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Sparse Pre-Columbian Human Habitation in Western Amazonia

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Science **336**, 1429 (2012);
DOI: 10.1126/science.1219982

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Acknowledgments: The data reported in this paper are tabulated in the supplementary materials. This research was funded by NASA Lunar Science Institute contract NNA09DB33A (D.A.K.), NASA Cosmochemistry grant NNX11AG78G (G.R.H.), and NASA Cosmochemistry grant NNX08AH77G (K.N.). This is Lunar and Planetary Institute contribution number 1665. We thank the three reviewers for helpful comments and D. Mittlefehldt, J. Berlin, R. Jones, and H. McSween for sharing meteorite data sets.

Supplementary Materials
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25 January 2012; accepted 2 May 2012
Published online 17 May 2012;
10.1126/science.1219633

Sparse Pre-Columbian Human Habitation in Western Amazonia

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Locally extensive pre-Columbian human occupation and modification occurred in the forests of the central and eastern Amazon Basin, but whether comparable impacts extend westward and into the vast terra firme (interfluvial) zones, remains unclear. We analyzed soils from 55 sites across central and western Amazonia to assess the history of human occupation. Sparse occurrences of charcoal and the lack of phytoliths from agricultural and disturbance species in the soils during pre-Columbian times indicated that human impacts on interfluvial forests were small, infrequent, and highly localized. No human artifacts or modified soils were found at any site surveyed. Riverine bluff areas also appeared less heavily occupied and disturbed than similar settings elsewhere. Our data indicate that human impacts on Amazonian forests were heterogeneous across this vast landscape.

The Amazon Basin, an area approximately the size of the continental United States, is an important reservoir of biodiversity. A major recent question is the degree to which humans settled and modified Amazonian landscapes before European contact. It was initially thought that prehistoric Amazonia supported mainly small and highly mobile human populations, who exerted little impact on their environments (*1*, *2*), but recent work has documented dense and complex human settlements in eastern Amazonia and on the river bluffs of the central Amazon. The evidence includes the presence of highly modified soils such as terra pretas (anthropogenic "black earth") (*3*) and large-scale landscape alterations (Fig. 1) (*4*, *5–10*). The evidence is impressive, but comes largely from riverine environments with abundant natural resources, especially river bluffs, or the driest parts of the eastern Amazon (Fig. 1).

The extent of this impact on terra firme settings has been uncertain. The terra firme forests of the interfluvial zone occupy 95% of Amazonia and have less-fertile soils and poorer-quality resources (*11*). Available data from several regions suggest that the prehistoric impacts on interfluvial landscapes were heterogeneous and highly localized (*12, 13*). Here we reconstruct histories of fire, vegetation, and soil modification from charcoal, phytolith, and geochemical data recovered from 247 soil cores collected from 55 locations, including sites with known impacts, across 3,000,000 km^2 in western Amazonia (Fig. 1 and table S1) (*14*). We sampled soils from sites where the probability of past disturbances was high, such as river bluffs with known archaeological histories and nearby terra pretas, including Tefe, Barcelos, and Iquitos; from a previously unstudied river bluff at Los Amigos; and from terra firme sites, including Acre, Iquitos, Tefe, and a transect from Porto Velho to Manaus (PVM).

Natural fires in Amazonia are rare today (*15–17*), but fire was a mainstay of prehistoric land use in the tropics (*11, 18, 19*). Consequently, charcoal recovered from soils can provide evidence of past human disturbances, and phytoliths, which document mature and disturbed vegetation, reflect the intensity of those occupations. In our samples, charcoal was most common in soils from riverine bluffs, especially in the central basin (Fig. 2, C to F). At Barcelos and Tefe, charcoal was present in many intervals in most cores, especially from 0 to 40 cm (Fig. 2, D and F). Charcoal dates ranged from ca. 500 to 2700 calendar years before the present (cal yr B.P.) at Tefe and from ca. 1200 to 1300 cal yr B.P. at Barcelos (table S2). The vegetation at Tefe appears to have been more heavily affected than that at Barcelos, which is in agreement with the

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longer span of documented occupation. In riverine settings, Tefe soil phytoliths contained elevated amounts of early successional herbaceous taxa (ESH, such as grasses, *Heliconia*, and sedges) and some grass phytoliths that were burned. These patterns probably reflect forest clearing and other human disturbances (see phytolith analyses in the supplementary materials and fig. S1). However, neither site yielded crop phytoliths. Arboreal-dominated phytolith assemblages and relatively sparse charcoal from riverine Iquitos sites indicate that the forest remained relatively undisturbed there, and nutrients and black carbon concentrations in soils from these sites were low. At Los Amigos, the charcoal dates ranged from 1000 to 4000 cal yr B.P. (table S2), but the soils were not enriched in nutrients and arboreal taxa dominated phytolith assemblages, which is consistent with a light and shifting human impact (table S4, Fig. 2E, and fig. S1).

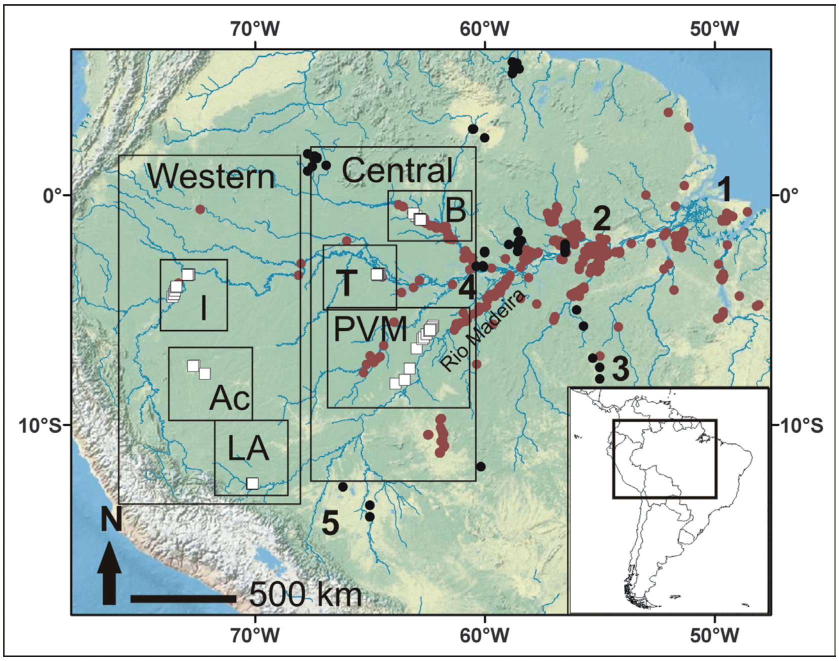

Fig. 1. Sampled locations within western Amazonia (white squares) in relation to major pre-Columbian archaeological sites (1, Marajó Island; 2, Santarém; 3, Upper Xingu; 4, Central Amazon Project; 5, Bolivian Beni), known terra preta locations (brown circles) (*3*, *32*, *33*), and soil charcoal survey locations (black circles) (*12*, *22*). Charcoal and phytolith data are presented from regions outlined in black (B, Barcelos; T, Tefe; PVM, Porto Velho-Manaus transect; I, Iquitos; Ac, Acre; LA, Los Amigos). The locations of Rio Madeira and associated terra pretas are shown. Here we define Amazonia as the region drained by the Amazon River and its tributaries.

