Finding Osama bin Laden:

An Application of Biogeographic Theories and Satellite Imagery

Thomas W. Gillespie and John A. Agnew are professors of geography at UCLA. They may be contacted respectively at tg@geog.ucla.edu and jagnew@geog.ucla.edu. Erika Mariano, Scott Mossler, Nolan Jones, Matt Braughton, and Jorge Gonzalez are undergraduates in UCLA's geography department. They may be contacted respectively at erikmari@ucla.edu, smossler@ucla.edu, nolanjones@ucla.edu, mbraught@ucla.edu, and jorgon@ucla.edu.[1]

Abstract

One of the most important political questions of our time is: Where is Osama bin Laden? We use biogeographic theories associated with the distribution of life and extinction (distance-decay theory, island biogeography theory, and life history characteristics) and remote sensing data (Landsat ETM+, Shuttle Radar Topography Mission, Defense Meteorological Satellite, QuickBird) over three spatial scales (global, regional, local) to identify where bin Laden is most probably currently located. We believe that our work involves the first scientific approach to establishing his current location. The methods are repeatable and can be updated with new information obtained from the US intelligence community.

Introduction

Osama bin Laden remains at large. Thought to be isolated from al-Qaeda's daily operations, bin Laden's direction may no longer be a relevant factor in the group's effectiveness. Yet the image of the bearded demagogue remains a source of inspiration to enemies of the West. Where is he?

In his confirmation hearings before the Senate Intelligence Committee, then-CIA Director-designate Leon Panetta emphasized the hunt for Osama bin Laden as a top priority for the new administration (1). He remains the FBI's most wanted terrorist. A number of al Qaeda commanders have been captured or killed, including Mohammed Atef, Mohammad Saleh, Khalid Shaikh Mohammed, and Abu Zubaydah. And yet despite seven years of espionage and a $25 million reward for his capture, the mystery of bin Laden's whereabouts persists (2). Perhaps the CIA has availed itself of every gizmo, gadget, and theory the world has ever known to bring bin Laden to justice. The public, on the other hand, has never seemed to engage wholeheartedly in the debate over the manhunt; nor, to our knowledge, has the scientific community offered up any testable hypotheses on the subject.

In informal conversations in the Geography Department at UCLA, we began to ask ourselves if the biogeographic theories we use every day – theories that predict how plants and animals distribute themselves over space and over time – employed in conjunction with publicly available satellite imagery, could shed some light on this question. The outcomes of this musing, presented below, are our thoughts and experiment. By bringing these methodologies to bear, it is our hope that a long overdue debate might bring bin Laden back to the fore of the public consciousness – and possibly to justice.

True to the scientific method, a biogeographer starts with the best information available, makes a set of assumptions, and employs theories and technologies to home in on a progressively testable hypothesis. There have been significant advances recently in biogeographic theory and remote sensing imagery that can be applied to provide testable propositions about bin Laden's current location (3-4). Distance-decay theory and island biogeography theory are two biogeographic theories associated with the distribution of life and extinction that can be used to identify the location of bin Laden at global and regional spatial scales. Distance-decay theory states that as one goes further away from a precise location, there is an exponential decline in the turnover of species and a lower probability of finding the same composition of species (5-7). The theory of island biogeography states that large and close islands will have higher immigration rates and support more species with lower extinction rates than small isolated islands (8-9).

These theories can be applied over varying spatial scales to posit bin Laden's current location based on his last reputed geographic location. Distance-decay theory would predict that he is closest to the point where he was last reported and, by extension, within a region that has a similar physical environment and cultural composition (that is, similar religious and political beliefs). For instance, the further he moves from his last reported location into the more secular parts of Pakistan or into India, the greater the probability that he will find himself in different cultural surroundings, thereby increasing the probability of his being captured or eliminated. Island biogeographic theory predicts that bin Laden is in a larger town rather than a smaller and more isolated town where extinction rate would be higher. Finally, high-resolution analyses of a city can be undertaken to identify individual buildings that match bin Laden's life history characteristics. For example, he reportedly has a small entourage of body guards, requiring a structure that contains at least three rooms. (See Table 1 for a complete list of life history characteristics used to derive structural building requirements.)

