Article

Anthropogenic indicators and mapping of socio-spatial events: aid to human retrospective in the Brazilian Amazon

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Anthropogenic indicators and mapping of socio-spatial events: aid to human retrospective in the Brazilian Amazon

Abstract

The Amazon is a complex mosaic of interwoven human-natural systems that is the result of a lengthy process of occupation and indicates substantial potential to humanize the region, in which the search for answers, or part of them, is to impartially analyze its socio-spatial events and forms of use of natural resources. The objective of this work is to describe the socio-spatial events of human groups within the natural domains of the Brazilian Amazon to establish a chronological sequence of human actions and the historical periodization of the dynamics of occupation processes in the Holocene Amazon. The methodological supports included survey, cartography, and analysis of the anthropogenic increment of a set of traces of human action contained in the physiographic fabric of landscapes of natural systems. The results pointed to a marked mosaic of anthropogenic evidence, historically produced and accumulated, triggering wide geographic variability.

Keywords: Amazon. Natural domain. Holocene. Anthropogenization

Indicadores antropogênicos e cartografação de eventos socioespaciais: subsídio à retrospectiva humana na Amazônia brasileira

Resumo

A Amazônia é um mosaico complexo de sistemas humano-naturais acoplados que resultam de um longo processo de ocupação e sinalizam um substancial potencial de humanização da região, onde a busca de respostas, ou de parte delas, está justamente na análise de seus eventos socioespaciais e das formas de uso dos recursos naturais. O objetivo deste trabalho é resgatar eventos socioespaciais de grupos humanos no âmbito dos domínios naturais da Amazônia brasileira para estabelecer uma sequência cronológica das ações do Homem e uma periodização histórica da dinâmica de processos de ocupação da Amazônia holocênica. Para tanto, foram tomados como suporte metodológico o levantamento, a cartografação e a análise

do incremento antropogênico de um conjunto de vestígios da ação humana contido no tecido fisiográfico das paisagens de sistemas naturais. Os resultados apontaram um acentuado mosaico de evidências antropogênicas, produzido e acumulado historicamente, desencadeando ampla variabilidade geográfica.

Palavras-chave: Amazônia. Domínio natural. Holoceno. Antropogenização.

Indicadores antropogénicos y mapeo de eventos socio-espaciales: subsidio a la retrospectiva humana en la Amazonía brasileña

Resumen

La Amazonía es un mosaico complejo de sistemas humano-naturales acoplados, desencadenados por un largo proceso de ocupación, que señala el potencial sustancial de humanización de la región, donde la búsqueda de respuestas, o parte de ellas, está precisamente en el análisis de sus acontecimientos socio-espaciales y formas de uso de los recursos naturales. El objetivo de este trabajo es realizar un rescate de eventos socio-espaciales de grupos humanos, dentro de los dominios naturales de la Amazonía brasileña, con el objetivo de establecer una secuencia cronológica de acciones humanas y una periodización histórica de la dinámica de los procesos de ocupación de la Amazonía del Holoceno. Para ello, se utilizó como apoyo metodológico el levantamiento, la cartografía y el análisis del incremento antropogénico de un conjunto de huellas de la acción humana, contenidas en el tejido fisiográfico de los paisajes de los sistemas naturales. Los resultados apuntaron a un mosaico acentuado de evidencias antropogénicas, producidas y acumuladas históricamente, desencadenando una amplia variabilidad geográfica.

Palabras clave: Amazonas. Dominio natural. Holoceno. Antropogenización.

Introduction

The aim of this paper is a retrospective of the socio-spatial dynamics of human groups in the natural domains of the Brazilian Amazon (NDBA) from anthropogenic evidence introduced into the structure of the physiographic fabric, to analyze and map the socio-productive periodization, throughout the Holocene.

Although the main phases of human occupation and environmental changes have been explored in local and disciplinary research, a more comprehensive approach to human expansion in the Amazon should be adopted that combines anthropogenic evidence of resource use with socio-spatial events and their respective biophysical substrates in the NDBA.

Ecologists suggest that the Amazon is a complex mosaic of interwoven human-natural systems typical of anthropogenic biomes that occurred prior to the European conquest (Clement et al., 2015). This, combined with more contemporary anthropogenic evidence, signals an even greater potential for humanization of its natural domains. These elements give the region a unique importance in geographic studies, as they combine a set of environmental indicators that point to a high anthropogenic pressure. The answers, or part of them, provide analysis and better understanding of its occupation processes.