We recovered little charcoal from soils at Acre or interfluvial Iquitos sites, indicating a lack of recurrent or extensive fires over the past several thousand years (Fig. 2, A and C, and table S2). Similar results were obtained from the phytolith records, which were dominated by forest taxa; ESH phytoliths were absent or rare (0 to 1%). No evidence for crops or burned phytoliths was found (fig. S1). Charcoal was more common in soils of the PVM transect than in the western interfluvial Iquitos or Acre sites (Fig. 2, A to C). However, phytolith records showed no signs of a significant human presence at most sites. ESH phytoliths were absent or scarce (0 to 6%), and burned tree phytoliths were nearly absent (Fig. 2B and fig. S1); forest taxa dominated in all samples. Site 121 contained evidence of maize cultivation and elevated frequencies of grass and *Heliconia* phyoliths, many of which were burned. No other crops, including squash (*Cucurbita* spp.), manioc (*Manihot esculenta*), arrowroot (*Maranta arundinacea*), and leren (*Calathea allouia*), were found. Because manioc produces fewer phytoliths than many other crops, we cannot state with the same confidence that it was not grown nearby.

We found no prehistoric ceramics, stone tools, or terra pretas in any of the 247 soil cores, and none of 184 samples analyzed for phytoliths contained evidence of intensive or persistent forest clearing. In many soil levels, no ESH phytoliths were observed in scans of >500 to 1000 additional phytoliths, underscoring the lack of disturbance that took place in these interfluvial forests. Together, the data suggest that human population densities in the sampled regions were low and highly localized, and were not consistent with major population centers with associated areas of widespread, extensive agriculture (*20*). Our data support the idea that humans had much less impact on interfluvial forests than on riverine environments (*21*) or in the drier eastern forests (*22*). However, even regions with known human sites and terra pretas (such as Barcelos and Tefe) were not subjected to continuous or large-scale forest clearing or intensive agriculture (Fig. 2), and show a lesser disturbance signature than found in modern slash-and-burn systems (see phytolith analyses in the supplementary materials). Forest clearings were probably small and short-lived, and the interior forests were apparently not permanently or intensively occupied by humans in prehistory. We found little indication that repeated fire, vegetational disturbance, and/or agriculture extended more than 5 km into the terra firme forests of the Tefe, PVM, Acre, and Iquitos regions (Fig. 2).

Our data imply that the disturbance signature was stronger in both riverine and interfluvial forests of the central basin than in the western basin (Fig. 2). Even in the PVM transect, however, evidence for disturbances was patchy and localized, despite being located 20 to 50 km from the Madeira River and within 100 to 200 km of dense concentrations of terra pretas (*23*) (Fig. 1). The frequency and distribution of terra pretas documented along the Madeira River (*24*) may have continued southward, parallel to our interfluvial transect. The resulting contrasting pattern of highly concentrated terra preta soils along the river, with localized and patchy disturbance 20 to 50 km into the uplands, illustrates how even in the central Amazon, intensive landscape modifications appear to be confined to near-riverine locations.

We interpret the charcoal presence along with low frequencies of burned tree phytoliths, and the dominance of forest over grass phytoliths, to mean that fires were mainly confined to the forest floor. The apparently infrequent and low-intensity fires do not appear to have penetrated canopies and altered forest structure substantially at most sites. Therefore, soil charcoal alone should not be taken to mean that fires were of sufficient intensity and duration to cause canopy disruption and major forest alteration [see also (*12*)].

It is likely that in some forests, edible or other useful fruit trees were planted or managed, resulting in an enrichment of those species (*25*). Palms such as peach palm (*Bactris gasipaes*) and *Astrocaryum* are economic mainstays in the Amazon and are prolific phytolith producers. We found no evidence for these species in most samples from every site studied (fig. S1 and palm distributions in the supplementary materials). There was no association between palm phytolith frequencies and other evidence of vegetation disturbance, and palm frequencies were never so high that they implied that a local grove was present. These data suggest that humans were not cultivating or selectively managing palms at most of our study sites. There was also no indication that many noneconomic species were selectively removed (*26*), because little change in forest composition was seen from the bottom to the top of the soil cores, including when early successional herbaceous taxa and/or charcoal were present.

Our data imply that the terra firme forests we studied in the western Amazon Basin were