The public also now has at its disposal a number of new remote sensing tools to put these theories into action to create testable hypotheses. There have been over 73 successful launches of earth-observation satellites between 2000 and 2007. Most of these satellites can be utilized by scientists to examine natural and man-made features on the earth's surface. Although these satellites and sensors are not as high resolution as US intelligence satellites, some may be accurate enough to create working hypotheses on bin Laden's current whereabouts.

Methods

Three spatial scale analyses (global, regional, local) were examined to identify bin Laden's likeliest current location (10). Osama bin Laden was last seen by non-local observers in Jalalabad, Afghanistan on November 13, 2001 and, according to radio traffic, he was last heard from in a transmission from Tora Bora on November 28, 2001 (Figure 1) (11). At a global scale, we used his last known location (Tora Bora) to create distance-decay probability maps over satellite imagery (Figure 2). At a regional scale, we overlaid the distance-decay map on the city islands to identify cities with the highest probability of bin Laden's occurrence based on island biogeography theory. At a local spatial scale, we systematically searched the city with the highest probability of occurrence – that is, the highest probability of hosting bin Laden –to identify structures that match his six life history characteristics (see Table 1). Details on all satellite imagery and method used are in Appendix 1.

TABLE 1: LIFE HISTORY CHARACTERISTICS OF OSAMA BIN LADEN AND ASSOCIATED PHYSICAL STRUCTURE ATTRIBUTES

Life History Characteristics	Physical Structure Attribute
Is 6'4" tall	Tall building
Requires a dialysis machine that uses electricity	Electric grid hookup or generator
Prefers physical protection	Walls over three meters high
Enjoys personal privacy	Space between structures
Retains a small number of body guards	More than three rooms
Prefers to remain protected from aerial view	Trees for cover when outside

When we applied a distance-decay model to his last known location from 2001, the FATA – or Federally Administered Tribal Area – of Kurram had the highest probability of hosting bin Laden (98%) (Figure 3). There were 26 city islands within a 20-km radius of his last known location in northwestern Kurram. Parachinar figured as the largest and the fourth-least isolated city (Figure 4). Nightlight imagery also shows that Parachinar is the closest city to his last known location and by far the brightest city by nightlight intensity in Kurram (Figure 5). When we undertook a systematic building search in the city of Parachinar, this approach resulted in three structures that meet all six of them (Figure 6) and 16 structures that meet five of them.

The Global Scale

There are few published reports concerning bin Laden's current global or regional location. One comes from a letter from Atiyah Abd al-Rahman to Abu Musab al-Zarqawi, bin Laden's presumed second-in-command, dated December 11, 2005 (12). It suggests that he and the al-Qaeda leadership were based in the Waziristan region of Pakistan at the time. However, it is difficult to believe that a letter would be written by such a high-ranking official giving away bin Laden's location. Another alternative hypothesis is that he resides in the southern or northern FATAs where there is significantly greater Taliban (Afghan and Pakistani) military activity.

At a global scale, distance-decay theory suggests that Osama bin Laden's current location is not likely to be random, and his probability of occurrence exponentially decreases the further he moves from his last known location (5-7). Our results based on his last know location in 2001 indicate that there is a 98% probability that he is in Kurram, Pakistan, and an 86.6% probability that he is within one of the seven FATAs. The FATAs have long been outside of central government control and served as reservoirs of militant Islamists working to

change the governments in both Kabul and Islamabad since the 1970s. Based on his last known location in Tora Bora, we estimate that he must have traveled 3.1 km over an approximately 4,000 meter pass in winter to enter Kurram, Pakistan. Doing so would have been extremely difficult for a 44-year old man with diabetes. Kurram is surrounded on three sides by the Afghan border (known as the Durand Line), which essentially cuts right though the ethnically Pushtun belt that straddles it. It is unlikely that he would have headed back into Afghanistan after leaving Tora Bora, if only because doing so would have required him to abandon the mountains for more open countryside.

