Using the Planet

Even before the advent of agriculture, *Homo sapiens* kicked off an entirely new process of planetary change. Earth would never be the same. Instead of mere centuries, **Erle C Ellis** advances a broader view of the Anthropocene, over many millennia, and what that means for land stewardship.

Unlike prior geological time periods, the long-term driving forces of global change in the Anthropocene are not solely within the realm of physics, chemistry or even biology. The ultimate drivers of the Anthropocene are inherently social: *Homo sapiens* is able to create, pass on and spread adaptive technological and social innovations across individuals, generations and societies more effectively than any other species.

Human activities have led to global changes in Earth's atmosphere, climate, lithosphere and biosphere that are unprecedented in human history, if not the history of the planet. Recognition of these human-made shifts prompted the call for the Anthropocene as a new geological epoch, starting with the rise of the Industrial Revolution (circa 1850) or its "Great Acceleration" since 1950.

Yet the evidence from archaeology, palaeoecology and environmental history is clear: human societies have been reshaping the terrestrial biosphere, and perhaps even global climate, for millennia. The entire past 11,000-plus years of the Holocene might simply be renamed the Anthropocene (see the references below, in particular, Ruddiman 2013 and Smith and Zeder 2013).

Formal recognition of the Anthropocene is ultimately a decision for geologists. But global-change science has much to gain from a more geologic view of humanity's role in Earth system dynamics. By exploring how people have used land over many millennia, we can better understand the social processes that have made it possible for a single species to alter the course of Earth's history (Ellis 2011, Ellis *et al.* 2013).

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Land-use intensification

Humans and their land-use practices have profound and persistent effects over periods from centuries to millennia (Figure 1). Land clearing by hunter-gatherers and farmers, soil tillage, and wet rice production all emit major amounts of carbon dioxide and methane. As a result, early human use of land might have initiated global changes in climate long before human use of fossil fuels, beginnining as early as 7000 years ago, by gradually increasing methane and carbon emissions on the continents and shifting the baseline of global climate sensitivity to these emissions, according to evidence presented by Ruddiman (2013).

While this "Early Anthropocene" hypothesis remains an active area of research, understanding the role of early land use in determining both the onset and magnitude of anthropogenic climate change is necessary to evaluate the biosphere's role in both current and future climate change. That assessment includes the prospects for biofuels, as well as reduced deforestation and tillage to mitigate carbon emissions from fossil fuels. But global changes in climate are perhaps the least important effects of our ancient ancestors' land-use practices.

While landscapes with the most people using them tend to be the most altered, even the least intensively used landscapes have been transformed: rangelands and seemingly undisturbed areas near human populations tend to have exotic species, altered fire regimes, nutrient pollution and other pervasive human effects (Ellis 2011, Hobbs *et al.* 2013). Recognition of humans' huge and sustained influence is now leading to a wholesale rethinking of ecological science and conservation that moves away from humans as recent destroyers of a pristine nature and towards humanity's role as sustained and permanent stewards of the biosphere (Hobbs *et al.* 2013). But understanding that role requires understanding how humans have managed to sustain ever larger populations over millennia.