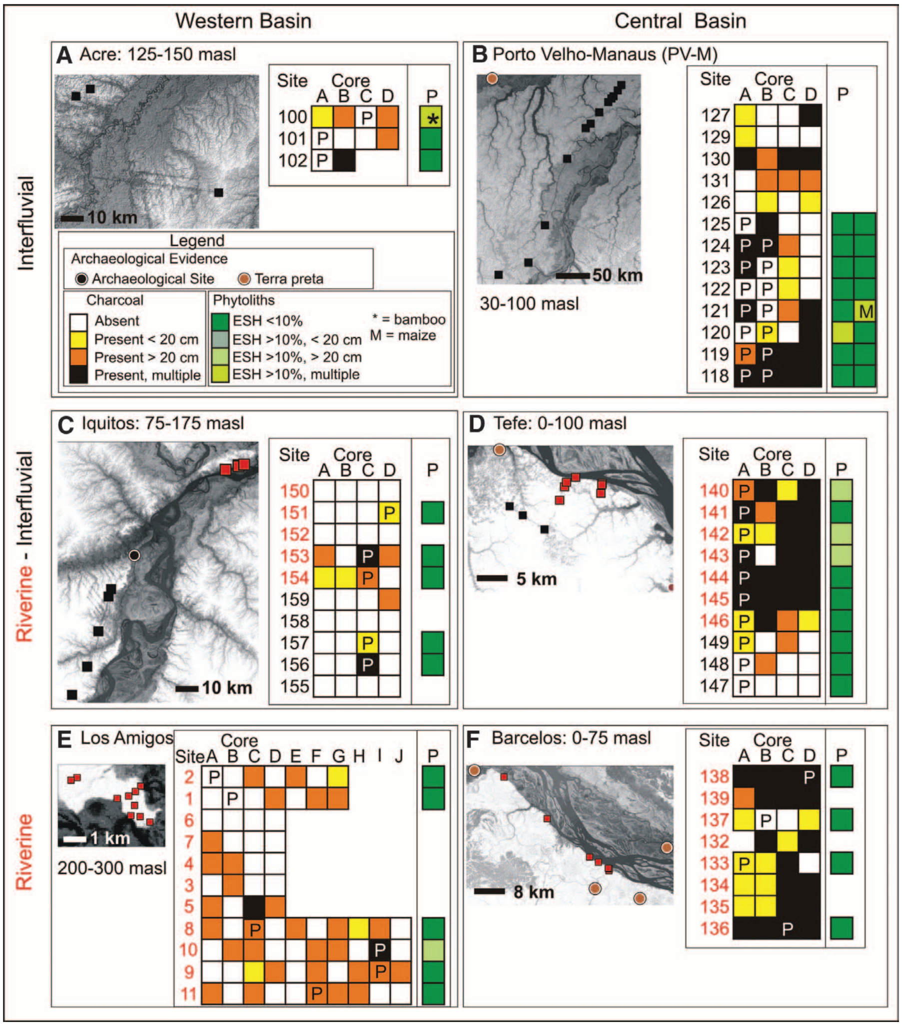

Fig. 2. Regional maps, soil charcoal distributions, and phytolith percentages for soil cores from riverine (red squares and text) and interfluvial (black squares and text) sites in each region: Acre (**A**), PVM (**B**), Iquitos (**C**), Tefe (**D**), Los Amigos (**E**), and Barcelos (**F**). Areas of lower (darker) and higher (lighter) elevations illustrate drainage and rivers (from 90-m–resolution data from the Shuttle Radar Topography Mission) on each regional map. Colored boxes indicate charcoal results for each core within each site (see legend). Sites are listed in a north-to-south orientation. Soil cores with accompanying phytolith data are denoted with P. Phytolith percentages (column P) are listed to the right of the charcoal results. Geographic coordinates of all sites are provided in table S3.

predominantly occupied by relatively small and shifting human populations during the pre-Columbian era. This has many implications for hypotheses about human effects on Amazonian forests. First, humans may have augmented the alpha-diversity of some Amazonian landscapes, but the hyperdiverse floras and faunas are more a product of long-term evolutionary and ecological processes (*27*) than anthropic landscape alteration (*4*, *26*, *28*–*30*). Second, to the extent that prehistoric deforestation occurred, it was apparently primarily in the eastern Amazon, and this may have limited the proposed impact of post-Columbian population collapse and reforestation on atmospheric CO_2 and CH_4 levels (*18*, *31*). Third, we cannot assume that Amazonian forests were resilient in the face of heavy pre-Columbian disturbance, because vast areas were probably never heavily disturbed. Prehistoric peoples settled most densely in habitats where resources were abundant and easily captured, fertile soils were available, and transportation routes were nearby, making ecological factors important in pre-Columbian settlement patterns.

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Acknowledgments: Field work and ^{14}C dating of charcoal fragments were funded by the NSF Ecology Program (awards DEB 0742301 and DEB 0743666). Other funding was provided by the Florida Institute of Technology; the Smithsonian National Museum of Natural History, including a Restricted Endowment and Small Grant Award; and the Smithsonian Tropical Research Institute. All data will be deposited in the Neotoma Database (www.neotomadb.org/). We thank B. McMichael, A. Correa-Metrio, J. Hernandez, T. Harrison, and B. Rado for field assistance.

Supplementary Materials

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2 February 2012; accepted 16 April 2012
10.1126/science.1219982

www.sciencemag.org/cgi/content/full/336/6087/1429/DC1

Supplementary Materials for

Sparse Pre-Columbian Human Habitation in Western Amazonia

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Published 15 June 2012, *Science* **336**, 1429 (2012)
DOI: 10.1126/science.1219982

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Materials and Methods

Design and sampling

We carried out randomized soil sampling from directly beneath existing vegetation in interfluvial forests, along transects totaling c. 650 km, including surveys extending from Porto Velho to Manaus, Brazil (450 km), Tefe (10 km), Iquitos to Nauta, Peru (75 km), and near Cruzeiro do Sul in Acre, Brazil (75 km). As a comparison, river bluff and other near-riverine situations in Los Amigos, Peru (c. 25 km2), Tefe (c. 50 km2) and Barcelos, Brazil (60 km transect) were sampled. To create a more comprehensive fire history, we implemented stratified soil sampling for reconstructions (e.g. 34). The overall sampling area, delineated as areas of Amazonia west of 60°W (e.g. 35), was divided into two main components, termed the western and central basins (Fig 1, Table S1). One riverine region (within 5 km of a major river), one interfluvial region (> 5 km from a river), and region containing both riverine and interfluvial sites were selected in each basin (Fig. 1 and Table S1). Within each region, 3-13 randomly located sites were sampled, and multiple soil cores (3-10) were randomly collected within a 100m radius of the selected GPS point for each site to account for the inherent variability in post-fire charcoal deposition across the forest floor (36-38). Samples were collected during the boreal summers (June-August) from 2008 – 2010. A priori site criteria were established that sampling locations must be located on relatively flat terrain where erosion and depositional processes would be minimal, and contain no evidence of recent disturbance.

Site descriptions

Western Sites

Los Amigos was selected as river bluff sampling regions within the western basin. Los Amigos is located approximately 120 km upriver from Puerto Maldonado at the confluence of the Madre de Dios and Los Amigos Rivers and only accessible by boat. The sampling area was the research station boundaries, and all sites were within 3 km of the Madre de Dios River. The c. 50 km^2 of forests surrounding the research station contain typical closed-canopy elements that receive 2700-3000 mm precipitation per year with a 3-5 month dry season (precipitation less than 100 mm per month) (2000-2006 data) (*39*).

