, perhaps?

If our concern is the political ecology of accumulation crisis, Foster's objection may be a case of generating more heat than light. For what O'Connor sought to do, if I have understood the enterprise correctly, is to bring ecological contradictions into the very heartland of crisis theory. And this is precisely what is missing from Foster's formulation. Foster, the intellectual heir of Sweezy and Magdoff, says little about the relation between the nature-society antagonism on the one hand, and monopoly capitalism's tendency of the surplus to rise, on the other (Baran and Sweezy, 1966). What is the political ecology of tradition's theoretical pivot: "Stagnation is the normal state of monopoly capitalism"? O'Connor and Foster are not alone in facing these difficulties. Rather they express the broader problem. Put glibly, we can see that O'Connor has worked ecological crisis into his theory of accumulation crisis, but omitted a historical account of the second contradiction's development; Foster has yet to locate his theory of

[435] Burkett (1999) scores O'Connor for failing to specify the dialectical connections between the first and second contradictions, which is fair enough. But Burkett has been reluctant to build his own ecologically-informed crisis theory, which points to the challenges of the project itself.

global ecological crisis into the theory of monopoly capitalism. And to show that they are in very good company, David Harvey has yet to work ecological degradation into his theory of spatial fix and uneven development.[436]

The question of just when the day of reckoning will hit is fundamentally unanswerable. But the question of the socio-ecological limits of the capitalist mode of production is not. It is a question that has been approached in many effective ways. (And many ineffective ways as well). Curiously, indeed strikingly, absent from these approaches (a few modest reflections aside) is the historical approach. If we can agree that human social organization is indeed living through an era of global ecological crisis that will compel fundamental revisions in the organization of economic life and social power, among the most effective means of coming to grips with the crisis and its possible trajectories is through the study of the origins of the relations that generated the crisis in the first place. That is to say, in order to understand the crisis today we need to understand the origins of these crisis tendencies in their historical and geographical specificities. For all the easy explanations of the thorny problems of ecological crisis today – industrialization, overpopulation, globalization, commercialization, "Western" culture, and so forth – there has been little effort to identify the historical origins (and therefore world-historical ruptures) signified by any of these, much less their peculiar crystallization under the sign of modernity. This is what is missing from the work of O'Connor, Foster, and others in Marxist ecology.

It has been my argument that the origins of today's global ecological crisis are to be found in the unusual responses of Europe's ruling strata to the great crises of the long fourteenth century (c. 1290-1450). There are indeed striking parallels between the world-system today and the situation prevailing with a broadly feudal Europe at the dawn of the fourteenth century – the agricultural regime, once capable of remarkable productivity gains, enters stagnation; a growing layer of the population lived in cities; vast trading networks connected far-flung economic centers (and epidemiological flows between them); climate change had begun to strain an overextended agro-demographic order; resource extraction (in silver and copper for instance) faced new technical challenges, fettering profitability. After some six centuries of sustained expansion, by the fourteenth century, it had become clear that feudal Europe had reached the limits of its development, for reasons that had to with its environment, its configuration of social power, and the relations between them.

As we saw in Chapter One, the outcome of this crisis was something that we have come to call capitalism. If one were to survey the previous three thousand years or so of Eurasian history, one would have confidently surveyed the landscape of crisis and pronounced the transition to capitalism Dead On Arrival. "Tributary" civilizations (so called because the politically-enforced distribution of surplus defined them) were favorable to commercialization; civilizational "golden ages" and commercial efflorescences were virtually synonymous. But nowhere had capital accumulation been able to topple the tributary apparatus, at least not for long, and not across large space.

Since there was no inevitability towards a capitalist (rather than feudal) resolution of Europe's fourteenth century crisis, we may safely dispense with an articulated model of transition in favor of identifying its essential driving force. What is clear, as I have suggested, is that this new historical system emerged slowly, shakily, and continually

[436] It is however clear that this is the direction in which he moving, albeit quite cautiously (Harvey, 2006).

(albeit discontinuously) in the direction of the endless accumulation of capital after 1450. While the feudal crisis compelled a dramatic reversal of commercialization and monetization, no such decommodification would sweep across the capitalist system in the centuries that followed, for all the gravity of the crises that rattled bankers, merchants, and kings no less than peasant, proletarian, and slave. The modern world-system centered upon Europe and the Americas during the fifteenth and sixteenth centuries was a historical formation that retained a modified variant of Europe's parcellized sovereignty (many states compared to one or few states in comparable world-regional zones in South and East Asia) as a key pillar of the generalized, progressive dissipation of restraints on the endless accumulation of capital – such that by the middle of the sixteenth century, the capitals had begun to discipline the states rather than the other way around. (Philip II could restructure but not repudiate the debts he accumulated in pursuit of global power). This was a momentous turn of events in human history.