Broadly defined, land-use intensification is an adaptive

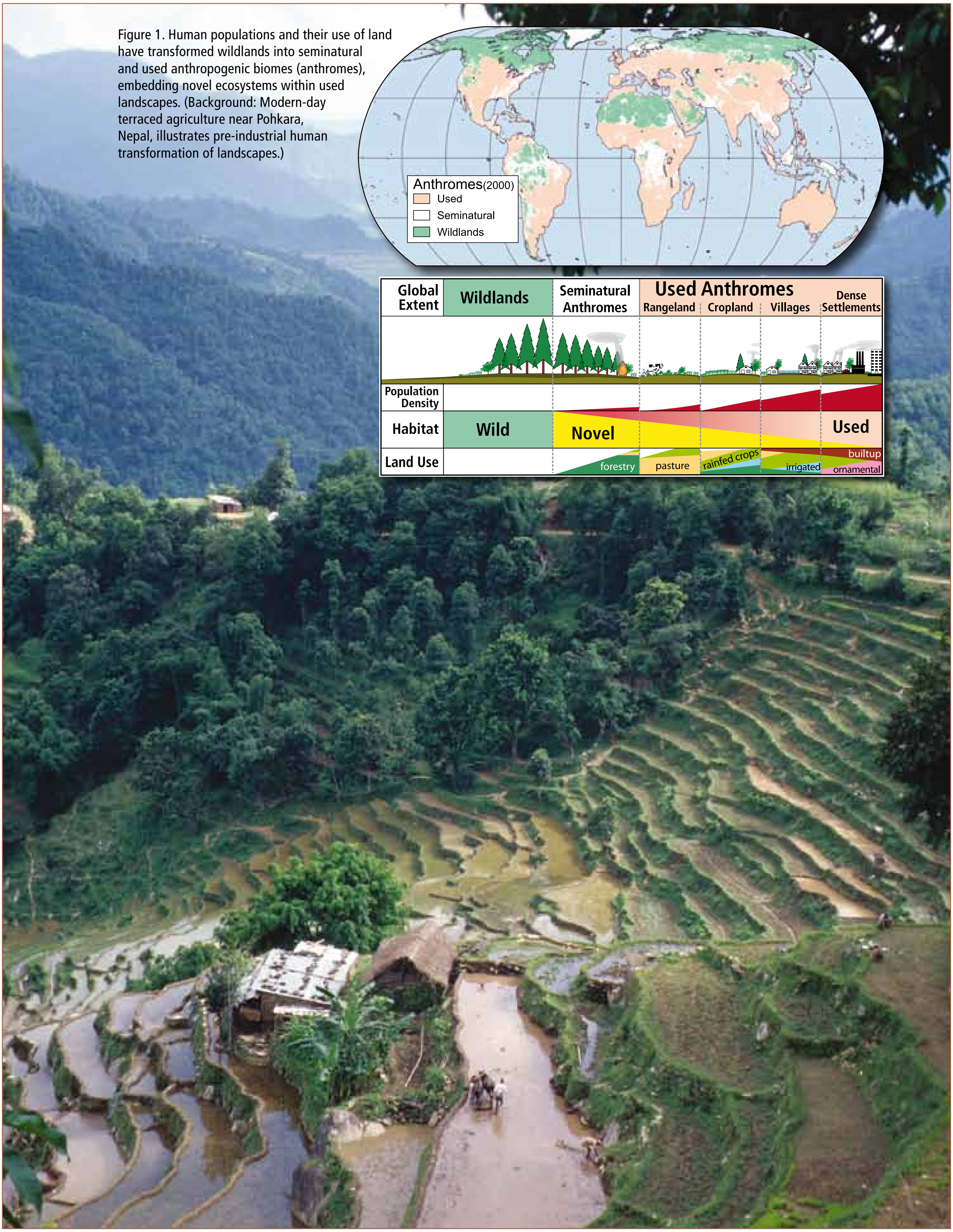

Figure 1. Human populations and their use of land have transformed wildlands into seminatural and used anthropogenic biomes (anthromes), embedding novel ecosystems within used landscapes. (Background: Modern-day terraced agriculture near Pohkara, Nepal, illustrates pre-industrial human transformation of landscapes.)

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response of human populations to demographic, social and economic pressures, leading to the adoption of increasingly productive land-use systems (Ellis *et al.* 2013). Put simply, humans don't make the effort to use land efficiently unless they must, for example, to feed a growing population with the same amount of land or to satisfy social or commercial demands. The least dense, least developed societies tend to use the most land per person.

Land use, long before the Holocene

Archaeological evidence in the form of plant and animal remains, charcoal, isotopic records and other legacies demonstrate that hunter-gatherers long ago engaged in pre- and proto-agricultural land-use intensification practices, to support larger populations on the same available land. At the same time, expanding populations also migrated to wilder regions.

Early humans broadened their diets by learning to eat more species once their preferred megafauna such as woolly mammoths became rare or extinct, often a result of hunting success by earlier generations. They set fire to parts of landscapes (a form of ecosystem engineering), burning vegetation to enhance hunting and foraging. They processed plant and animal foods to enhance their nutritional value, by developing cooking, grinding and other culinary tools that made many species, such as grasses, useful to humans for the first time. And they spread the plant foods they liked and managed populations of animals they hunted – and later would domesticate (Kirch 2005, Ellis *et al.* 2013).