For Cavalcanti and Rodriguez (1997), human systems are characterized by the ways humans organize themselves in society and how they manage the "natural systems" in which socio-spatial dynamics recur and re-influence these relations.

This approach is justified by the relative scarcity of research with a wide temporal-spatial scale focused on mapping and analyzing environmental evolution, since most works prioritize smaller scales.

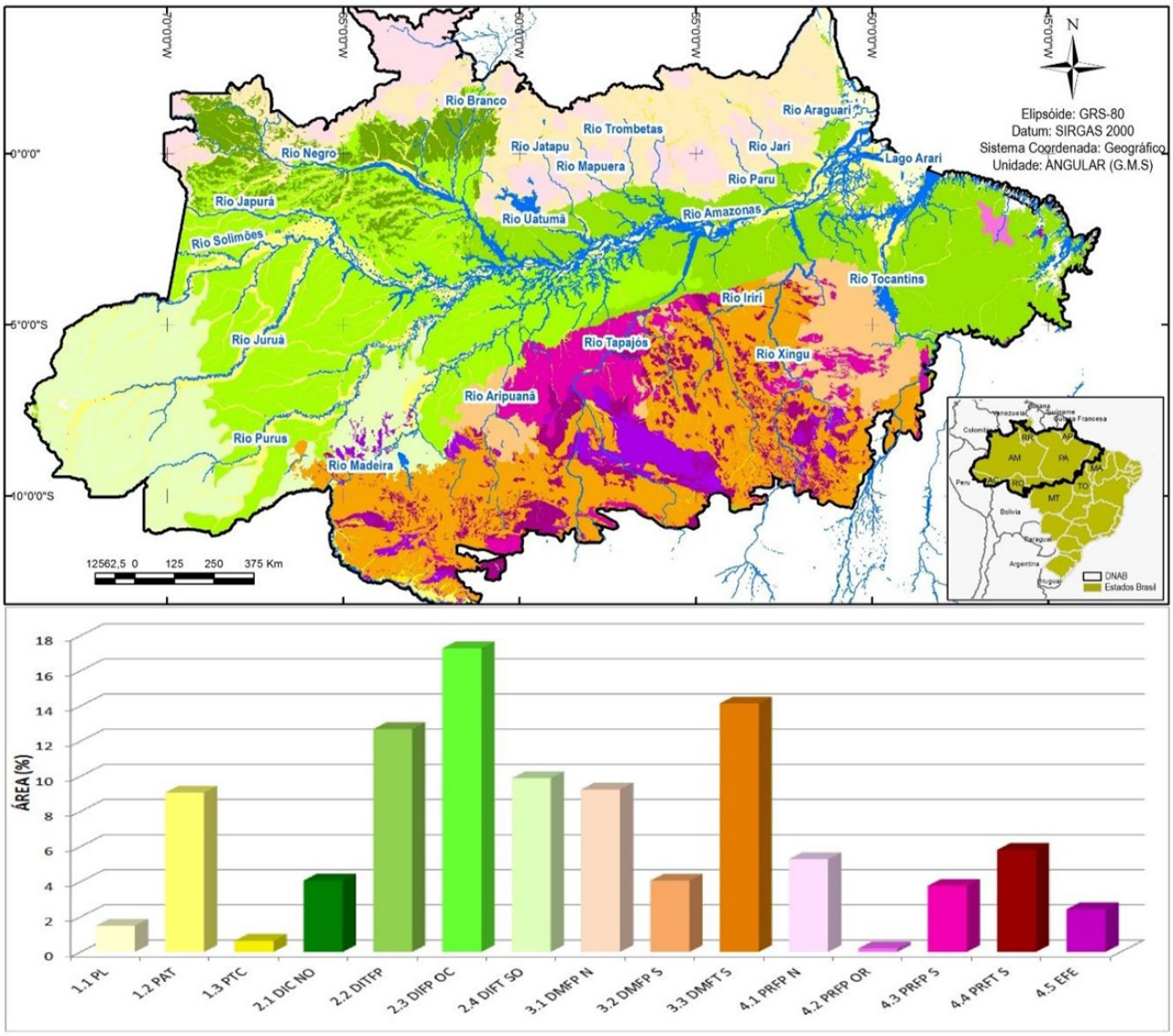
Study area

The study area includes the NDBA that has approximately 3.7 million km2 (44% of the Brazilian national territory) (Figure 1). This encompasses biophysical aspects (morphostructure, morphosculpture, soils, vegetation) (IBGE 2017b, 2017c, 2017d, 2017e), according to morphoclimatic and phytogeographic concepts (Ab' Saber, 1967).

