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Amazonia 1492: Pristine Forest or Cultural Parkland?

Michael J. Heckenberger,1* Afukaka Kuikuro,4 Urissors Tabata Kuikuro,1 J. Christian Russell,2 Morgan Schmidt,3 Carlos Fausto,4 Bruna Franchetto5

Archaeology and indigenous history of Native Amazonian peoples in the Upper Xingu region of Brazil reveal unexpectedly complex regional settlement patterns and large-scale transformations of local landscapes over the past millennium. Mapping and excavation of archaeological structures document pronounced human-induced alteration of the forest cover, particularly in relation to large, dense late-prehistoric settlements (circa 1200 to 1600 A.D.). The findings contribute to debates on human carrying capacity, population size and settlement patterns, anthropogenic impacts on the environment, and the importance of indigenous knowledge, as well as contributing to the pride of place of the native peoples in this part of the Amazon.

References and Notes

1. Department of Anthropology, 2Land-Use and Environmental Change Institute, 3Department of Geography, University of Florida, Gainesville, FL 32611, USA. 4Associação Indígena Kuikuro do Alto Xingu, Parque Indígena do Xingu, Mato Grosso, Brazil. 5Department of Anthropology, Museu Nacional, Universidade Federal do Rio de Janeiro, Quinta da Boa Vista, Rio de Janeiro 20940–040, Brazil.

*To whom correspondence should be addressed. E-mail: mheckenb@anthro.ufl.edu
under indigenous resource management [Parque Indígena do Xingu (PIX)]. It remains little affected by 20th century mechanized development (Fig. 1). The Upper Xingu is a long-standing case study of indigenous Amazonian agriculture and ecology (9, 10) and one of the few places where contemporary observations about indigenous agriculture, land use, and settlement pattern can be systematically linked with archaeological and oral historical evidence (11). Long-term in situ cultural development of Xinguano peoples over more than 1000 years (12) is clearly documented by continuity in (i) utilitarian ceramics used to process and cook staple foods (13); (ii) settlement placement (at forest/wetland transitions) and local land use, marked by substantial forest and wetland alterations; and (iii) settlement form, notably circular plazas with radial roads (14) (movie S1).

In the Kuikuro study area (Fig. 2) (15), 19 major pre-Columbian settlements have been identified, generally separated by 3 to 5 km and linked by a system of broad, straight roads (16). Recognition and mapping of major earthworks at these sites reveal their articulation in a remarkably elaborate regional plan (14). The earthworks include (i) excavated ditches in and around ancient settlements (up to 2.5 km long and 5 m deep); (ii) linear mounds or “curbs” positioned at the margins of major roads and circular plazas (averaging about 0.5 to 1.0 m in height); and (iii) a variety of wetland features, such as bridges, artificial river obstructions and ponds, raised causeways, canals, and other structures, many of which are still in use today. Similar constructed features (such as settlements, roads, weirs, and ponds) are known from culturally related peoples (principally Arawak speakers) across the southern Amazonian periphery (17–19) [supporting online material (SOM) text].

The integrated settlement configuration was in place by c. 1250 to 1400 A.D., based on radiocarbon dates from stratified deposits at X6, X11, and X13 (Table 1) (14, 20). Major curbed roads (10 to 50 m wide) articulate with plazas, ditches, and partition space within villages and across the broader landscape, notably linking settlements into “galactic” clusters across the region (21). The Ipatse cluster includes four major residential settlements (X6, X17, X18, and X22), linked to a fifth unfortified “hub” site (X13), with only limited residential occupation (Fig. 3A). Another cluster of sites, centered on X11, shows a similar pattern of a large (50 ha) fortified settlement connected to other smaller but still elaborate settlements. In the case of the Kuhikugu (X11) cluster, the largest residential center is the hub (Fig. 3B). The primary nodes of each cluster are also linked by roads to smaller plaza settlements (fig. S1). On the basis of artifact and dark-earth distributions, it has been estimated that large sites, such as X6 and X11, had 15 to 25 ha of residential space, medium sites (X17, X18, X22) had 5 to 10 ha, and small sites had 2 to 5 ha (14). Thus, the actual residential area of a cluster like X6 or X11 was at least 40 to 80 ha in an area of about 400 km², with an estimated population of between 2500 and 5000 persons (or about 6 to 12.5 persons per km² in the study area).