The Regional Scale

Parachinar has a long history of housing mujahideen during the Soviet invasion of Afghanistan in the 1980s, so it most likely contains a large number of Taliban soldiers who cross over from here into Afghanistan. Residing near or in a large city should reduce bin Laden's chances of exposure and elimination due to a military raid on a small city or an isolated structure. Smaller cities would greatly reduce his security and privacy, and there are only a small number of structures that appear well-protected in smaller towns (Figure 7). Nightlight imagery also reveals that Parachinar is one of the brightest cities in the FATAs after the city of Miram Shah in North Waziristan, which is 102.3 km away. Most cities there have little or no nightlight signature. The city of Peshawar has the brightest nightlight signature in the region and may soon fall to the Taliban. If Peshawar falls under Taliban control, the search for bin Laden will become significantly more difficult due to the large number of structures in that city compared to the relatively small number of structures overall in the FATAs.

The Local Scale

Based on Osama bin Laden's life history characteristics, three buildings should be closely monitored to test the hypothesis that he is located at one of them. Structures A, B, and C are the best fortified and some of the largest residential homes or structures in the city of Parachinar. Structures A and C are residential homes, while structure B appears to be a prison. However, if it is a prison, it has one of the best-maintained gardens in all of Parachinar. There are also 16 structures that match five of bin Laden's life history characteristics (Figure 6 and Table 2-1). If one follows our approach, one would predict that he is located in one of these three buildings. Alternatively, there is a popular perception that bin Laden is currently residing in a cave. A cave would have to have a sealed entrance, be heated and ventilated, and have supplies transported to the cave monthly or annually. We feel that most of these requirements would have

physical manifestation that might easily be seen from space, and that the cave hypothesis is unlikely but could be tested.

Conclusions and Implications

Our conclusion results from applying a model that, like all other models, makes critical assumptions. What we have attempted to demonstrate is that it is possible to narrow down where Osama bin Laden is by ruling out where he is unlikely to be and by providing a scalable hypothesis that can be tested, and accepted or rejected, like any other in science. High-resolution imagery of all structures in the FATAs is currently available from a number of international commercial satellites with a 0.4 meter pixel size; however, open-access satellite images can be high enough to be a national security risk in the region (13-14). For instance, in an attempt to aid disaster relief efforts after the October 8, 2005 earthquake in Kashmir, numerous international aid agencies posted high-resolution satellite images on the web. The Pakistani government forced these images to be removed because they feared that the security of the Kashmir region might be compromised. Perhaps it is past time to embrace this technology and create a public database concerning models or hypotheses about bin Laden's current location.

The US intelligence community has at least three agencies that have been involved in searching for bin Laden. The National Security Agency does code-breaking and communications monitoring, the National Geospatial Intelligence Agency makes maps and analyzes surveillance photographs, and the National Reconnaissance Office provides satellite imagery. Altogether, the US intelligence community spent over $50 billion on intelligence activities last year alone. Ideally, some of this money should have been spent looking for bin Laden and the US intelligence community could make public a report based on all data collected from 2001 to 2006. The three agencies mentioned above should also disprove the hypotheses that Osama bin Laden is: (1) located in the Kurram region of Pakistan, (2) located in the city of Parachinar, and (3) at one of the three hypothesized buildings. These methods are repeatable and could easily be updated with new information obtained from the US intelligence community on his last known location.

End Notes

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Figures

Figure 1. The last known location of Osama bin Laden in Tora Bora using two-dimensional spectral and three-dimensional spectral and elevation imagery