Sample sites at Iquitos, which lies in the Peruvian state of Loreto and is only accessible by boat or airplane, included river bluffs locations on the main Amazon River channel north of the city. Interfluvial forest samples were collected at least 100 m off the road extending southward from Iquitos to the small village of Nauta. Lake Quistococha, an archaeological site ca. 10 km south of Iquitos and ca. 20 km north of Site 159, contains artifactual evidence of occupation from 1300-2500 cal yr BP (*40*). The soils immediately around the archaeological site were not black, and therefore not *terra pretas*, but contained levels of pottery sherds. The soils outside of the bluff overlooking Lake Quistococha contained no evidence of disturbance. Iquitos typically receives 3400 mm/yr^{-1} with basically no dry season (1999-2005 data) (*41*).

The Acre region was selected as interfluvial forest sampling locations within the western basin. Sites were randomly located around the city of Cruzeiro do Sul. Bombacaceae are common in all Acre forests (*42*), and Caesalpinaceae, Moraceae, Mimosaceae, Meliaceae, and Apocynaceae are the most abundant families in the 10 ha Rio Branco permanent vegetation plot containing c. 133 species per hectare (*43*). Annual rainfall is c. 1900 mm/yr^{-1}, and the dry season lasts from May to September and is most severe (i.e. < 60 mm per month) during June, July and August (*44*).

Central Sites

Barcelos and Tefe, located in the central basin, contain nearby *terra preta* and have a known archaeological history (*23, 33*). Barcelos is situated on the Rio Negro midway between Manaus and Sao Gabriel da Cachoeira, and is only accessible by boat or small plane. All sampled sites were located on bluffs overlooking the Rio Negro. Barcelos receives 2500 mm/yr^{-1} precipitation per year, with a dry season from January to March (*45*). Tefe is located on the southern side of the Amazon River, and is only accessible by boat or small plane. Similarly to Iquitos, sampling was conducted both atop river bluffs and in the interfluvial forests (> 5 km from the river) alongside roads heading south of the city to examine within-region variation. Tefe receives ca. 2500 mm/yr^{-1} precipitation, with a dry season lasting from July to September (*46*).

The Porto Velho – Manaus transect (PV-M) region was selected as an interfluvial forest sampling location within the central basin. Sites were randomly located along BR-319, constructed in 1972-1973 which ran from the cities of Porto Velho to Manaus, but became impassible in 1988 (e.g. *47*). Sample sites were required to be at least 500 m from the road itself. *Terra preta* and archaeological sites concentrated along the Rio Madeira are ca. 60 km east of the northernmost sites in the sampled transect. Annual rainfall in the region ranges from 1800 - 3500 mm/yr^{-1}, and a dry season of June through September with precipitation levels < 50 mm month (*48*).

Field sampling

All soil cores were collected with a 10 cm diameter AMS Soil Sampling hand auger in 20 cm depth increments to total depths of 80 cm at Acre, PV-M, Barcelos, Tefe, and Iquitos, and in variable depth increments, usually 7 to 20 cm, to total depths ranging from 50-120 cm at Los Amigos. Leaf litter and debris were cleared from the soil surface before augering to prevent modern material from falling into the core. Any surface debris falling into the soil core made between drives of the auger was removed by hand. Samples from each depth interval were individually bagged and labeled, and each site was georeferenced with a Garmin 60 csx GPS. All depth increments of all cores were analyzed for soil charcoal, and randomly selected cores from each site were analyzed for phytoliths.

Charcoal analysis

Amazonian soils contain several components that resemble charcoal but are actually minerals. Although charcoal can be visually distinguished from minerals with a stereoscope, we confirmed that our visual identification of charcoal fragments was accurate. Approximately 20 particles of small, black, shiny soil components, 10 believed to be charcoal, 10 believed to be minerals, were analyzed under an SEM-EDAX at Florida Institute of Technology. EDAX (energy dispersive x-ray spectroscopy) is an analytical technique used to identify chemical composition of specific substances. EDAX analysis revealed that our visual identifications of charcoal were 100% accurate and that the other similarly sized and colored particles were manganese-based minerals.

Soils were volumetrically measured in water, deflocculated with 3% hydrogen peroxide, wet sieved to 500 µm and analyzed for charcoal particle surface area (mm^2/cm^3) using Image J software. Surface area per charcoal particle was converted to volume (mm^3/cm^3) to down-weight the smaller fragments (*49*). Charcoal abundances were calculated for each depth interval of each core. Selected fragments of charcoal were ^{14}C AMS dated at NOSAMS Laboratory and the ages calibrated using the Fairbanks et al. (*50*) calibration curve to provide temporal frameworks for historical fires.

Soil charcoal abundances cannot accurately reflect certain fire parameters, such as intensity, but clearly indicate fire presence (e.g. *38, 51*). However, Type I error (i.e. false positive) may result from increased weathering and migration rates of charcoal particles through the soil profile (e.g. *52, 53, 54*) or from long distance transport of charcoal from more regional sources (e.g. *55*). To account for the potential of Type I error, charcoal abundance measurements for each depth interval (mm^3/cm^3) of each core were classified as trace amounts ($< 0.25\ mm^3/cm^3$) or significant charcoal (hereafter referred to as 'present' charcoal) ($> 0.25\ mm^3/cm^3$). Trace values include a several tiny particles ca. 500 µm in size found within samples, and abundances designated present usually contained enough carbon for ^{14}C AMS dating, and interpreted as an in situ fire event.

Phytolith Analyses

Like macroscopic charcoal, phytoliths--the silica bodies produced by many Neotropical plant species--are deposited locally and can be used to identify different types of vegetation such as old-growth forest, early successional growth typical of human disturbance, and crop plants (*19, 56, 57*). They directly document the intensity of vegetation disturbance when charcoal is present. Fires also leave diagnostic records in the form of charred but still morphologically identifiable phytoliths that document ignition of both woody and non-woody taxa (*56*).