Areas within each galactic cluster can be characterized as saturated anthropogenic landscapes, because virtually the entire area in and between major settlements, although not entirely cultural in origin, was carefully engineered and managed. Indeed, the road networks, oriented by the same system of cardinality that characterizes plaza spatial organization, partitioned the landscape into a gridlike or latticelike organization of nodes (plazas) and connecting thoroughfares, although patches and corridors of secondary and perhaps managed forests were likely common, as they are today. Mapped archaeological features correspond to patches of acutely modified secondary growth, distinctive from surrounding forest and easy to recognize in

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**Fig. 1.** Upper Xingu region image [Landsat 7 Enhanced Thematic Mapper, path 225, rows 68 to 69; 12 August 1999; image is a composite false-color infrared with bands assigned as red-green-blue to provide the appearance of natural vegetation] with the approximate boundaries of the PIX and the Kuikuro study area (inset of Upper Xingu, Brazil). The ecological transition between the closed forests of southern Amazonia and the more open savanna/gallery forest of the Brazilian Planalto Central is shown (lower right).

**Fig. 2.** Kuikuro study area showing the distribution of major ditched plaza centers (stars in circles), major plaza centers (open circles), and small plaza and non-plaza villages (black dots).
radiocarbon dates from Nokugu (X6) and other sites in the Kuikuro study area, southern PIX.

Table 1. Radiocarbon dates from Nokugu (X6) and other sites in the Kuikuro study area, southern PIX. Beta 176135 to Beta 176144 are reported here for the first time. Calibrated age ranges for samples dated in 2003 (numbered 176135 and up) were reported by Beta-Analytic laboratory; previous (1994) dates were calibrated using CALIB 4.0 ([29]; ET, excavation trench of 1.0 by 10.0 m or more; EU, excavation unit of 1.0 m²; S, southern side of plaza or site; N, northern side; Ditch 1, outermost; Ditch 2, middle; Ditch 3, innermost ditch in all sites.

