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Two thousand years of garden urbanism in the Upper Amazon

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Supplementary Material

Two Thousand Years of Green Urbanism in the Upper Amazon

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Materials and Methods

S1: Field work

Surveys and excavations

Apart from the debatable information published by Pedro Porras in 1987 (*25*), most of our knowledge about the pre-Columbian occupation of the Kilamope/Upano cultures comes from the archaeological investigations of Stéphen Rostain and his team (*18*). These have been designed from the start within an interdisciplinary framework, bringing together geoscientists and archaeobotanists in particular, and thus have yielded exceptional results in various fields: the pre-Hispanic cultural sequence, the habitat and food consumption pattern of these ancient populations, as well as the past volcanic activity and geomorphological formation of the valley. The first excavations were carried out in the Sangay site, one of the most extensive sites with earthen platforms in the region. It is located on the alluvial terrace of the Upano at the edge of the cliff of almost 100 m height above the river. The site consists of several hundred platforms clustered into groups or complexes (**Fig. S1**). A network of excavated streets extends throughout the entire settlement and some of these streets continue outside of the agglomeration to connect other cities.

At Sangay archaeological site, the excavations were concentrated in the Complex XI (**Fig. S2**) located about 600 m southeast of the central complexes of the core area, on the banks of the Huapula Creek. The complex covers an area of 70 x 50 m (0.35 hectares). Its organization corresponds to the typical spatial pattern of Upano sites, with several anthropogenic reliefs delineating low plazas. An excavated pathway links the complex to the stream below. A dump was discovered on the northeast side, at the edge of the ravine (**Fig. S3**).

Other excavations were carried out in the settlement of Kilamope, on the left bank of the Upano, ca. 9 km north of Macas. Only the westernmost part of this large site was explored and particularly one platform complex was excavated (**Fig. S4**). It is located 320 m east of the edge of the cliff plunging into the bed of the Upano. The platforms of this complex are built on the highest point where they dominate a pond, about thirty meters to the south, which gives rise to a stream flowing southward. This architectural complex, which covers nearly 0.6 hectares, is organized according to a precise spatial pattern: two rectangular sunken plazas, separated by a central oval platform, are delimited by four elongated peripheral mounds. Open area excavations summing up to nearly 100 m² were carried out at the top of the southern mound, where a housing structure was uncovered (**Fig. S5**). Two black layers cutting the stratigraphy were interpreted as possible volcanic ashes that would have fallen on the site (**Fig. S6**).

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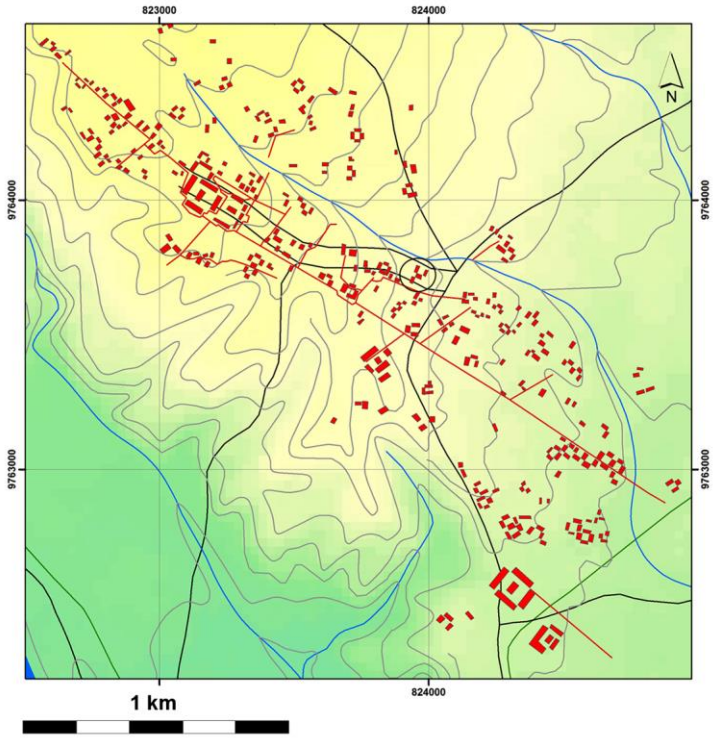