Figure 2. Exponential distance-decay model of bin Laden's location with percent probability and distance
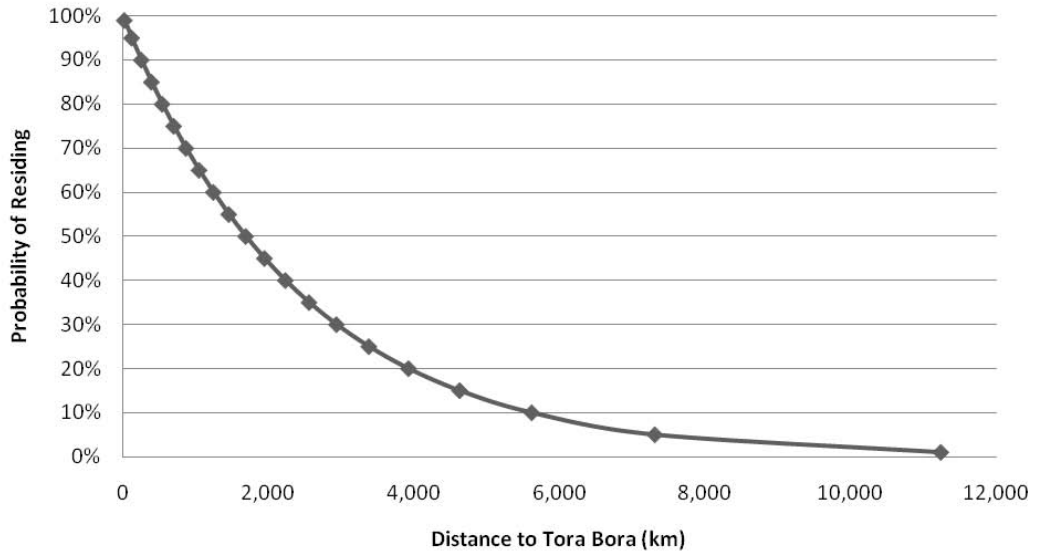
Figure 3. Probability model of bin Laden's current