<table>
<thead>
<tr>
<th>Lab no.</th>
<th>Site/unit</th>
<th>Conventional radiocarbon</th>
<th>2σ-calibrated age range</th>
<th>Provenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta 176142</td>
<td>X6/ET2</td>
<td>20 ± 50</td>
<td>modern*</td>
<td>Ditch 3 (S), upper ditch infill</td>
</tr>
<tr>
<td>Beta 72260</td>
<td>X6/ET1</td>
<td>180 ± 60</td>
<td>1520–1940 A.D.</td>
<td>Ditch 2 (S), upper ditch infill</td>
</tr>
<tr>
<td>Beta 176137</td>
<td>X6/ET10</td>
<td>340 ± 60</td>
<td>1460–1640 A.D.</td>
<td>Ditch 2 (N), upper ditch infill</td>
</tr>
<tr>
<td>Beta 81301</td>
<td>X6/ET1</td>
<td>360 ± 70</td>
<td>1420–1640 A.D.</td>
<td>Ditch 2 (S), mid-ditch infill</td>
</tr>
<tr>
<td>Beta 78979</td>
<td>X6/ET1</td>
<td>390 ± 70</td>
<td>1400–1650 A.D.</td>
<td>North road, intact/curb interface</td>
</tr>
<tr>
<td>Beta 78979</td>
<td>X6/ET1</td>
<td>530 ± 60</td>
<td>1400–1430 A.D.</td>
<td>Small plaza, subcurb intact</td>
</tr>
<tr>
<td>Beta 72262</td>
<td>X6/ET3</td>
<td>590 ± 60</td>
<td>1200–1410 A.D.</td>
<td>Small plaza, subcurb intact</td>
</tr>
<tr>
<td>Beta 176140</td>
<td>X6/ET3</td>
<td>600 ± 60</td>
<td>1260–1300 A.D.</td>
<td>Central plaza, subcurb intact</td>
</tr>
<tr>
<td>Beta 176139</td>
<td>X6/ET2</td>
<td>590 ± 60</td>
<td>1300–1420 A.D.</td>
<td>Ditch 3 (N), basal fill</td>
</tr>
<tr>
<td>Beta 177724</td>
<td>X6/ET2</td>
<td>670 ± 60</td>
<td>1260–1410 A.D.</td>
<td>Ditch 3 (N), basal fill</td>
</tr>
<tr>
<td>Beta 88362</td>
<td>X6/ET2</td>
<td>690 ± 60</td>
<td>1260–1300 A.D.</td>
<td>Central plaza, subcurb intact</td>
</tr>
<tr>
<td>Beta 78979</td>
<td>X6/ET1</td>
<td>700 ± 70</td>
<td>1230–1410 A.D.</td>
<td>Ditch 2 (S), sub-berm intact</td>
</tr>
<tr>
<td>Beta 176136</td>
<td>X6/ET4</td>
<td>710 ± 50</td>
<td>1270–1300 A.D.</td>
<td>Ditch 1 (S), basal fill</td>
</tr>
<tr>
<td>Beta 176139†</td>
<td>X6/ET2</td>
<td>590 ± 60</td>
<td>1300–1420 A.D.</td>
<td>Ditch 3 (N), basal fill</td>
</tr>
<tr>
<td>Beta 177724†</td>
<td>X6/ET2</td>
<td>670 ± 60</td>
<td>1260–1410 A.D.</td>
<td>Ditch 3 (N), basal fill</td>
</tr>
<tr>
<td>Beta 88362</td>
<td>X6/ET3</td>
<td>690 ± 60</td>
<td>1260–1300 A.D.</td>
<td>Central plaza, subcurb intact</td>
</tr>
<tr>
<td>Beta 78979</td>
<td>X6/ET1</td>
<td>700 ± 70</td>
<td>1230–1410 A.D.</td>
<td>Ditch 2 (S), sub-berm, base intact</td>
</tr>
<tr>
<td>Beta 176136</td>
<td>X6/ET4</td>
<td>710 ± 50</td>
<td>1270–1300 A.D.</td>
<td>Ditch 1 (S), basal fill</td>
</tr>
<tr>
<td>Beta 176137</td>
<td>X6/ET10</td>
<td>1600–1700 A.D.</td>
<td>1260–1300 A.D.</td>
<td>Central plaza, subcurb base intact</td>
</tr>
<tr>
<td>Beta 72262</td>
<td>X11/EU1</td>
<td>900 ± 60</td>
<td>1000–1250 A.D.</td>
<td>North road, subcurb, basal intact</td>
</tr>
<tr>
<td>Beta 88363</td>
<td>X13/EU1</td>
<td>910 ± 80</td>
<td>1040–1250 A.D.</td>
<td>Central plaza, subcurb base intact</td>
</tr>
<tr>
<td>Beta 72261</td>
<td>X6/ET1</td>
<td>1000 ± 70</td>
<td>950–1210 A.D.</td>
<td>Ditch 2 (S), sub-berm, base intact</td>
</tr>
<tr>
<td>Beta 176141</td>
<td>X6/ETS 1</td>
<td>1030 ± 60</td>
<td>980–1030 A.D.</td>
<td>Central plaza, subcurb base intact</td>
</tr>
<tr>
<td>Beta 176142</td>
<td>X6/ET2</td>
<td>1370 ± 60</td>
<td>640–690 A.D.</td>
<td>Mid-ditch 3 (N), mid-ditch</td>
</tr>
<tr>
<td>Beta 176138†</td>
<td>X6/ET10</td>
<td>2110 ± 40</td>
<td>190–60 B.C.</td>
<td>Ditch (N), basal fill</td>
</tr>
</tbody>
</table>

†Two additional modern dates, Beta 98978 and Beta 176144, are considered invalid. The former was redated with a sample slightly higher in profile (Beta 81301). Beta 176139 is inverted with 176143 and was redated by 177724. Beta 176138 also comes from stratified but mixed context of ditch infill, and both likely represent earlier materials that are mixed in ditch construction.