Fig. S1. Map of Sangay site (the black circle delimits the excavated platform complex XI)

Fig. S2. Archaeological excavation of the central platform of complex XI in Sangay

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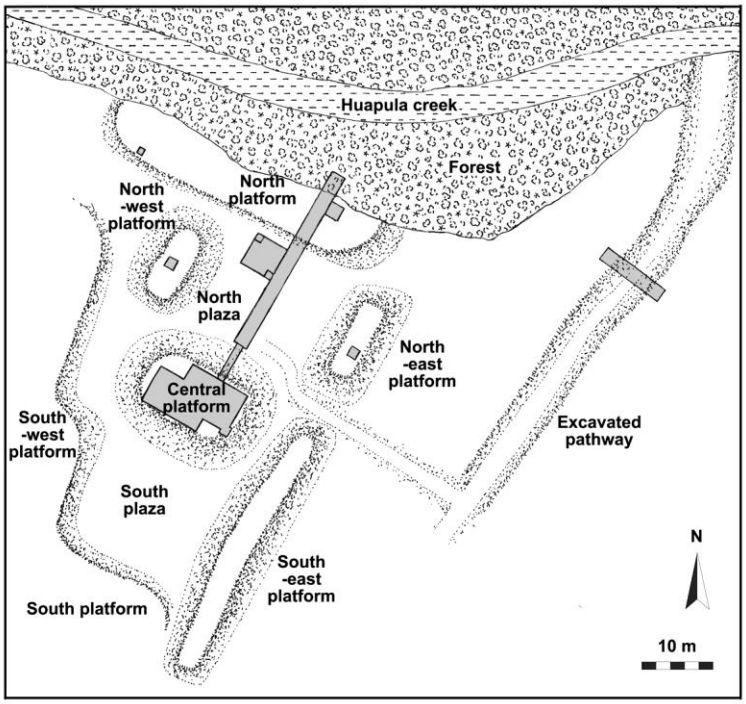

Fig. S3. Map of complex XI in Sangay

	TOP	BOTTOM	HIGH	EXCAVATIONS
Central platform	16 x 8 m	24 x 20 m	200-350 cm	4 areas 90 m^2, 2 test pits, 1 trench
South-east platform	40 x 2-4 m	44 x 11 m	100-200 cm	-
North-east platform	13 x 3-4 m	20 x 10 m	100-200 cm	1 test pit
North platform	33 x 4 m	-	100-300 cm	2 test pits
North-west platform	11 x 3 m	18 x12 m	100-200 cm	1 test pit
South-west platform	17 x 9 m	-	300-500 cm	-
South platform	19 m	-	100-300 cm	-
South plaza	-	20 x 18 m	-	-
North plaza	-	20 x 20 m	-	1 area 25 m^2, 2 test pits, 1 trench
Excavated pathway	102 x 5-7 m	400 x 80 cm	0-200 cm	1 trench

Table S1. Archaeological excavations in the platform complex XI of the Sangay site

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Fig. S4. Western complex in Kilamope