And yet we are in certain respects running ahead of our story. If we are to say that the present historical moment represents one of unfolding global ecological crisis, three questions present themselves immediately – What is global? What is ecological? And what does it mean to attach the word "crisis" to these signposts?

We might begin with the meaning of the global. Globalization is among those signifiers uttered so frequently these days as to become thoroughly meaningless. It is not without considerable persuasive force that Frederick Cooper argues for its abandonment (2001). I will not go so far at this juncture, if only to ease the task of communication. My conception of historical capitalism's globalization moves beyond the banal notion of interconnectivity[437] in favor of the system's double movement of geographical expansion. Large-scale movements of "outer expansion," signifying the incorporation of new regions into the capitalist world market and thence its systemwide division of labor, have, it is widely agreed, characterized the historical geography of capitalism. This outward movement has in turned enabled, and been driven forward by, large-scale movements of "inner expansion," comprising all manner of social and technical innovations in the interests of raising the productivity of labor. The two movements are, of course, always found together – the plantation system for instance, the fruit of outer expansion, pioneered advances in the technical division of labor that prefigured metropolitan large-scale industry. The question is one of relative primacy.

Put schematically, this is a rough-and-ready world-historical rendering of Marx's distinction between absolute and relative surplus value. Globalizing and globalization, in this sense, are signifiers that refer to the spatial movement of endless accumulation – endless geographical expansion and the endless impressment of socio-spatial innovation in the service of capital. If my emphasis in this study has been placed necessarily on the first moment – Webb was right to emphasize the centrality of the "Great Frontier" for the rise of capitalism, with its seemingly endless outpouring of "windfall profits" (1964) – the dialectic of geographical expansion and socio-spatial intensification should not be eclipsed. What has often been forgotten in the Marxist (and by no means only Marxist) literature is the dialectical connection between the two. Perhaps a casualty of the academic division of labor in which, for example, historians may study the early factory system in England or the plantation system in the Caribbean, but not both, the connection

[437] Trumpeted so by world historians in recent years, e.g. Manning (2003, 2006).

between plunder and productivity has often been lost.[438] Capitalism has always been organized as a *mode of plunder*, stealing from the poor and giving to the rich.[439] Capitalism has always been organized as a *mode of production*, introducing unprecedented waves of productivity-maximizing and transaction-minimizing innovations. Both are true, albeit never in equal measure.

The mistake is to see the two as moments in a linear evolution. There is no telos that moved history from the plunder of imperial capitalism to the productivity gains of large-scale industry. It is more certain that the relation between the two has shifted, and the recent history of neoliberalism and resurgent imperialism suggests that plunder has hardly been consigned to the pre-history of capital. Long waves of plunder have given way to the centrality of productivity – is this not the conventional story of the rise of capitalism and the era of "primitive accumulation" paving the way for the Industrial Revolution? For their part, these long waves of expanded reproduction have inevitably faltered, setting the stage for successive "new imperialisms." Is not the resurgence of hyper-militarized accumulation today (clustered around resource access above all) an expression of the long stagnation the world-economy entered in the 1970s? (Signified above all by the American shift from the post-1945 "permanent" war economy to the endless war strategy of Cheney-Bush.) If the Great Frontier has long since disappeared (although a whiff or two is present in China's ongoing economic revolution and the worldwide colonization of the oceans), its importance to world accumulation has not.

While our first question turns on the meaning of globalization, the second concerns the world-historical meaning of the "ecological." If globalization in this study has referred to capital's primal imperative for endless geographical conquest, this movement has been fundamentally one of the conquest of the earth (and in time, the Earth). It is of course an asymptotic process. Its completion is presumed by the logic of the system, but is practically impossible. Any discussion of the "ecological" moment of global ecological crisis then must begin with long-run patterns of evolution (secular trends), recurrence (cyclical movements), and crises that have embodied and enabled capital's progressive domination of the earth. To state the problem in these terms immediately moves us onto the terrain of the nature-society dialectic. The independent variable, as it were, in the creation of ecological "consequences" (say, deforestation) therefore becomes the socio-ecological *regime* (at whatever scale) rather than social forces and ecological process narrowly conceived and neatly contained. To conceive this relation broadly is to challenge the consensus view, and to walk down a path that leads to a veritable no-man's land in world-historical studies, between the environmental determinisms of Jones (1982), Landes (1999) and Diamond (1997) and the social reductionisms of North and Thomas (1973), Arrighi (1994), and Gunder Frank (1998).