Fig. 3. Satellite image (Landsat 4 Thematic Mapper, path 225, row 69; 21 June 1992; bands were assigned as 5(red)-4(green)-3(blue)) with global positioning system–mapped Ipatse cluster sites X6 and X13 (A, insets) linked by the “north-south road” and transit-mapped X11 (B, inset). Ditches are colored in red; road and plaza curbs are black. Fieldwork in 2003 demonstrates that roads extend fully from X13 to X18, and continue on to X19, X20, and beyond along the north-south road, as well as across high ground to X17 and X22 (fig. S1); X11 roads also connect it to the four satellites. MTFX, Mato Grosso (the state), Formadores do Xingu (the archaeological region). The number refers to the site number.
depopulation (25) led to the abandonment of these works and many settlements, resulting in extensive reforestation in many areas. The scale of the prehistoric settlements, including exterior constructions, such as roads, hamlets, wetland structures, and cultivation areas, suggests that agricultural and parkland landscapes, rather than high forest, characterized the broad landscapes around ancient villages, as is true in contemporary villages. Metal technology, however, has increased the speed at which forests can be converted into mosaic parklands of dispersed manioc gardens, sapé grass fields, piqui groves, and secondary forests (26) (Fig. 4).

The Upper Xingu is a unique Amazonian example of a tropical forest way of life that supported large, densely settled, and politically integrated regional populations over the past 1000 years. Local ecology reflects the dynamic interaction between the natural environment, the influence of fairly large, settled human populations, and the legacy of Euro-American colonialism over the past ~500 years. Evidence of large, well-engineered public works (such as plazas, roads, moats, and bridges) in and between pre-Columbian settlements suggests a highly elaborate built environment, rivaling that of many contemporary complex societies of the Americas and elsewhere (SOM text). To suggest that Xinguano lands were intensively managed and developed, c. 1492, however, does not imply that indigenous land-use strategies, based on patchy development within long rotational cycles, are comparable to modern nonindigenous clear-cutting strategies (27, 28). Xinguano cultivation and land management, indeed, provides a viable alternative. The present research emphasizes the critical importance of collaborative research strategies, including archaeological and ethnographic fieldwork, remote-sensed data analysis and geographic information systems, and most important, indigenous participation, to understand the complex interplay of ecological, historical, and political conditions in Amazonia before and after 1492.

Fig. 4. Aerial photographs (U.S. Air Force/Força Aérea Brasileira 1967; 1:60,000) of Lake Ipate (A) and Lake Kuhikugu (B) showing land-cover change during 6-year period (1961 to 1967) after abandonment (Kuhikugu) and reoccupation (Ipate). Comparison with Fig. 3 (1992) of same areas shows an ~30-year period. Graphic testimony of post-1492 decline in village size is shown by comparing the size of X11 with the four sequential Kuhikugu villages (c. 1870s to 1961) in and north of the ancient site and by comparing X6 with the active village in 1967 and 1992.