Phytoliths were extracted from soils using standard laboratory techniques (*56*). Identification was based on Piperno's modern reference collection comprised of over 2000 species of tropical plants. Phytolith content was high in virtually all soil samples. Percentages of five phytolith categories named forest taxa, Arecaceae (palms), early successional herbaceous taxa (grasses, *Heliconia* – referred to as ESH phytoliths in the main text), burned arboreal taxa, and burned herbaceous taxa were calculated for each depth interval of randomly selected soil cores (*N* = 8 sites and 50 samples at Porto Velho to Manaus; 10 sites and 39 samples at Tefe; 4 sites and 16 samples at Barcelos, 6 sites and 24 samples at Iquitos, 6 sites and 30 samples at Los Amigos, 3 sites and 25 samples at Acre). At least 100 phytoliths were counted for each sample followed by extended scanning of from 500 to 1000 phytoliths of each slide to confirm presence/absence and frequency of different phytoliths. The category forest taxa included a number of different kinds of phytoliths. Many were globular to oval types with characteristic surface features of different kinds that are produced in the leaves, trunk, and twigs of various trees and shrubs (e.g., Bombacaceae, Burseraceae, Chrysobalanaceae, Moraceae, Lauraceae, Sterculiaceae, Guttiferae, Fabaceae, Meliaceae, Proteaceae) (*56, 58, 59*). They are excellent indicators of lowland tropical forest cover and density in the New and Old World (*56*). Other kinds of phytoliths found in trees, such as faceted forms diagnostic of a few Annonaceae genera (*Guatteria*) and irregular shapes characteristic of the bark of a number of families routinely occurred. An important point is that phytoliths in the arboreal category predominantly derive from taxa of old/mature forest not early secondary woody growth (*56*). Diagnostic phytoliths from understory plants of little disturbed forest canopies such as the bamboos *Streptochaeta* and fern *Trichomanes* also were present (*56*). Unidentified phytoliths also characteristic of old growth forests in modern phytolith assemblages were frequently observed (*56*).

Arecaceae (palm) phytoliths were quantified separately from the category forest taxa in order to assess whether human disturbances were associated with palm increases, possibly from deliberate management and manipulation of palms as some researchers have suggested (*4, 60*). The Arecaceae are prolific phytolith producers, occurring in high numbers in all structures of the plants, including leaves, trunk, petioles, and fruits (*56*). Identification to the family is readily made on the basis of shape and surface characteristics, and although genus and species-specific determinations aren't usually possible, individual palm genera are marked by the presence of either conical-shaped (e.g., *Bactris gasipaes* [the peach palm], *Astrocaryum*) or spherical (e.g., *Attalea, Euterpe, Oenocarpus*) phytoliths (*56, 61*).

Presence of cultivars provided direct evidence of agriculture. Crop plants known or thought to have been grown in Amazonia during the pre-Columbian period that have identifiable phytoliths include: maize (*Zea mays*), squashes of different species (*Cucurbita moschata*, *C. maxima*), and the root crops manioc (*Manihot esculenta*), leren (*Calathea allouia*) and arrowroot (*Maranta arundinacea*) (*56, 62*). All with the exception of manioc and some varieties of the squashes produce phytoliths in abundant quantities in leaves (maize, arrowroot, and leren), culms (maize), seeds (arrowroot and leren), cobs (maize), fruit rinds (squashes) and subterranean organs (arrowroot and leren). The production of different, diagnostic phytoliths in more than one structure of a crop plant increases the likelihood of recovering them from ancient soils. Manioc produces a single type of phytolith in few numbers in its leaves, making it of lesser visibility than the other crops. Some of the major fruit species in question do not leave a phytolith record (e.g., *Bertholletia excelsa* [Brazil nut] and *Theobroma grandiflora* [wild cacao].

Increases of grass phytoliths, especially from the sub-families Panicoideae and Chloridoideae, along with phytoliths from the early successional herb *Heliconia* that often was present along with Panicoid and Chloridoid grasses (hereafter PC phytoliths), provide indirect evidence for forest clearance associated with human activities, as these taxa are typical of re-growth vegetation in and on the edge of cultivated fields and habitation areas. We also used modern phytolith records from modern fields in Panama that were recently planted in maize and manioc by slash and burn methods, together with lake sediment data from Panama and Brazil to assess the significance of burned arboreal phytoliths recorded in our transect samples. For example, in the modern slash and burn fields, frequencies of burned arboreal phytoliths often ranged between 30% and 70%. In lake sediment cores from Brazil and Panama dating to between 7600 and 3000 BP where persistent slash and burn agriculture was indicated in pollen and phytolith records, frequencies of burned arboreal phytoliths were between 15% and 20% (*11, 56, Fig. 6.4*). It should be noted that the lake sediment values are likely to have be diluted because areas of the watershed not under slash and burn cultivation also contributed to the records. Even when burned phytoliths were observed in the regions surveyed for this study, their frequencies were much lower than found in modern slash and burn fields planted in maize and manioc, and in the lake sediment cores.

Phytolith Dating

Phytoliths in selected cores and depths were directly dated by ^{14}C AMS at Beta Analytic Laboratory, Miami, Florida using techniques explained in Piperno (*56*). It is not possible to date a single or a few phytoliths as it is to a date a small charcoal fragment or fragments representing a discrete moment of time. Therefore, a ^{14}C phytolith age represents the mean age of all the phytoliths present in a particular soil assemblage and is a mixture of phytoliths of somewhat different ages. For this reason, it is unrealistic to expect very close dating conformity between charcoal and phytoliths. It is nonetheless clear from phytolith dating in this and other Amazonian soil research (*12, 13*) that phytolith records span at least the last several thousand years of vegetation history.

Soil Geochemistry

Soil geochemistry, including total organic carbon (TOC), pyrogenic carbon (black carbon, BC), phosphorus and calcium levels were used to indicate human presence such as settlement sites or agriculture. Both TOC and BC can be indicative of anthropogenic enrichment of soils and agricultural burning, respectively. Total phosphorus (P) has been used to detect anthrosols, particularly settlement sites (*63*) and exchangeable Ca is one characteristics often associated with *terra preta* (*64*).

Soils were analyzed, in triplicate, for BC content using chemical and thermal treatment to remove non-BC OM followed by C analysis (modified from *65*). Chemical treatment consisted of two additions of 8 ml 1 M NaOH to 4 g finely ground dried soil, followed each time by 15 min. sonication, centrifugation and removal of supernatant. Similar treatments with 70% HNO_3, 1M NaOH (5 times), 1% HCl, and nanopure water (2 times) followed. After drying, ~0.4 g of the residual sample was heated at 340 °C for 60 min. in 5 mL glass beakers under pure oxygen atmosphere (flowing 500 mL min^{-1}) leaving only BC. Both TOC, after inorganic C removal via HCl fuming, and isolated BC were analyzed in duplicate (with only <5% relative error accepted) on a Carlo-Erba NA-1500 CHS Elemental Analyzer.

Total P in soils was measured following method AOAC 985.01 (dry ashing 4 h at 500 ^{o}C then acid digestion using both HCl and nitric acid) whereas exchangeable Ca was obtained using a standard Mehlich 1 extraction. Concentrations of both these ions were measured using a Spectro Ciros CCD inductively coupled plasma spectroscope.