Now we may turn to the question of crisis. As I've suggested, the relevant crisis is a socio-ecological crisis, during which the underlying contradictions between the mode of production and its material substrate become unmanageable. These in turn reinforce the impact of exogenous "shocks," such as the El Nino events of the late nineteenth century

[438] See Blackburn (1997) for an important exception.

[439] The recent history of neoliberalism, effecting the radical upward redistribution of wealth while presiding over worldwide stagnation for what is now more than three decades, is testament to the enduring character of plunder.

(Davis, 2001).[440] If the relevant form of crisis is socio-ecological, and if we wish to avoid the pitfalls of the Crystal Ball problem, then we begin with an elementary statement of historical and geographical specificity. Benton states this well:

> What *is* required is the recognition that each form of social/economic life has its own specific mode and dynamic of interrelation with its own specific contextual [ecological] conditions, resource materials, energy sources and naturally mediated unintended consequences (forms of 'waste,' 'pollution,' etc.). The ecological problems of any form of social and economic life would have to be theorized as the outcome of… *specific structure[s] of nature/social articulation*" (1989: 77, emphasis added).

Benton is referring to modes of production in a rather generic sense, but I think we can extend the logic of the argument. In this passage, he does not use the language of crisis and transition, although these are implied. We might immediately identify three broad forms of crisis to supplement the elementary distinction between general and partial crises: *systemic crises* that compel a transition from one mode of production to another; *developmental crises* that compel fundamental shifts within a mode of production; and *partial crises* that spell devastation for a specific region without necessitating systemwide restructuring. This is, then, a historical-geographical recasting of the language of crisis theory from the standpoint of environmental history. I shall take as a given that ecological crises are by definition *socio*-ecological crises, that is turning points in the organization of social and economic power on the one hand, and ecological process on the other. Precisely what makes a "turning point" *fundamental* is a dicey question, and one that eludes precise specification. The question in nearly all instances comes down one basic question, How much is a lot?

In this study I have focused on the first and third moments of crisis (*systemic* and *partial crises*), and yet we cannot elude the task of identifying developmental crises. Indeed, the mounting toll of regional (partial) ecological crises over the long sweep of early modern capitalism was revealed in agro-ecological stagnation across Europe by 1750. The Industrial Revolution that ensued may be understood as a long wave of fundamental restructuring in response to the developmental crisis of early capitalism's conquest-driven ecological regime.

What I would suggest is that Benton's observation above holds not only for the transition from one mode of production to another (feudalism to capitalism, for instance), but also for two further layers of specificity in the modern world-system: phases of capitalist development on a world-scale, and regional production complexes. Crises of the latter build towards developmental crisis of the systemwide ecological regime inscribed in successive phases of world accumulation (Moore, 2000a; Arrighi and Moore, 2001). Put simply, every phase of capitalist development creates, as a condition of its emergence and reproduction, a new ensemble of nature-society relations. (These emerge from those developmental crises that emerge in successive long centuries of world

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[440] It is of course increasingly difficult to tell the difference between disasters created by the system, and those exogenous to modernity's contradictions. Was Katrina the result of global warming? In part for sure. But how big a part?

accumulation.) This new ensemble I would describe as an ecological regime.[441] Just as Pirenne once fruitfully observed that every new stage of economic development brings with it a new bourgeoisie (the industrialist replaces the merchant) (1914), so we can observe that every new stage of capitalist development brings with it a new relation to nature.

Early capitalism's ecological regime was one premised on a highly effective combination of military conquest, the vigorous geographical extension of commodity production directly (as in the plantation system) and indirectly (as in Poland's "second serfdom"), the creation of financial structures that radically accelerated turnover time and sustained economic interdependence on a globalizing basis, and the maximization of technological development oriented towards geographical expansion.[442] The regime was one predicated on the rapid pace of geographical expansion. Once its internal contradictions limited the pace of this expansion, the system as a whole fell into crisis. And this was precisely what happened to the European world-economy by 1750 – it is no accident that the ensuing half-century (1757-1815) was amongst the most turbulent in modern world history.