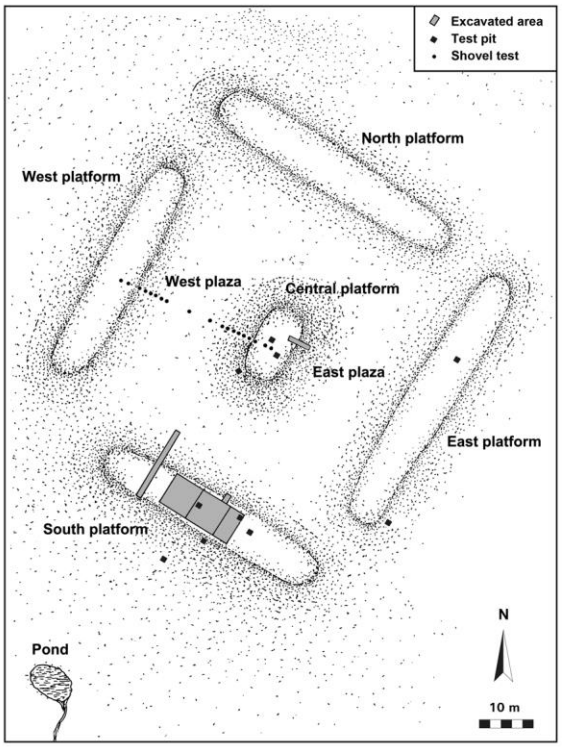

Fig. S5. Large-scale excavation of the southern platform of the western complex in Kilamope

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Fig. S6. Large-scale excavation of the southern platform of the western complex in Kilamope

	TOP	SURFACE	BOTTOM	HIGH	EXCAVATIONS
Central platform	16 x 8 m	128 m^2	26 x 16 m	190 cm	3 test pits, 1 trench
South platform	44 x 8 m	352 m^2	54 x 14 m	130 cm	5 test pits, 1 trench, 3 areas 92 m^2
West platform	46 x 8 m	368 m^2	56 x 18 m	116 cm	-
North platform	48 x 8 m	384 m^2	56 x 15 m	137 cm	-
East platform	52 x 8 m	416 m^2	62 x 16 m	105 cm	2 test pits
West plaza	-	832 m^2	52 x 16 m	-	19 shovel tests
East plaza	-	728 m^2	52 x 14 m	-	2 test pits

Table S2. Archaeological excavations in the western Kilamope complex

S2. Datings

Cultural sequence

The chrono-stylistic ceramic sequence has long remained unclear. Pedro Porras' (*25*) attemps to classify the Upano style and those of various other regions of Amazonia are now seriously questioned (*18*).

Almost 70 radiocarbon dates have been made during our program and led to the complete revision of the previous chronology (*27*). Here, we propose a new sequence based on a re-examination of the stratigraphic sequences of Sangay and Kilamope archaeological sites. The excavations in the platforms of these two sites yielded two complex and comparable stratigraphies (**Fig. S11**), resulting from different successive events: cultural occupations, building and embankments, black layer formation, etc.

Based on radiocarbon dating mentioned above and on the stylistic and stratigraphic classification of the remains discovered during our excavations, a cultural chronology of 2700 years could be established for the region. This sequence was recently revised and will be presented in a subsequent paper. It presents the succession of four or five cultural assemblages:

1. Sangay culture: from around 700 to 500 BCE. This first occupation left few remains.
2. Kilamope Culture: from 500 BCE. These were the first mound builders. Pottery of Kilamope culture is characterized by curvilinear incised decorations, the use of reddish slip and various fine prints and incisions.

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3. Upano Culture: probably from 500 BCE to 300/600 CE. They built earthen mounds and they were contemporaneous or successors of the Kilamope groups. Pottery of the Upano culture is mainly characterized by rectilinear incisions and painted decorations.
4. Huapula Culture: from 800 to 1200 CE. After the disappearance of the Upano, Huapula groups reused the mounds abandoned by their predecessors. Huapula ceramic is characterized by decorations based on the corrugated modality using wavy patterns, and marks the appearance of modern Jivaroan-speaking populations in the region.
5. Shuar Culture: They follow the Huapula of whom they are the direct heirs.
The cultural evolution of this region is comparable with that known in other Amazonian areas: after sparse occupation, appearance of dense societies during the first phases (Kilamope and Upano cultures) while around 800 CE, the archaeological record indicates a fragmentation of the system with the emergence of smaller and dispersed groups. Since the European contact and until the end of the 19th century at least, the Upano basin has been occupied by Shuar groups of the Chicham-Aents culture (recent self-naming to replace the previous inadequate term "Jivaro"). Then came the Spaniards and, later, settlers coming from the Andean high plateaus.