Communities adopting agriculture in the early Holocene grew more rapidly than those of hunter-gatherers, ultimately replacing them across Earth's most productive lands. Intensification of land use continued: cultivation shifted from longer to shorter fallow periods, until eventually, continuous cropping became the norm, enhanced by the plow, irrigation, fertilizing with manure, and other increasingly productive technologies. Intensive agricultural systems gradually carpeted Earth's most productive lands, supporting densely populated villages and eventually supplying food to growing towns and cities.

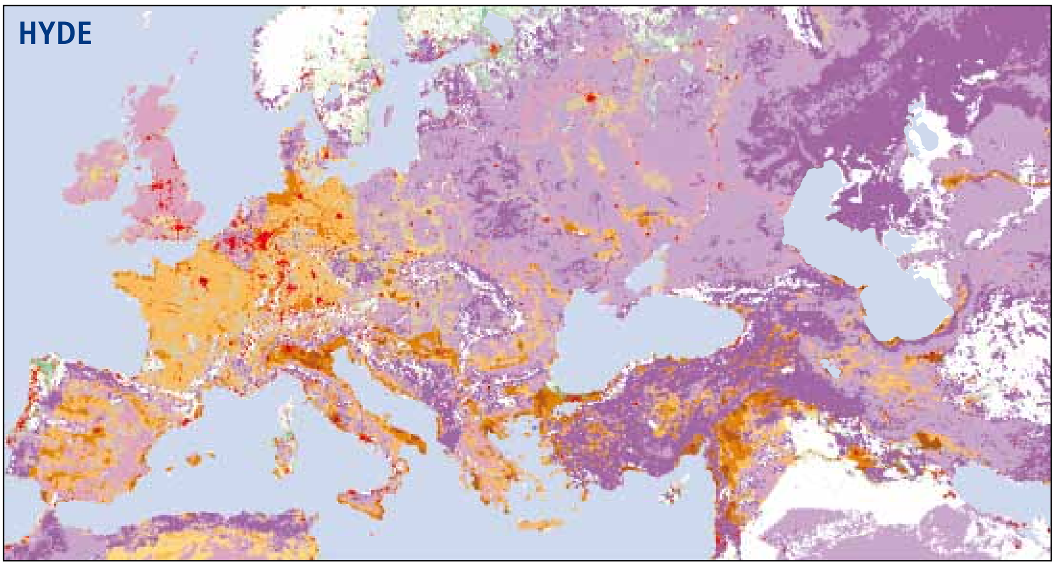


Figure 2. Land use in Europe more than 5000 years ago (3000 BCE) looks different in two models: the HYDE (left) shows less intensive human land use than the KK10 (right) model. Colour coding for the maps is below the map on the right.

Societies tend to adopt more productive land-use systems as populations increase.

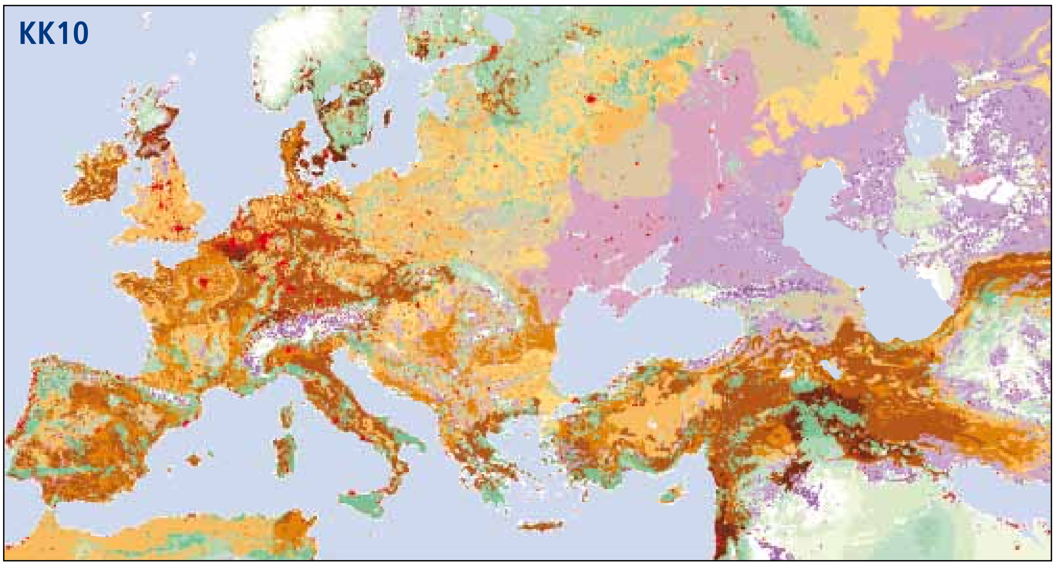
As the demands of urban populations grew, ever-larger farming operations, trading systems and technological institutions developed to support them. By the 1950s, these demands, combined with political support for them, led to the high-yield "Green Revolution" land-use systems that are still developing today. This system is sustained by fossil fuels and other industrial inputs – and now by emerging technologies such as genetic engineering.