I can do no more than allude to this eighteenth century developmental crisis. This study carries to the reader to the doorstep of developmental crisis, but not beyond it. Schematically, we can say that early capitalism's ecological regime was one predicated on the *extensive expansion* of commodity production and exchange, born of the multivariate movements of economic recovery beginning in the 1450s. Insofar as it was extensive, European expansion was little different from contemporary expansions in China, South Asia, and elsewhere (Pomeranz, 2000; Richards, 2003). Insofar as its mode of expansion was *globalizing* and theoretically endless – tendencies that (re)materialized landscapes through the generalization of the commodity form – Europe's expansionary moment was a world-historical rupture of epochal significance. This early modern ecological regime was stunning in its speed, scope, and scale: encompassing successive waves of expansion in sugar planting (the Atlantic islands, Brazil, the Caribbean), silver mining (central Europe, Peru, New Spain), cereal cultivation (the Baltic, England), iron and copper mining and metallurgy (central Europe, Sweden, England), timber extraction (the Baltic, Norway, Finland, Russia, and eventually North America). To name just a few.

These waves of expansion were successful, and therefore ultimately self-limiting. By the eighteenth century, the ecological regime was issuing stagnant or declining returns. Europe's iron output had been stagnant relative to population growth for the better part of a century, despite relocations to greenfield zones, in Sweden above all. Even more problematic, the agricultural revolutions of the previous three centuries had run out of gas. In England most notably, but all across Europe (Kjaergaard, 1994), the land-extensive demands of capitalism's early modern ecological regime had reached definite limits:

> [P]er-acre and total yields from arable land remained flat and the threat of decline constant, until Britain began mining, importing, and later

[441] Today there is much talk of environmental governance, which may be seen as expressive of the crisis of late capitalism's ecological regime.

[442] Including not merely innovations shipbuilding but also, for instance, in cartographic techniques.

> synthesizing fertilizer mostly after 1850…. [A]lthough the English studied continental practices, classical agricultural manuals, and their own experiments very intently, much of what they learned about how best to maintain soil fertility while increasing yields was not actually applied in England, because it involved highly labor-intensive methods and English capitalist farmers… were intent on labor-cost minimization and profit maximization. The methods they adopted instead, which raised labor productivity, represented a *fundamental break with much of the literature on best farming practices and actually interfered with preserving soil fertility in many cases*; it was in part because of these strategies that increasing amounts of off-farm phosphates and nitrates were needed in the nineteenth century just to keep yields from declining. In other words, without the new industrial inputs that came to its rescue, England might have had a hard time even maintaining its yields without putting far more labor into the soil" (2000: 216-217, emphasis added).[443]

The problem with putting it this way is that the debate has been so dominated by quasi-Malthusian economic historians, such that the limits to systemwide accumulation have been viewed as ecologically-posited rather than created by the contradictions of early modern capitalism itself (e.g. Pomeranz, 2000). The Marxist tradition has largely ceded the terrain of ecohistorical crisis theory to the Malthusians, a legacy that has stymied efforts from the left to account for these crises in a way that would inform our understanding of global ecological crisis today. So let it be said from the outset, that none of these crises – systemic, developmental, partial – have been ecologically-*driven*. Ecological contradictions, rather, have played a variable role, sometimes pivotal, but certainly not decisive at *every* juncture. Socio-ecological limits are not given but produced, albeit not under circumstances of one's choosing. Benton drives the point home: What constitutes a limit in one mode of production (or phase of capitalism) "may *not* constitute a limit for another" mode of production (or phase of capitalism) (1989: 79; also Moore, 2000a).

In this study, I've elected to examine the dynamic contradictions of capitalism's early modern ecological regime, rather than to detail the accumulation impasse of the mid-eighteenth century. These dynamic contradictions were punctuated, as we've seen, by successive regional ecological crises, conceived as crises of pivotal commodity production zones central to world accumulation – the sugar plantation and silver mining commodity frontiers above all. These regional crises were not developmental, but rather *partial* crises, viewed from the standpoint of the system as a whole. And yet, an

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443 Berg agrees: "[A]gricultural improvement was labour-using rather than labor-saving" (1986: 101). On the centrality of labor-intensification as the chief means of increasing Euro-American agricultural productivity prior to 1850, see Clark, 1987. Pomeranz's thesis is well-supported by the experience of Belgium, among Europe's fastest industrializers in the 19th century. Belgium's land productivity continued to increase over the period 1750-1830 (Dejongh, 1999), in contrast to the English situation. But it seems likely that Belgium's rising land productivity, as Pomeranz's thesis would suggest, was effected by means of labor intensification. While Belgium's manufacturing output trebles over this period, Britain's increased by a factor of *seven* (Bairoch, 1982: 290, 292); meanwhile despite (or because of?) the former's emergence as a grain exporter (Dejongh, 1999), its population just doubles over the period 1750-1850, relative to a threefold rise for England (McEvedy & Jones, 1978: 43, 63).

accounting of these partial crises in their historical and geographical specificity is crucial to understanding both the *systemic ecological crisis* that came before it (the crisis of feudalism), and the *developmental ecological crisis* that ensued from these crises (the crisis of the eighteenth century).