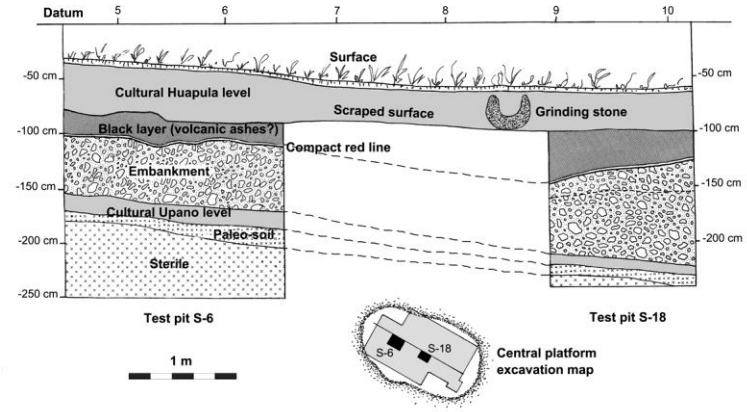

Fig. S7. Stratigraphy of the central platform of complex XI in Sangay

S3. Methodology of the LiDAR analysis

LiDAR Acquisition and equipment

The LiDAR coverage was conducted by the company Technoproject commissioned by the INPC. The aircraft used was a Cessna 206 equipped with a 2008 Optech Gemini laser scanner, calibrated at a scan rate of 100 kHz, a scan frequency of 40 kHz and a scan angle of 50°. These parameters yielded an average of 12.7 returns per square meter (no precisions were given by the team concerning average ground returns). Geolocation was ensured by three GNSS Leica GS09 receivers. A total of 20 flights were conducted in the course of 17 days, between July 25 and August 10, 2015, at a mean altitude of 305 m (1000 feet) and a mean speed of 180 km/h (100 knots). The operation team report (*35*) states that the equipment and parameters available were unfortunately not optimal for the Amazonian context, nor were the climatic and environmental conditions. The main constraints were the pre-mountainous environment and the areas of marked difference in altitude (the cliff-like terraces of the Upano river) to which the aircraft model was not well adapted, as well as the climatic conditions, which changed during the day. This led to a heterogeneous coverage. However, the resulting processed datasets are of fairly good quality and the technical constraints could be generally overcome during the interpretation phase.

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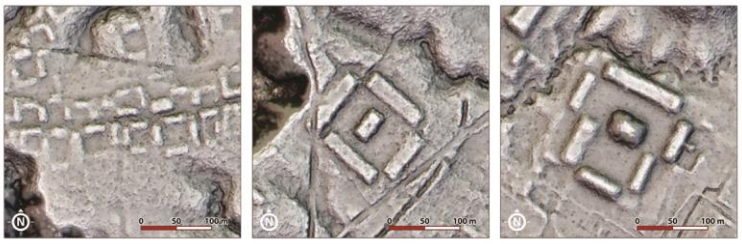

Fig. S8. Comparison of different sizes of complexes. Left: Kunguints small residential complexes. Middle: Sangay southernmost monumental complex. Right: vast monumental complex with seven earthen platforms at Copueno

DEM processing and remote sensing strategy.
Pre-processing was conducted by Technoproject using the automated point cloud classification of the Terramodeler Terrascan software.
The archaeological team therefore inherited a LiDAR dataset consisting of 300 one-square-kilometer tiles of raw data (LAS point cloud, 300 files), the corresponding tiles with the pre-processed digital elevation model (DEM) (ASCII raster format) with a resolution of one meter and a single orthophotography. The DEM tiles were combined into a single DEM covering the entire area.
Table S3 summarizes the main visualizations that we used, which were produced using RVT, SAGA, and QGIS software. Examples are given in **Fig. S8**.