These domains were synthesized into the following units: Amazon plain (Quaternary) – domain with more recent formation, characterized by an unconsolidated sedimentary structure; sedimentary depression (Phanerozoic) – composed of basins and sedimentary coverings, shaped by ancient deposition processes; crystalline depression (mobile belt); (Neoproterozoic) – sedimentary coverings, consolidated and deposited over a crystalline structure, modeled by old erosive and pediplanation processes; and plateau and montane relief (Craton) (Neoproterozoic) – very old consolidated formations, indicating structural control, represented by dissected residual plateaus.

In the context of regional differences, natural systems were defined from the development of the NDBA, constructing subdomains to facilitate the analysis of socio-spatial dynamics (Figure 1). The natural systems were shaped by the need to adopt a scale compatible with socio-spatial events.

Figure 1 - Natural domains of the Brazilian Amazon



Sources: IBGE (2017b, 2017c, 2017d, 2017e), with cartographic data grouped in millionth clipping sheets compressed and made available in shapefile format (vector file extension that stores geospatial attributes in Geographic Information Systems platform - GIS).

Compiled by the authors.

Note: The X-axis of the graph represents natural domains and systems (Table 1).

Natural domains: (1) Amazonian plains, (2) Sedimentary Depressions, (3) Crystalline Depressions, and (4) Plateaus and Montane Reliefs. Natural systems: (1.1) Coastal Plain (PL), (1.2) alluvial-terrace plain (PAT), (1.3) Crystalline Terrain Plain (PTC), (2.1) northwestern campinarana interplanaltic depression (NWICD), (2. 2) interplanaltic depression of the phyto-pluvial tablelands (DITFP), (2.3) Western Interplanaltic Phyto-Pluvial Depression (DIFP OC), (2.4) Southwestern Interplanaltic Phyto-Pluvial Depression (DIFT SO), (3. 1) Northern Marginal Phyto-Pluvial Depression (DMFP N), (3.2) Southern Marginal Phyto-Pluvial Depression (DMFP S), (3.3) Southern Marginal Phyto-Transitional Depression (DMFT S), (4.1) northern residual phyto-pluvial plateau (PRFP N), (4. 2) eastern residual phyto-pluvial plateau (PRFP OR), (4.3) southern residual phyto-pluvial plateau (PRFP S), (4.4) southern residual phyto-transitional plateau (PRFT S) and (4.5) phyto-ecological enclave (EFE).

Table 1 – The natural domains and systems and the acronyms used in this article.

#	Acronym	English natural domains and systems
		Amazonian plains
		sedimentary depressions
		crystalline depressions
		plateaus and montane reliefs
1.1	PL	coastal plain
1.2	PAT	alluvial terrain plain
1.3	PTC	crystalline terrain plain
2.1	DIC NO	northwestern campinarana interplanaltic depression
2.2	DITFP	interplanaltic depression of the phyto-pluvial tablelands
2.3	DIFP OC	western interplanaltic phyto-pluvial depression
2.4	DIFT SO	southwestern interplanaltic phyto-pluvial depression
3.1	DMFP N	northern marginal phyto-pluvial depression
3.2	DMFP S	southern marginal phyto-pluvial depression
3.3	DMFT S	southern marginal phyto-transitional depression
4.1	PRFP N	northern residual phyto-pluvial plateau
4.2	PRFP OR	eastern residual phyto-pluvial plateau
4.3	PRFP S	southern residual phyto-pluvial plateau
4.4	PRFT S	southern residual phyto-transitional plateau
4.5	EFE	phyto-ecological enclave

Compiled by the authors.

Materials and methods

The dynamics of occupation processes in the Amazon is the subject of much research and controversy, especially in recent decades, when archaeological and botanical studies have revealed that anthropogenization in the region dates back to the early Holocene.