Supplementary Text

The Interfluvial Forests

Little charcoal was recovered from Acre, and a single date of ca. 1900 cal yr BP was obtained. Phytoliths shows forest-dominated taxa throughout the soil profiles except in core 100C, in which grass percentages exceeded 10% (Fig. 2A), but the composition of those grasses were mostly bamboos as opposed to those typically associated with human disturbance. In Iquitos, a diversity of forest taxa dominated (> 90%) in all cases, no crop phytoliths occurred, and no phytoliths exhibited evidence of charring (Fig. 2C). No ESH phytoliths were observed in any soil level in extended scans of 1000 additional phytoliths. The little datable charcoal recovered provided ages of 1000 and 2600 cal yr BP (Table S2).

Prehistoric charcoal dates at PVM ranged from ca. 500-3800 cal yr BP, with the majority occurring from ca. 800-1300 cal yr BP (Table S2). The upper 20 cm of soil often contained charcoal of modern origin and in sites 120 and 126, all charcoal dated was modern, showing fire had recently penetrated these forests. With the exception of a 519 BP age from Site 130, no charcoal dated to the last 400 to 500 years of prehistory. Five phytolith preparations were directly dated from sites 124 and 121 from the PVM transect (Table S2). As in soils studied from other Amazonian localities (29, 30), the phytoliths document at least the last several thousand years of vegetation history with stratigraphic trends through time also evident, as at Site 124 phytoliths in the lowest level were far older than those in the uppermost soils. Dates on phytoliths from three levels of Site 121 yielded approximately contemporaneous ages of from ca. 4700 to 4200 cal yr BP, likely reflecting soil mixing that occurred when cultivation was practiced.

Heterogeneous disturbances were found in the PVM transect. Of the 13 cores at PVM containing little disturbance, most samples contained no ESH phytoliths even in extended scans of 500-1000 additional phytoliths, underscoring again how little disturbance appears to have taken place in these interfluve forests. Maize leaf phytoliths occurred in core 121B at 20-40 cm. In 121B and 120A, frequencies of ESH grasses were elevated in soil levels between 0 and 40 cm, achieving maximum percentages of 21 and 12%, respectively. These were predominately from the Panicoideae and Chloridoideae sub-families, which are especially characteristic of human clearings in tropical forest. Burned PC and other grass phytoliths were also high at these sites between 0 and 40 cm, reaching frequencies of between 30 and 70% and *Heliconia* was often observed in extended scans. Forest taxa phytoliths still dominated (usually > 80%) throughout these profiles and burned tree phytoliths were absent to rare. Phytoliths from other crops known to have been grown in Amazonia such as the root crops manioc (*Manihot esculenta*), arrowroot (*Maranta arundinacea*) and leren (*Calathea allouia*), and squash were absent in these cores as in the PVM sites showing no disturbance.

<u>Areas Closer to Rivers</u>

Los Amigos charcoal recorded fire events ranging from 1000-4000 cal yr BP, but overall has a weaker fire signal than Tefe and Barcelos, which have known archaeological histories and nearby *terra preta*. Phytoliths contain no evidence of persistent canopy openings or agriculture (Fig. 2E). Soil geochemistry at Los Amigos is similar to that found at Quistococha, Peru and at previously reported western Amazonian sites (*12*), and contained no evidence of soil modifications or enrichment (Table S4). Two of five sites in the Iquitos riverine transect contained charcoal in almost all cores, with a prehistoric date of 2600 cal yr BP. The other three sites contain little to no charcoal (Fig. 2C).

Charcoal fragments from Barcelos and Tefe dated in the upper 20 cm revealed both modern and historic fire (Figure 2D and F, Table S2). Prehistoric fires between ca. 500 and 2700 cal yr BP had no temporal clustering at Tefe, but most dates at Barcelos ranged from 1200-1300 cal yr BP. Even with many fires across the landscape during this interval, ESH phytoliths were not observed in most cores from Barcelos and burned phytolith percentages occurred between 3 and 12%. This evidence indicates that recurrence rates of most fires were not sufficient to persistently open the forest canopy or change forest structure. At Tefe an increase of ESH phytoliths (to 12% -15%) in three of the seven cores collected within 5 km of the river bluffs. Burned grass phytoliths occurred in most cores at elevated frequencies ranging from 9-33% . Crop plants were absent, however, and burned arboreal phytoliths were absent or occurred in very low frequencies (maximum, 3%). The interfluvial sites contained a much weaker disturbance signature, soil cores had low levels of ESH phytoliths (range: 0- 9%), and the dominance (>87%) of forest taxa phytoliths. These low-disturbance percentages are similar to those seen in the riverine sites near Barcelos, which also contain nearby *terra preta*.

<u>Palm Distributions</u>

The overall absence of conical palm phytoliths is a strong indication that the genera *Bactris* and *Astrocaryum* were not present at the sampling localities. Only three soil samples contained a fairly significant number of phytoliths that could possibly (but not definitively) derive from these species (11% at Tefe 145, 0-20 cm, located little more than 1 km from the bluffs), and Iquitos 157, 0-20 and 20-40 cm (15% and 12%, respectively) (Fig. S1). At the Puerto Velho to Manaus transect, 47 out of 50 samples including six sites in their entirety (120-125) lacked these phytoliths, and they occurred in amounts ranging from 1% to 3% in three sample levels (118 A and B, 20-40 cm; 119 A, 20-40 cm). At the Tefe transect, these phytoliths were absent from 33 out of 39 samples and five sites. They occurred in percentages ranging from 1% to 2% at Site 144, 0-20 and 40 cm; 146, 0-20 cm, and 147, 0-20cm. At Barcelos, the phytoliths were absent from 12 out of 16 samples. They occurred in percentages of 1% at 133 A, 0-20 cm and 138 D, 20-40 cm (two other samples did not possess sufficient phytolith quantity for assessment).