Visualization	**Parameters**
Multiple hill shading MHS	Sun azimuth 315°; Sun elevation 35°; 16 directions
Slopes	No parameters; color reclassification (see Dorison et al. 2022: *40*)
SLRM 10	Radius 10 px (10 m)
SLRM 50	Radius 50 px (50 m)
Sky View Factor SVF	Radius 10 px; 16 search directions

Table S3. Visualizations used and corresponding parameters produced using RVT, SAGA, and QGIS software

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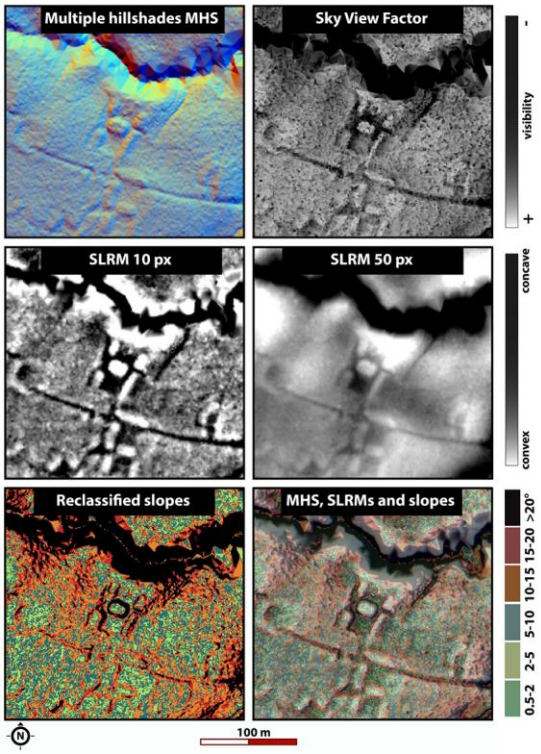

Fig. S9. Examples of the main visualizations used showing complex XI in the Sangay site excavated by the team

All were used during the desk-based interpretation. The overlay of a 10-px radius SLRM, a 50-px SLRM and the MHS emerged as the standard visualization best suited to our case at the first level of interpretation. Another visualization based on the reclassification of slopes according to "natural" breaks as defined by geomorphological models (*40*) also proved relevant. In addition, some dense forest areas, where the algorithms gave poor results, could be partially interpreted by varying the color gradient applied to elevations. Finally, 3D views generated in QGIS provided useful tools to complete the interpretation process.
To limit misinterpretations, any identification of an object as pre-Hispanic was validated by systematically overlaying satellite images of various dates and origins upon the DEM. Images from Google, Bing, Mapbox, and ESRI world imagery, loaded through the QuickMap Services plugin on QGIS, as well as the orthophotography generated during the LiDAR coverage were used. In addition, open-access geographic and cadastral data were integrated into the GIS to help distinguish recent (as roads, fields or pools that have another orientation) and current features from pre-Hispanic ones on lidar-derived visualizations. Original data for the latter can be accessed here:
- WMS geopedologic dataset:
<http://geoportal.agricultura.gob.ec/fisiografia/E25k/wms?version=1.3.0>
- WMS cadastral dataset:
<http://geoportal.agricultura.gob.ec/sigtierras/catastro_rural/wms?version=1.3.0>
- General maps repository:
<http://geoportal.agricultura.gob.ec/geonetwork/srv/fre/catalog.search#/home>

Digitization and spatial analysis

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The digitization was conducted on QGIS. First, we single-pointed all the earthen platforms (locally called *tolas*) to assess the extent of this cultural phenomenon, which is typical of the area (**Fig. S9**). The existing count undertaken by the team that carried out the LiDAR coverage (*35*) was completed and corrected, and served as a base file to create heat maps and categorize the settlements.
Then, we recorded the ground extent of anthropogenic features and remarkable landforms with polygons (as in **Fig. 4** in the main article). All footpaths were systematically recorded, taking into account the degree of reliability of each digitization according to the quality of the image and the visible morphological characteristics. For other features, such as platforms and mounds, only a selection was digitized in order to provide a diagnostic sample of each type of feature throughout the area.