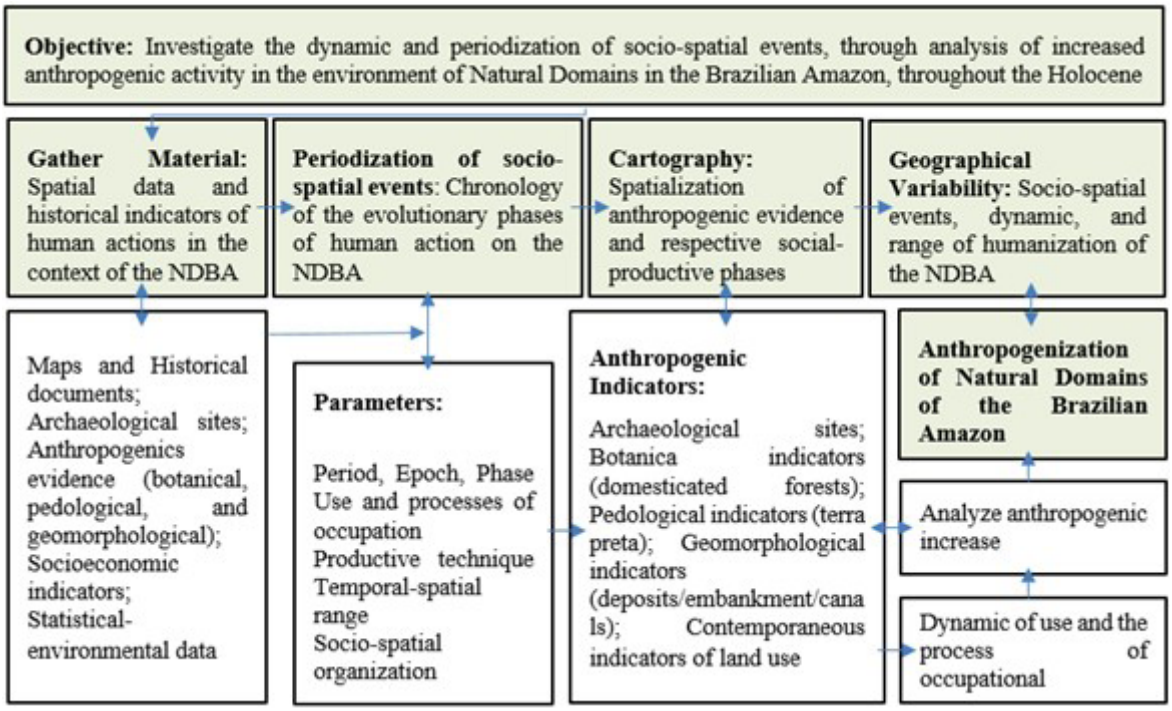
Anthropogenic evidence has supported the analysis of human evolution in the Amazon through archaeological (Neves, 2006), pedological (McMichael et al., 2014), and vegetational (Levis et al., 2017) evidence. However, these traces imply a wide range of aspects, meanings, and interpretive possibilities, including the dynamics and range of socio-spatial events in natural systems.

Anthropogenic evidence is characterized as the sum of human actions in nature, constituting indicators in the analysis about what caused the disturbances and/or environmental transformations, whether physical-natural (e.g., geomorphological, pedological, phytoecological agents), or human-social (e.g., socio-spatial aspects) in character.

The cartographic reproduction of socio-spatial events was based on the investigation of the dynamics and processes of change of use and occupation experienced by Amazonian societies.

The procedures were defined according to the following steps (Figure 2):

Figure 2 – Methodological flowchart



(1) Survey of traces – identification and grouping of temporally and spatially correlated anthropogenic traces

(2) Periodization – definition of periods, epochs, and socio-productive phases in accordance with the evidence and the prevailing occupation processes

(3) Cartography – temporal slicing and spatialization of archaeological evidence and the other typologies of use. For this purpose, the following were adopted:

(a) Pre-Colonial Period – data collected from CNSA (Iphan, [s.d.]) and scientific papers. As these sites are sporadically evidenced, two variables were used to delimit potentially anthropogenized areas:

(i) Average distance between sites – circular radius delimitation (in km): Paleo-indigenous (100), Archaic (50), Early Formative (30), and Late (15)

(ii) arqueoecológico

(iii) Archaeological indicators (e.g., CLEMENT et al., 2015)

(b) Colonial Period – location of nuclei, villages, religious missions, and other socio-spatial events (Denevan, 2003; Araújo, 2004; Miranda, 2007; Chaves; Pena, 2013). We also considered the predominant activity in the period – the extraction of herbs. The delimitation of the possible areas of influence was based on:

(i) Geographical location of spatial occupations - 17th and 18th centuries

(ii) Sectoring of the Amazon River and tributaries correlated to the places

(iii) Delimitation of terrain units (IBGE, 2017c)

(iv) Hydrographic basins – ottobacias, level 4 (Pfafstetter, 1989)

(c) Post-Colonial Period – supported by data about contemporary use typologies considering two economic cycles:

(i) Agro-extractivist (1850-1950) – data on concentration and extraction of forest species (Leite et al., 1999; Thomas et al., 2014; Homma, 2014)

(ii) Agro-industrial (from 1950 onwards) - evidence of mining, farming, and urban areas (MapBiomas, 1985, 2019; Inpe, 2018)

(4) Anthropogenic estimation – analysis of occupational dynamics considering socio-spatial similarities and anthropogenic increment of natural systems.