The Industrial Revolution retains its hold on the popular imagination as the historical and geographical locus of today's environmental crisis. A view that coexists, sometimes more easily than at others, with a profound faith in technological progress. I would suggest that a perspective on the Industrial Revolution as the *resolution* of an early moment of modern ecological crisis, *and* as the detonator of another, more expansive and more intensive reconstruction of global nature, offers a more historical – and therefore more hopeful and democratic – means of thinking through the problem of ecological crisis in the modern world. While the technological marvels of the past two centuries are routinely celebrated, it had become clear to Stanley Jevons as early as the 1860s that all advances in resource efficiency promised *more* (not less) aggregate resource consumption. *This* is how the modern world market functions, towards profligacy not conservation. The technological marvels of the industrial era have rested on geographical expansion neither more nor less than they did in the formative centuries of capitalist development. Not only has the pressure to enclose vast new areas of the planet, and penetrate ever-deeper niches of social and ecological life, continued unrelented. (Witness the revival of interest in the so-called "new" enclosures.) All of this has been reinforced, in the same manner, by a radical plunge into the depths of the earth, to extract coal, oil, and all manner of strategic resources. It is an ecological regime that has reached, or will soon reach its limits. Whatever the geological veracity of the "peak oil" argument, it is clear that the American-led ecological regime that promised – and for half a century delivered – cheap oil is now done for. (An issue that of course has to do with much more than oil alone.)

It is from the standpoint that an accounting of earlier crises may help us discern the contours of the present global ecological crisis. At a minimum, it seems safe to say that historical capitalism's preference for spatial fixes to its recurrent waves of crisis would seem to present a major problem on a world with very definite geographical limits. As long as fresh land and labor existed beyond the reach of capital (but still within capital's reach), the system's socio-ecological contradictions could be attenuated. The possibilities for external colonization foreclosed by the twentieth century, capital has been compelled to pursue strategies of "internal" colonization, among which we might include the explosive growth of genetically modified plants and animals since the 1970s; drilling ever-deeper and in ever more distant locales for oil and water; and perhaps most ominously, converting human bodies — especially those belonging to women, people of color, workers and farmers — into toxic waste dumps for a wide range of carcinogenic and otherwise lethal substances (Davis, 2007).

These developments are new and not new at the same time, and this dialectic of continuity and rupture is precisely what so many observers of the present conjuncture have missed. There is of course no shortage of analysis when it comes to the proximate factors of contemporary environmental degradation — government policies, multinational corporations, international trade organizations and agreements, and so forth. But there has been insufficient care given over to the task of situating these factors systemically, much less historically. Which means that we are left with abstractions rather than concrete totalities, "as if the task were the dialectical balancing of concepts, and not the grasping of real relations!" (Marx, 1973: 90).

There is a certain urgency to all this. There is by now widespread agreement that the world-economy has driven to the limits, and in some cases beyond, a whole range of ecological thresholds. The global ecological crisis is not impending. *It is here*. Ecologically-oriented social scientists and environmental historians would do well to take to heart the chief methodological insight of the historical perspective on globalization – namely that the most effective means of distinguishing the new from the old in the present conjuncture is to situate contemporary dynamics world-historically (esp. Arrighi and Silver, 1999). By locating today's ecological transformations within long-run and large-scale patterns of recurrence and evolution in the modern world, we might begin to illuminate the distinctiveness of the impending ecological crunch. This means, as an initial step, situating ecological relations *internal* to political economy of capitalism – not merely placing concepts of ecological transformation and governance *alongside* those of political economy, but reworking the fundamental categories of historical political economy from the standpoint of the actually existing dialectic of nature and society.