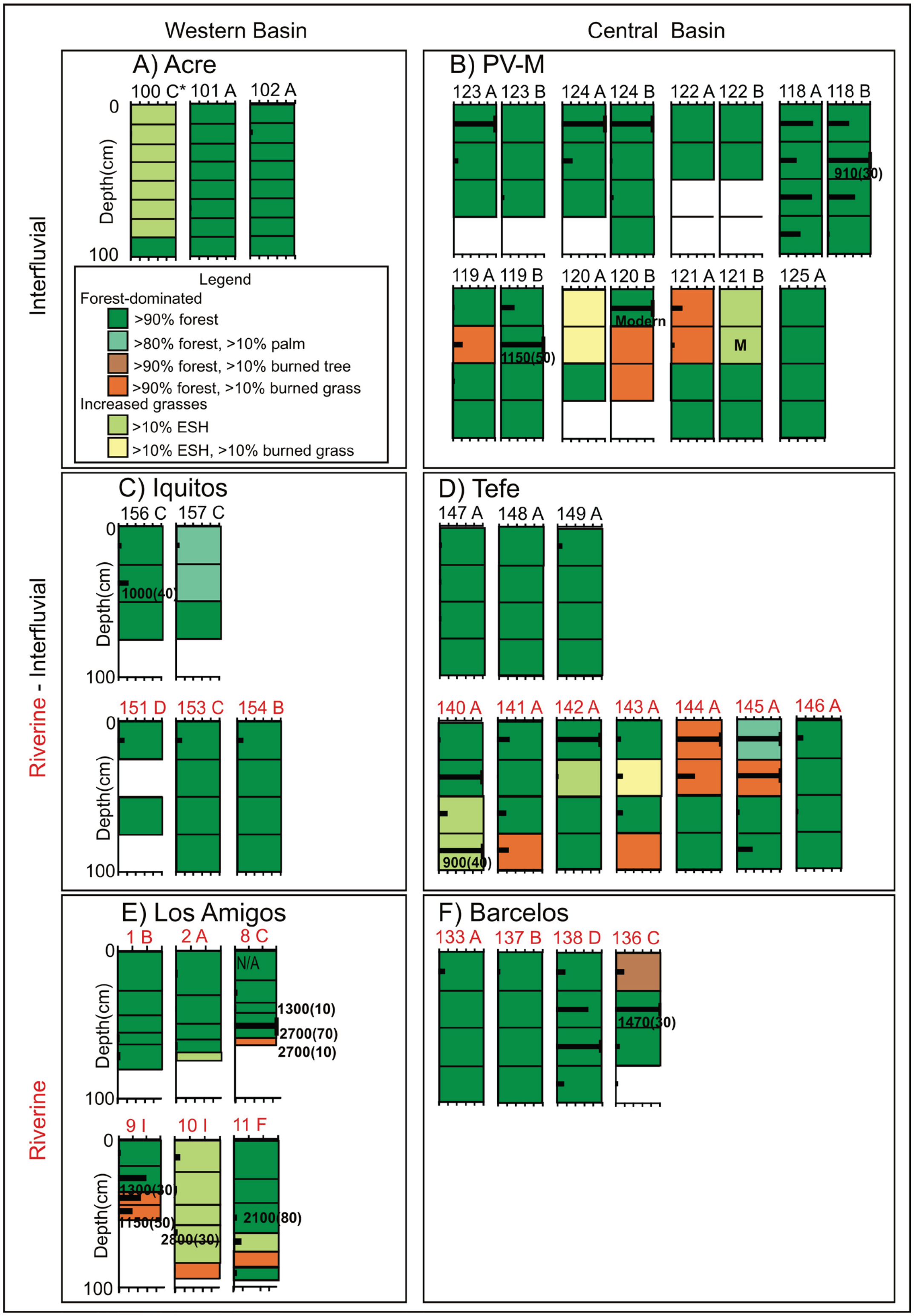

Fig. S1.

Phytolith results from cores within each region. ^{14}C AMS dates are listed in core and depth interval where charcoal fragment was recovered (see Supplementary Online Text for descriptions of phytolith categories). * in Acre 100C denotes that grass increases are due to almost entirely to bamboo taxa instead of Panicoid or Choloridoid grasses. Black bars indicate charcoal abundances (mm^3/cm^3) for each depth increment. Horizontal black bars on charcoal abundances indicate where abundance exceeds the maximum value of the axis ($5mm^3/cm^3$).

Table S1.

Sampling design, including the regions within each basin, the number of sites within each region (N sites), and the number of cores within the region (N cores).

Basin	Region	forest type	N sites	N cores
western	Acre	I	3	10
	Iquitos	I/R	10	40
	Los Amigos	R	11	74
central	Porto Velho-Manaus	I	13	52
	Tefe	I/R	10	40
	Barcelos	R	8	31
	totals		**55**	**247**

I = Interfluvial
R = Riverine

Table S2.

^{14}C AMS dates for individual charcoal fragments and phytolith assemblages (phyto.). All dates were calibrated using Fairbanks (2005) calibration curve, with the median age and one-sigma level reported. N/A indicates calibration was not possible because of young age.

Region	basin	forest type	Site	Core	Depth (cm)	14C Age	Age Error	Cal age	std dev
Acre	west	interfluve	102	B	55-60	1970	30	1912	32
Barcelos	central	riverine	132	A	0-20	140	30	N/A	
Barcelos	central	riverine	133	B	0-20	>Modern			
Barcelos	central	riverine	136	A	0-20	1380	25	1294	11
Barcelos	central	riverine	136	C	20-40	1470	25	1351	22
Barcelos	central	riverine	138	C	20-40	1290	25	1241	34
Barcelos	central	riverine	138	C	40-60	1310	30	1259	29
Barcelos	central	riverine	138	C	0-20	1150	25	1051	33
Iquitos	west	riverine	153	D	60-80	2490	30	2599	88
Iquitos	west	riverine	154	B	0-20	95	30	N/A	
Iquitos	west	interfluve	156	C	20-40	1110	30	1006	37
Los Amigos	west	riverine	2	E	29-40	>Mod			
Los Amigos	west	riverine	5	C	39-51	1360	25	1287	10
Los Amigos	west	riverine	5	D	69-82	3900	50	4341	80
Los Amigos	west	riverine	8	C	37-44	1380	25	1294	11
Los Amigos	west	riverine	8	C	44-62	2540	35	2686	67
Los Amigos	west	riverine	8	C	62-67	2620	30	2744	12
Los Amigos	west	riverine	8	G	45-52	2130	30	2114	53
Los Amigos	west	riverine	8	H	46-54	2250	30	2277	57
Los Amigos	west	riverine	9	F	49-57	3540	30	3830	44
Los Amigos	west	riverine	9	I	44-55	1220	30	1147	48
Los Amigos	west	riverine	9	I	36-44	1360	45	1285	26
Los Amigos	west	riverine	9	J	34-44	2500	25	2616	80
Los Amigos	west	riverine	10	B	50-58	3110	30	3341	29
Los Amigos	west	riverine	10	F	57-75	1850	35	1788	47
Los Amigos	west	riverine	10	G	16-27	2510	30	2637	83
Los Amigos	west	riverine	10	I	58-70	2730	30	2814	33
Los Amigos	west	riverine	11	C	60-83	2570	30	2721	31
Los Amigos	west	riverine	11	C	83-99	2530	35	2671	75
Los Amigos	west	riverine	11	F	43-64	2140	45	2130	76
Los Amigos	west	riverine	11	G	32-50	1470	30	1351	26
Porto Velho	central	interfluve	118	B	20-40	980	25	910	30
Porto Velho	central	interfluve	118	C	0-20	890	25	797	45
Porto Velho	central	interfluve	118	C	40-60	1130	25	1028	33
Porto Velho	central	interfluve	119	B	20-40	1230	30	1162	48
Porto Velho	central	interfluve	120	B	0-20	>Modern			
Porto Velho	central	interfluve	120	B	0-20	>Modern			
Porto Velho	central	interfluve	121	D	0-20	1300	35	1248	38
Porto Velho	central	interfluve	123	C	0-20	3530	25	3818	41
Porto Velho	central	interfluve	124	C	20-40	5	25	N/A	
Porto Velho	central	interfluve	124	C	60-80	>Modern			