location based on distance-decay theory at a global spatial scale
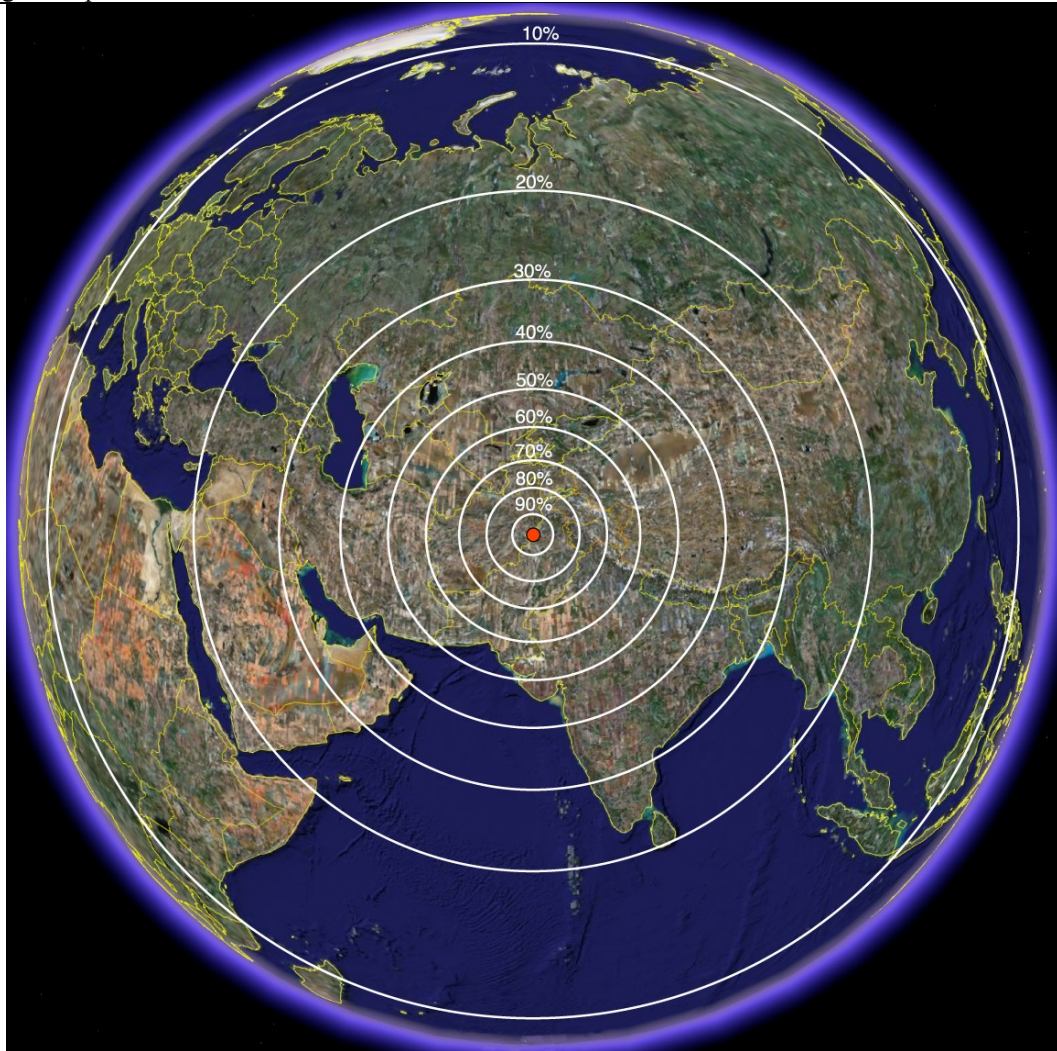
Figure 4. Regional analysis of city islands within a 20-km radius of bin Laden's last known location (red dot)