Once ecological relations of production are put into the mix, one of the chief things that comes into view is the production of socio-ecological regimes, on regional and world-scales both, that initially liberate the accumulation of capital. Over time, these regimes generate self-limiting contradictions that culminate in renewed ecological "bottlenecks" to continued accumulation. Whereupon the cycle starts anew, and historically speaking this has entailed progressively more expansive and intensive relations between capital, labor, and external nature (Moore, 2000a). Although the point is certainly arguable, the moment of global expansion seems to have been central over the long run and it is not at all clear that capitalism can survive on the basis of the internal fix (*pace* Harvey, 2003). This historical approach get us closer to a more useful formulation of "ecological crisis," and the idea of multiple forms of ecological crisis in the modern world, past, present, and future.

Nature, Crisis, Freedom

I would suggest that the globalization of capitalism and the globalization of ecological crisis are no less tightly bound in the twentieth century than they were in the sixteenth. The difference is the scale of crisis (although it is far more than this too), and this makes a world of difference for the kind of ecological crisis that we are talking about. There has been a quality-quantity shift over the past half-century, and this has quite a lot to do with the enclosure of the last significant frontiers. Without a conception of ecological crisis that identifies its distinct historical geographies, however, we are left with vague notions of crisis that serve the political right and center rather more than the political left. The best that can be said is that the outcome of the contemporary ecological crisis — which I believe is bound up with crisis of capitalism as a historical system — will depend to a large degree on whose historical-geographical knowledge captures the popular imagination.[444]

[444] See Harvey's important article (2000b) on geographical knowledges.

A big part of any potentially liberatory historical-geographical knowledge concerns not just the prediction and retrodiction of ecological crisis, but equally the identification of the possible agents of an ecologically sustainability society. I think here Marx's notion of metabolism becomes especially important. Too often, thinking in terms of Marx's categories means thinking solely in terms of class and capital. While problems of ecological crisis under capitalism can be conceptualized fully through Marx's categories, these problems cannot be reduced at all times to capital and class. The dialectics of nature, nature and society, and the metabolism of the labor process itself, although dialectically bound to capital and class in the modern era, are inexplicable solely within these latter.

They can, however, be conceptualized in terms of metabolism, and the division of labor that shapes — and is shaped by — those material exchanges with nature. In the capitalist epoch, the degradation of the soil occurs because of the world-historical (and globally expansionary) relation between town and country; the degradation of the worker occurs because of the world-historical (and globally expansionary) relation between capital and labor. In this way, we might extend the reach of historical materialism to the "larger problem of the 'fate of the earth' and its species" (Foster, 2000: 254). Thus, to say that nature has its own dialectics, and in various ways its own autonomy, is not to succumb to environmental determinism (which would displace class struggle as the driving force of history), but rather to reinforce the idea that classes make history, but not in geographical conditions of their own choosing.

I think this is where we can begin to think seriously and actively about the agents of an environmentally sustainable society. Bourgeois ideology has scored one of its greatest victories in separating environmental degradation from class exploitation — indeed, this is but one particularly important manifestation of a Cartesian mind-body dualism whose intellectual history dates back to the long sixteenth century (Merchant, 1980). Environmentalism, according to the received wisdom, is a "non-class" movement (O'Connor, 1998: 14). While there is a small kernel of truth in the formulation, it obscures a more significant underlying reality. Since the 1980s, the upsurge in environmental organizing on a world-scale has been driven in large part by the collective action of the direct producers, especially in underdeveloped regions — for instance, South Asian peasants or the U.S. environmental justice movement. The locus of environmental action has begun to shift towards the sites of production (such as the farm) and reproduction (the community), and beyond narrow struggles to preserve "wilderness." Struggles over food and water safety have begun to shift the population imagination away from the environment as "out there" to a conception of the environment as "in here" — unsafe meat, hormone-laden milk, and genetically-modified produce have become contested sites of environmental transformation. Cancers, auto-immune diseases, and other health problems are now increasingly linked to, even conceptualized as, environmental degradation.

While the precise translation of these popular concerns into class concerns is an open question, the present conjuncture seems a propitious moment to retool the left's historical-geographical critique of capitalism in order to put these questions at the center. By privileging the labor process in ecological transformation, we are able to identify working people as the agents of a more sustainable society. For the socio-ecological contradictions of modern class relations promise not just degradation but liberation.

"Freedom," Marx argues, can only be found when a new society of "the associated producers govern[s] the human metabolism with nature in a rational way" (1981: 959). By locating the origins of environmental crisis in the origins of the capitalist system, the world left might begin to make a strong case that environment and class are inseparable, and that the liberation of the soil and the worker are dialectically bound to the same degree as their degradation.

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