Porto Velho	central	interfluve	126	B	0-20	>Modern			
Porto Velho	central	interfluve	130	A	40-60	1910	30	1855	31
Porto Velho	central	interfluve	130	A	20-40	930	30	851	50
Porto Velho	central	interfluve	130	A	0-20	490	30	519	12
Puerto Maldonado	west	interfluve	9	9	42-53	>Mod			
Puerto Maldonado	west	interfluve	34	34	20-33	125	30	N/A	
Puerto Maldonado	west	interfluve	34	34	54-80	>Mod			
Puerto Maldonado	west	interfluve	70	70	64-78	2940	35	3096	65
Tefe	central	riverine	140	A	60-80	970	25	901	36
Tefe	central	riverine	141	B	60-80	1970	50	1914	53
Tefe	central	riverine	143	D	0-20	430	25	497	13
Tefe	central	riverine	144	B	0-20	>Modern			
Tefe	central	riverine	144	B	40-60	2580	30	2727	23
Tefe	central	riverine	145	B	40-60	1700	30	1597	44
Tefe	central	riverine	145	B	0-20	75	25	N/A	
Tefe	central	riverine	146	B	20-40	470	30	512	11

Table S3.

Geographic coordinates (in decimal degrees) of sampled sites.

Region	Site	lat	long
Acre	100	-7.4073	-72.6406
Acre	101	-7.43281	-72.6916
Acre	102	-7.77622	-72.1791
Barcelos	137	-0.91602	-62.9703
Barcelos	138	-0.79413	-63.0966
Barcelos	139	-0.804	-63.1044
Barcelos	132	-1.02848	-62.8463
Barcelos	133	-1.04424	-62.82
Barcelos	134	-1.06146	-62.7916
Barcelos	135	-1.0631	-62.7883
Barcelos	136	-1.069	-62.7893
Iquitos	150	-3.44428	-72.8504
Iquitos	151	-3.4519	-72.8756
Iquitos	152	-3.445	-72.8785
Iquitos	153	-3.46813	-72.9302
Iquitos	154	-3.4635	-72.9327
Iquitos	155	-4.42094	-73.5859
Iquitos	156	-4.30236	-73.5216
Iquitos	157	-4.1511	-73.4738
Iquitos	158	-4.0034	-73.4305
Iquitos	159	-3.97213	-73.4193
Los Amigos	1	-12.5639	-70.0987
Los Amigos	2	-12.5632	-70.1039
Los Amigos	3	-12.5576	-70.102
Los Amigos	4	-12.567	-70.0931
Los Amigos	5	-12.5423	-70.1341
Los Amigos	6	-12.5441	-70.1376
Los Amigos	7	-12.5539	-70.1114
Los Amigos	8	-12.5525	-70.1052
Los Amigos	9	-12.5471	-70.0986
Los Amigos	10	-12.55	-70.1013
Los Amigos	11	-12.5471	-70.0986
Porto Velho-Manaus	118	-8.20462	-63.8868
Porto Velho-Manaus	119	-8.20444	-63.8867
Porto Velho-Manaus	120	-8.04229	-63.4868
Porto Velho-Manaus	121	-7.54725	-63.2638
Porto Velho-Manaus	122	-6.66399	-62.9653
Porto Velho-Manaus	123	-6.25442	-62.7171
Porto Velho-Manaus	124	-6.19599	-62.6527
Porto Velho-Manaus	125	-6.04587	-62.537
Porto Velho-Manaus	126	-5.90618	-62.4154

Porto Velho-Manaus	127	-5.68069	-62.2418
Porto Velho-Manaus	129	-5.75246	-62.2873
Porto Velho-Manaus	130	-5.83001	-62.3443
Porto Velho-Manaus	131	-5.86086	-62.3732
Tefe	140	-3.40025	-64.6001
Tefe	141	-3.40837	-64.5621
Tefe	142	-3.4236	-64.5634
Tefe	143	-3.4116	-64.5619
Tefe	144	-3.40717	-64.6137
Tefe	145	-3.41395	-64.6167
Tefe	146	-3.43389	-64.6238
Tefe	147	-3.4757	-64.6457
Tefe	148	-3.45512	-64.6774
Tefe	149	-3.4421	-64.6965

Table S4.

Comparison of soil geochemistry among study regions (Los Amigos and a single long core at Quistococha, a settlement site on a lake bluff near Iquitos), and with other locations in western Amazonia (Lakes Gentry-Parker and Ayauchi – see (12)).

	TOC mg/g				BC mg/g				BC/TOC %			
Location	mean	sd	min	max	mean	sd	min	max	mean	sd	min	max
Los Amigos	4.24	1.70	1.70	8.20	0.50	0.13	0.18	0.79	13.02	4.48	4.22	22.40
Quistococha	2.89	1.40	0.58	5.95	0.23	0.16	0.09	0.67	8.77	4.72	1.62	17.10
Gentry-Parker	4.10	2.11	1.70	13.90	0.53	0.48	0.20	3.13	13.28	7.05	4.58	42.56
Ayauchi	41.61	27.83	3.30	117.80	5.83	7.29	0.08	42.57	14.65	13.45	0.28	48.77

References and Notes

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