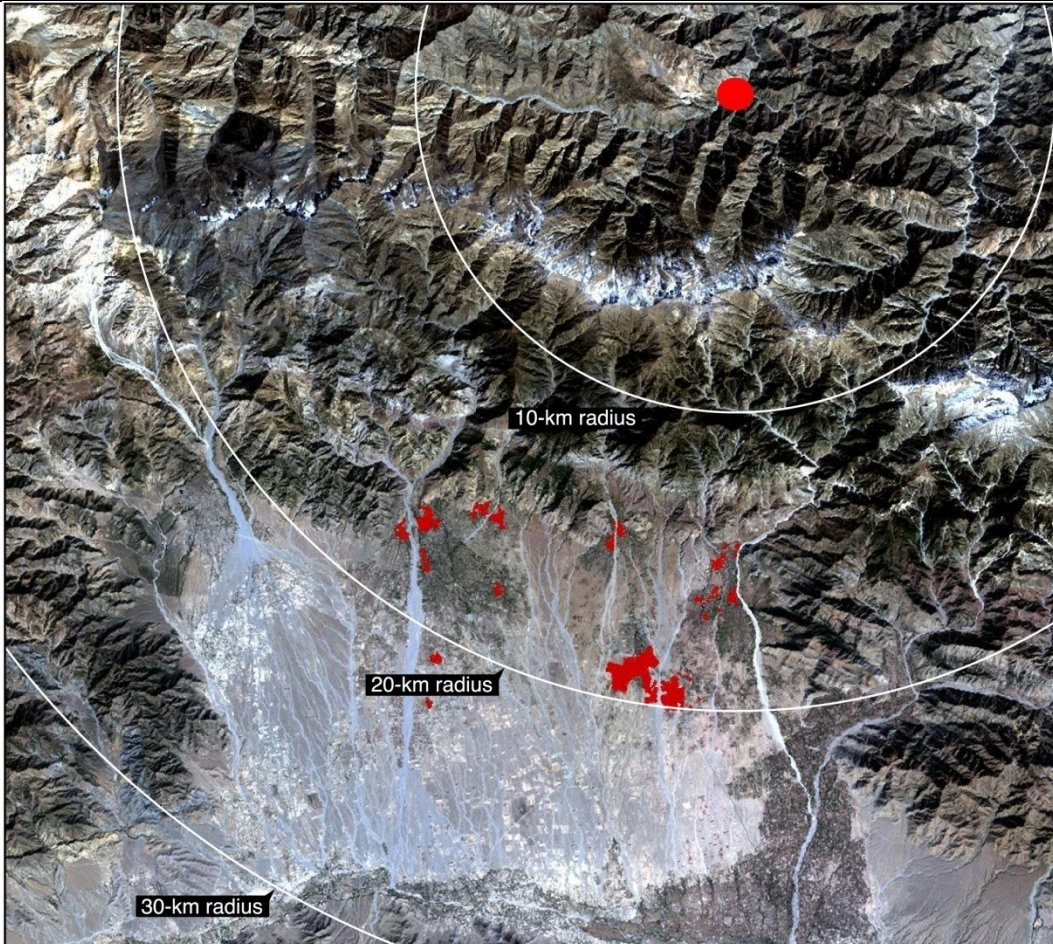
Figure 5. Regional analysis of city islands in Pakistan's FATAs using nightlight imagery
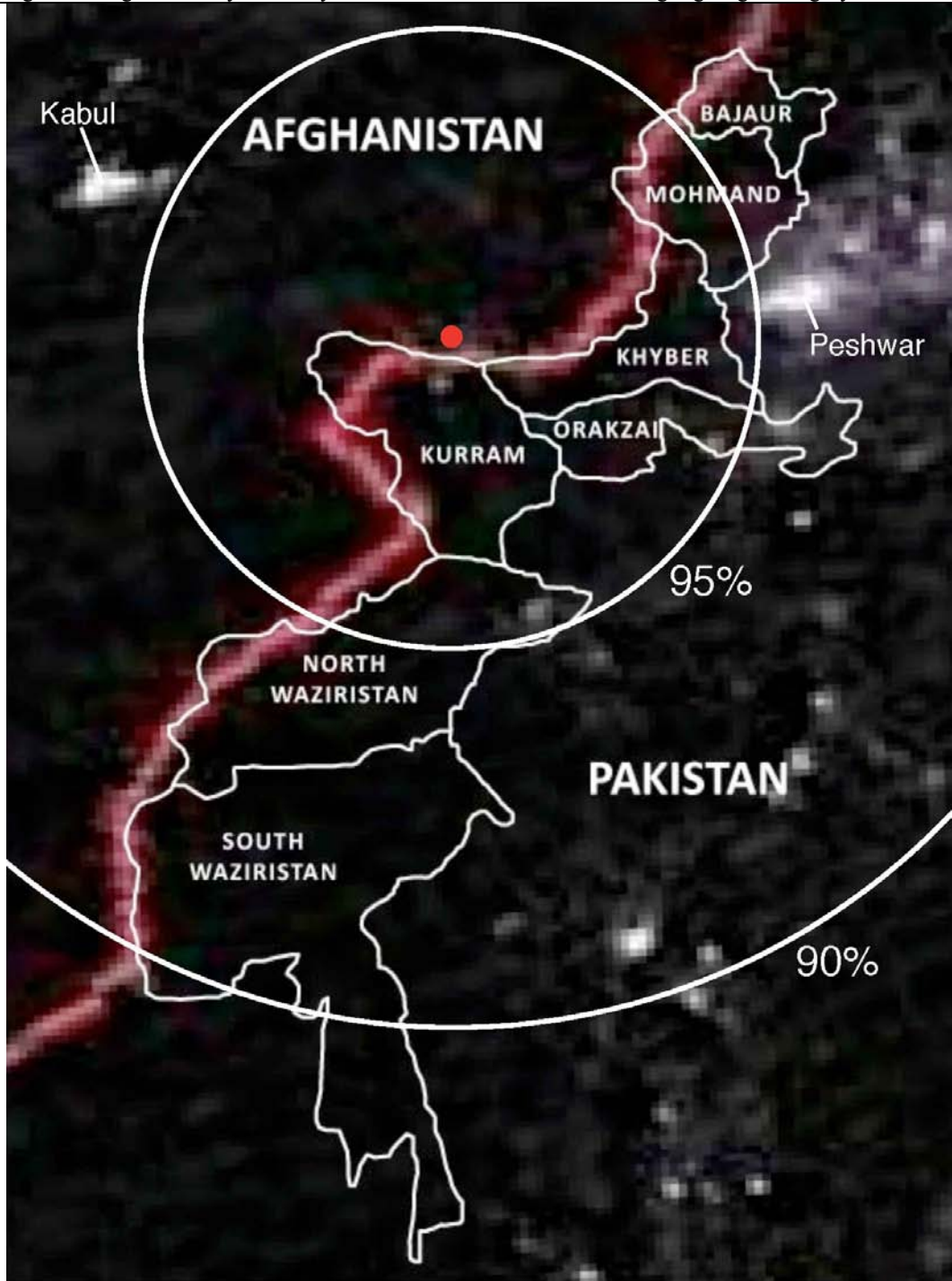