A tale of two planets

Societies tend to adopt more productive land-use systems as populations increase, but always within the shifting confines of their social, economic and environmental systems. Social and economic processes constrain land availability to potential users. Economic costs, governance systems and cultural values can limit adoption of more efficient technologies. Steep terrain, drought and other environmental constraints limit the potential productivity of land, which can also degrade with use over time, demanding greater inputs or even leading to land abandonment. Consequently, increasingly productive use of land is not a smooth and continuous process, but instead a complex succession of shifting land-use systems, with land sometimes backsliding into less productive uses. These changes subject populations to both surplus production and productivity crises.

Two new reconstructions of human populations and their use of land across the planet throughout the Holocene allow us to make the first quantitative assessment of the long-term dynamics of human land use (Figure 2; Ellis 2011, Ellis *et al.* 2013). Contemporary global patterns of land use and population come from modern census data and remote sensing imagery, which enable land use to be mapped from a bird's eye view. But land use prior to historical records (around 1700 in most regions) must be "backcasted" from contemporary patterns, using models of land use per person.

The results of these two reconstructions are so different



Years of Intensive Use
>8000 years
5000 – 8000
3000 – 5000
2000 – 3000
1000 – 2000
500 – 1000
250 – 500
100 – 250
< 100

Recovery (% from peak use)
1 – 5%
5 – 10%
10 – 20%
20 – 50%
> 50%

Dense Settlements
AD 2000

that they might as well come from two different planets (see Figure 2): a global land system model, HYDE (the History Database of the Global Environment dataset), shows that outside Europe's more developed regions, human use of land was insignificant before 1750. But a model nicknamed KK10 (the dataset from Kaplan & Krumhardt 2010) indicates that ancient people were using land at a global scale far earlier in the Holocene, with more than 20% of Europe and Asia already in use by 3000 Before Common Era (BCE), and large areas of Earth's land in recovery from higher levels of land use in earlier periods.

Why are the models so different? The first and most popular Holocene land-use reconstruction, HYDE, assumes that land use per person remained nearly constant over time: in other words, about the same amount of land was used to feed, clothe, house and otherwise satisfy the needs of each person, no matter the year. But KK10 takes an entirely different approach, estimating land use from population by means of empirically derived nonlinear relationships with population density based on data from palaeoecological and historical studies (Kaplan *et al.* 2011). The result is that low-density populations with high per-capita land use first expand to fill all usable land. Then they intensify their use of land, using less land per person as population densities increase over time.

So which model comes closer to the truth? At present, conclusively validating these global models of Holocene land use against empirical data across Earth's land is not yet possible. The requisite archaeological and palaeoecological data require compiling and standardising at global scale – a massive task. Nevertheless, by comparing existing models with what we know from archaeology, palaeoecology, geography and environmental history, it is clear that by incorporating adaptive changes in land use per capita over time, a more spatially detailed and plausible assessment of our planet's history is revealed, with a biosphere long ago affected by humans.

Learning from the ancestors

New models of land use across the many millennia of the Holocene suggest the central role of land-use intensification as a social process of global change in the Anthropocene. By enabling land productivity to increase over millennia, land-use intensification has allowed human populations to grow well beyond the potential of the unaltered biosphere to support them and helped sustain the emergence of large, technologically sophisticated, affluent and interconnected societies with the power to alter the course of Earth's history (Ellis *et al.* 2013). As we move deeper into the Anthropocene, strengthening our scientific understanding of the long-term social processes that sustain humanity has never been more important for the future stewardship of the planet.

New models of land use across the many millennia of the Holocene suggest [its] central role.

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