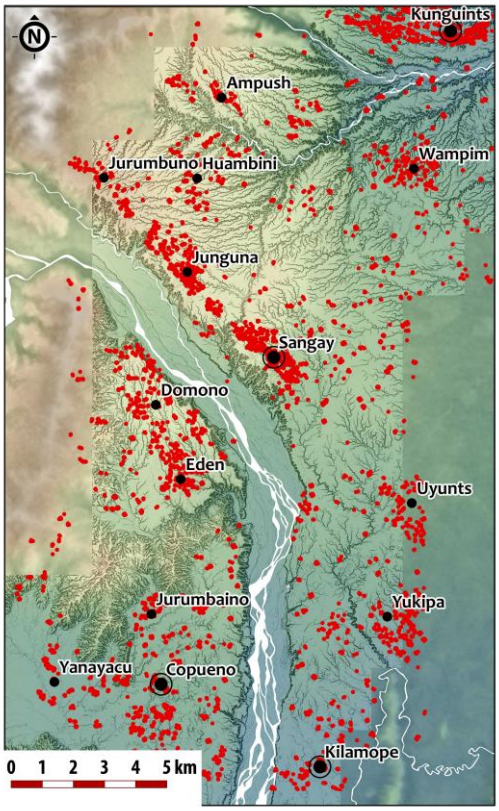

Fig. S10. Platforms count in the whole study area. Each red dot represents the center of an earthen platform

Criteria for the definition of the hierarchy of settlements
Clusters of complexes were defined as *settlements* based on three criteria: density, connectivity at regional scale and size of the platforms that compose them (**Fig. S10**). A site was considered "dense" as soon as it had more than 40 platforms per km² on an area of 50 hectares or more. It was considered "monumental" when two or more large complexes (over 100 m long) were registered within a 500 m radius. Regional-scale connectivity constituted a final criterion. Where known, settlements were named after bibliographic references or, otherwise, after the nearest river.

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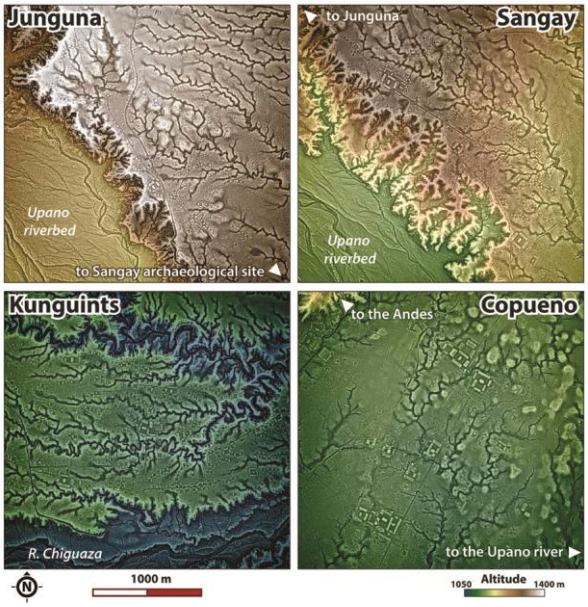

Fig. S11. Comparison of four main Upano sites

Hummocks
Hummocks are large clastic materials issued during violent volcanic debris avalanche events that may be encountered several dozens of kilometers away from the eruption epicenter. Sangay volcano experienced several of these violent events, and hummocks are therefore common formations in the study area, shaping hilly landscapes (*33*). Some of these present a flat summit that may be the result of anthropogenic levelling in some cases to create domestic areas (*41*).
In the Upano valley, hummocky formations are clustered within specific areas. The highest densities occur between Kilamope and Sangay, north of Copueno, and around Wampim and Ampush.