References and Notes

12. Initial Xinguano occupations date sometime between 200 B.C. and 800 A.D., but the exact date is uncertain because the two earliest radiocarbon dates are from mixed deposits, and in one case (Beta-Analytic Laboratory number 176143) the dates are demonstrably out of sequence.
13. Manioc, fish, and piqui fruit constitute 90% or more of the diet (9).
14. Materials and methods are available as supporting material on Science Online.
15. The Kuhikugu study area is about the same as the Kukuro (Carib Xinguano) traditional territory. It is about 1000 km² and is located in an area of traditional Xinguano occupations that is 25,000 to 35,000 km².
16. Several additional large sites are known in the study area, on the basis of indigenous knowledge of dark-earth locations, and numerous smaller occupation sites are also known, including small road-side hamlets along the major roads.
20. Here, "galactic" describes the regional site clusters organized around a center or hub (X11 and X13), with several major residential sites connected to it.
22. Dark earth forms in compost areas, although widespread burning produces minor but extensive soil alterations.
30. Ethnoarchaeological research in the Upper Xingu by M.J.H., conducted in collaboration with the Museu Nacional (UFRJ), the Museu Goeldi, and the Museu Nacional (UFRJ), the Museu Goeldi, and the
Vertebrate genomes contain six evolutionarily related nuclear receptors for steroid hormones: two for estrogens (ERα and ERβ) and each one for androgens (AR), progestins (PR), glucocorticoids (GR), and mineralocorticoids (MR). These ligand-activated transcription factors mediate the actions of hormones that direct sexual differentiation, reproduction, behavior, immunity, and stress response (1). There are no orthologs of these genes in the insect Drosophila melanogaster, the nematode Caenorhabditis elegans, or the urochordate Ciona intestinalis (2, 3), and a polymerase chain reaction (PCR) screen (4) failed to identify any of these genes outside the vertebrates. The most closely related nuclear receptors are the estrogen-related receptors (ERRs), an ortholog of which is present in the lineage leading to both phyla. A previous analysis of SR sequences indicated that the ancient progenitor of this protein class was most similar to extant ERs (10).

We used degenerate PCR and rapid amplification of cDNA ends to isolate an ER sequence (figs. S1 and S2) from a mollusk, the sea hare Aplysia californica. Using primers derived from vertebrate ERs, we amplified an ER-like cDNA sequence from both adult neural tissue and ovoestes of A. californica (11). The protein sequence of the Aplysia receptor’s DNA-binding domain (DBD) is highly similar to that of the vertebrate ERs but much less similar to those of other nuclear receptors, including the ERRs (Fig. 1A). Within the DBD, the P box, which mediates recognition of specific response elements by estrogen and other SRs (12), is identical only to that of the human ERs (Fig. 1B). The ligand-binding domain (LBD) of the Aplysia receptor is less conserved but is also most similar to that of the vertebrate ER. The Aplysia receptor’s AF-2 activation domain—a small region in the LBD that mediates ligand-regulated interactions with coactivators (13)—is nearly identical to that of the human ERs but not to those of the ERRs or other SRs (Fig. 1B).

The true test of orthology is phylogeny, so we analyzed the relations among 74 steroid and related receptors, including the Aplysia ER, using maximum parsimony (MP) and Bayesian Markov Chain Monte Carlo (BMCMC) techniques (11). Both methods (Fig. 2A) strongly indicate that the Aplysia sequence is an ortholog of the vertebrate ERs. The node indicating orthology with the vertebrate ERs is well supported, with a BMCMC posterior probability of 100%, a bootstrap proportion of 90%, and a decay index of 6. Although BMCMC probabilities can sometimes overestimate statistical confidence (14), a 90% bootstrap normally indicates confidence well over 95% (15). Further, the maximum likelihood of this phylogeny is >100,000 times greater than that of the best phylogeny in which the Aplysia receptor is placed outside the clade of SRs. As this phylogeny shows, the gene duplication that produced the first SR preceded the ancient divergence of deuterostomes (the superphylum that includes chordates and echinoderms) from protostomes (mollusks, arthropods, nematodes, anne-

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**Fig. 1.** The Aplysia ER protein sequence is most similar to that of human ERs. (A) Percent similarity of the Aplysia ER to steroid and related receptors of vertebrates and insects in the DNA- and ligand-binding domains. (B) Detail of sequences in the P box of the DBD, which mediates recognition of the core response element on DNA; in the AF-2 activation function of the ligand-binding domain, which is essential for ligand-activated transcription; and in the C-terminal extension (CTE) of the protein, with the length of the CTE in amino acids indicated. Dots show residues identical to those of Aplysia ER; an asterisk indicates the end of the coding sequence.