Figure 6. Three predicted locations of bin Laden based on his life history characteristics

Structure A
N 33.901944°
E 70.093746°

Structure B
N 33.911694°
E 70.0959°

Structure C
N 33.888207°
E 70.113308°

Figure 7. Small city islands and structures in Kurram, Pakistan

Appendix 1: Satellite Imagery and Methods

Satellite Imagery

Landsat ETM+, Shuttle Radar Topography Mission, QuickBird, and Defense Meteorological Satellite Program-Operational Linescan System imagery were used to provide hypotheses on the current location of bin Laden. All imagery was georectified into the same geographic coordinate system (WGS84). Two Landsat 7 ETM+ images of Afghanistan and Pakistan with a pixel size of 30 m × 30 m were acquired from March 28, 2001 and September 22, 2002. Shuttle Radar Topography Mission data on elevation with a pixel size of 90 m × 90 m were acquired and combined with Landsat ETM+ imagery of the region. QuickBird imagery with a pixel size of 0.6 m × 0.6 m in the visible wavelengths was acquired via Google Earth for March 19, 2004 and November 12, 2007. Defense Meteorological Satellite Program-Operational Linescan System imagery under cloud-free and low moon conditions was collected for 2007.

Data Analysis.

Global Scale. A three-dimensional model of the Tora Bora landscape, using Landsat ETM+ and Shuttle Radar Topography Mission imagery, identified the point that bin Laden would have passed in Tora Bora based on spectral imagery and topography. A distance-decay model using an exponential curve was used with his last known location in Tora Bora (N 34.0641° E 70.1375°) set at 99% probability of bin Laden's occurrence, and with the White House in Washington D.C., located 11, 246 kilometers away, set at 1% probability of bin Laden's occurrence (N 38.8976° W 77.0366°) (Figure 1). We use a simple exponential model ($P(d) = k^d$) where k is the constant derived from our assumed values of there being a 1% chance of Osama bin Laden being located in Washington, D.C. and a 99% chance that he is located in the area he was last seen, d is the distance from his last known location and $P(d)$ is the resulting probability of his being located at that distance. Thus, we predict according to distance-decay theory that the further Osama bin Laden is from Tora Bora and the nearer he is to Washington, D.C. the lower the probability that he is located there. The resulting equation ($P(d) = 0.99959058977238^d$) was then used to calculate individual values of probability given a certain distances.

Regional scale. City islands larger than 100 m x 100 m were digitized over geo-referenced QuickBird imagery in ArcGIS 9.0 to quantify area and isolation metrics. City-islands were quantified as area of continuous man-made structures and the distance in kilometers to all other city-islands was used as an

isolation metric (9).   Boundaries of the Federally Administered Tribal Areas (FATAs) were overlaid on nightlight imagery to identify city islands in the region.

Local scale. QuickBird imagery of the city with the highest probability of occurrence – that is, the highest probability of having bin Laden – was systematically searched across 1 km × 1 km grids to identify structures that match his six life history characteristics (Table 1). Each structure was quantified as 1 or 0 for accommodating each one of these six characteristics. Structure values were summed and the highest values (for example 5 or 6) were selected as his probable location.

Appendix 2: Coordinates

Table 2-1. Seven 1 km × 1 km grids in Parachinar, structure number within grid, and location of structures with a score of five and six based on the sum of physical structure attributes fitting bin Laden's life history characteristics
Source: The authors

Grid #	Structure	Score	Latitude	Longitude
1	1	5	33.903432°	70.091091°
	2	6	33.901944°	70.093746°
	3	5	33.902662°	70.095839°
2	1	5	33.899715°	70.104956°
	2	5	33.900707°	70.103338°
	3	5	33.906885°	70.105129°
	4	5	33.896283°	70.111935°
3	1	5	33.898657°	70.116777°
	2	5	33.899745°	70.118473°
	3	5	33.894525°	70.121523°
4	1	5	33.897951°	70.089383°
	2	5	33.898255°	70.087519°
5	1	5	33.892353°	70.106461°
	2	5	33.887763°	70.111442°
6	1	5	33.885623°	70.115935°
	2	5	33.891417°	70.114477°
	3	6	33.888207°	70.113308°
7	1	6	33.911694°	70.095900°
	2	5	33.913399°	70.097189°