S4. Comparison with Amazonian sites

Cotoca, Llanos de Mojos, Bolivia (*6*, *14*)
Many pre-Hispanic artificial mounds are located in the southern floodplains of the Llanos of Mojos, especially east of the Mamoré River. A total of 189 large monumental sites, 273 smaller sites and 957 km of canals and causeways have been identified. Only six large mounds have been partially excavated. Two large settlement sites and 24 smaller sites have been documented in detail with LiDAR by Heiko Prümers and his team. The two major sites are Cotoca (147 hectares) and Landívar (315 hectares). The Cotoca site is enclosed by massive ditches and ramparts of eminent defensive character. The core is occupied by a 22.5-hectare artificial terrace rising 2 m above the surrounding land. Upon the terrace stand a series of rectangular earth-platform buildings, which together with a 20 m high truncated pyramid in the southern part of the terrace, form the civic-ceremonial center. Rectilinear causeways built on straight embankments, generally 6-9 m wide, radiate from the center to connect other sites. These monumental sites were not solely ceremonial cores but settlement area too. They were inhabited by farmers that also used the residential mounds to bury their dead, sometimes with a special treatment that most likely reflects their elevated status within a stratified society.

Hertenrits, Western coastal plain, Suriname (*3*)

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The Guianas coastal zone is a sedimentary and low swampy plain bordered by mangroves on the mud flats along the seashore. Circa 300 CE, a Barrancoid group raised two earth-mounds. From 650 CE, Arauquinoid communities built new mounds. Their territory extended for over 210 km along the coast and 25 km inland. Hertenrits is the largest of the six Arauquinoid known mounds. It measures 200 to 320 m in diameter, is 2.5 m high, and presents a levelled area of about 4 hectares. The Hertenrits mound was occupied during a long period of time between 650 and 1250 CE. It has been built progressively, layer by layer. A moat of 20-100 m wide surrounds the mound. Five wharves of 20 m long and at least 1 m deep are disposed on the periphery to receive canoes. Rectangular or elongated raised fields have been built in the buffer zones in-between mounds. Shallow, seasonally inundated pathway/canals run radially, linking the Hertenrits mound to the raised-field area and to two smaller satellite mounds – Wageningen-1 and 3 –, which are equidistant from Hertenrits to the NW and SE. The canals were used as pathways during the dry season and as waterways during the rainy season, strongly suggesting that the three mounds were occupied at the same time.

Kuhikugu, Upper Xingu, Brazil (*8*, *13*)
The Upper Xingu is a forested region of the southern Amazon, Mato Grosso, Brazil. Pre-Hispanic ring-villages have been documented along the Xingu River. They are similar to modern villages such as Kuikuro, where *malocas* (larges collective houses) are disposed in circle around a huge circular, central plaza. The largest archaeological sites can reach up to 50 hectares delimited by peripheral ditches 500 to over 2000 m long, 1 to 3 m deep and 5 to 10 m wide. These ditches are bordered by a raised interior berm where a wooden fence was originally built. The ancient plazas measure 120 to 150 m in diameter. Wide roads (up to 40 m wide) radiate from this central space toward various directions to connect to other settlements or locations that may have been important for the provision of the inhabitants. Major political ritual centers structure a macro-local network comprising large towns (≥40 hectares), medium-sized villages (<30 ha) and smaller ones (<10 ha), as well as small villages without central plaza. Settlements are typically separated by 5-10 km following rivers. In each cluster of sites, the same spatial pattern connects a major political and ritual settlement to equidistant satellites smaller villages located in the hinterland areas. These territorial polities organize a hierarchical anthropized landscape.

El Gaván, Llanos de Barinas, Venezuela (*5*)
The El Gaván site is located in the high Llanos de Barinas, at the foot of the Eastern Andes, in Venezuela. The llanos are grass-covered plains of dry savannah with a few patches of forest. The archaeological sites found in this area are classified into four categories: regional centers of over 10 hectares, with mounds, plazas and raised paths leading to the other two types of settlement; second-order centers, from 5 to 10 hectares, with artificial mounds; third-order settlements, from 1 to 5 hectares, without architecture; and drained field areas. The earthworks are dated to the late Gaván phase (550-1000 CE) and are thought to correspond to the emergence of chiefdoms and of a strong population growth. The sites range in size from 1 to 33 hectares, though the majority (28 of them) measures only 1 to 5 hectares. The largest site, B-12 or El Gaván, features impressive earthworks with numerous mounds of varying dimensions, including one with an access ramp, an enclosing embankment and raised paths leading to secondary sites. Two irregular rows of small house mounds delimit a wide central alley leading to the main mound. The encircling causeway of the site has been destroyed on the western side by a meander of the Caño Mitaio Hondo.

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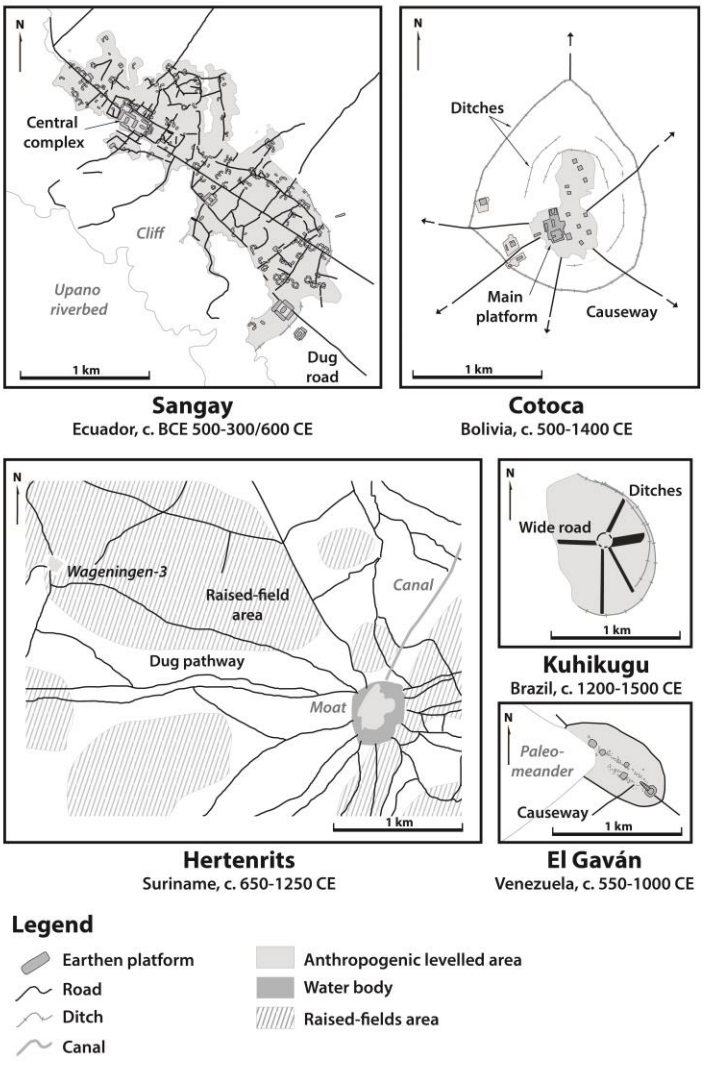

Fig. S12. Comparison of one of the main Upano sites, Sangay, and four low-density urbanism sites in Amazonia: Cotoca in Bolivia, Hertenrits in Suriname, Kuhikugu in Brazil, El Gaván in Venezuela (redrawn from *3*, *5*, *8*, *14*)

Fig. S13. Core of the mounded site of Eden, Upano Valley

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Figures

Tables

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