Human arrival in the Amazon: continentalization and "initial" settlement

The Bering Strait, which was a continuous land route in the Late Pleistocene, has been considered the main route between Asia and North America (Da-Gloria, 2019).

The earliest securely dated cultures in South America (~15,000 years BP) are contemporaneous with the paleo-indigenous complexes of North America (Roosevelt et al., 1996). In the Orinoco-Guiana area of Venezuela (15,000 years BP), sites considered archaeological complexes predate the Clovis culture, termed pre-Clovis, reinforcing the theory of an occupation via the Pacific (Neves, 2006).

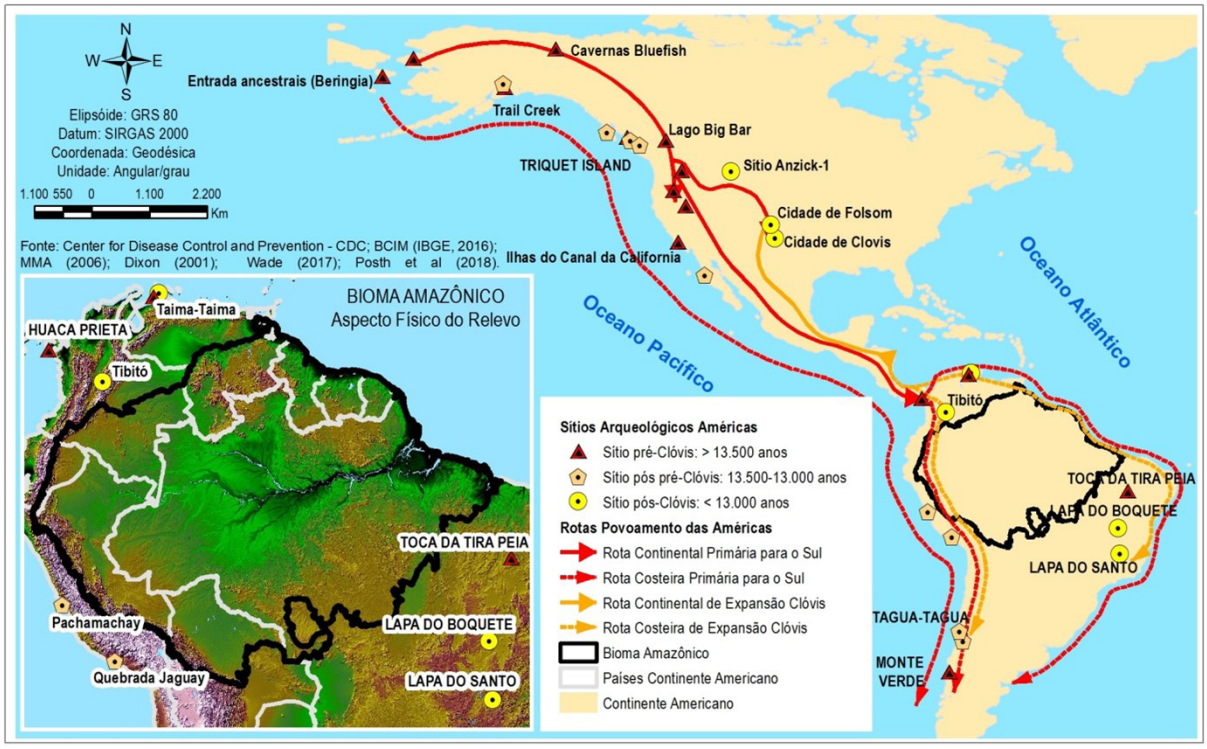
Figure 3 presents some hypotheses of probable settlement routes in the Americas, via the continent and via the Pacific coast: (1) the continental routes are subdivided into two: the first, at the oldest sites, is considered to be ancestors of the Clovis culture and of the first migratory routes to South America, via the Andes and the Atlantic coast (Late Pleistocene). The second is represented by groups originating from the Clovis culture, which would have populated the edge of the Amazon at the beginning of the Holocene. (2) The routes via the Pacific coast represent the first settlements in South America.

Another aspect that contributes to the hypothesis of the arrival of human beings in northern South America concerns environmental factors favorable to their sustenance, such as extensive savanna areas in central Guiana, which would have functioned as a corridor, going from Venezuela to the Guianas (Eriksen, 2011). Between 13,000 and 12,000 years BP, part of the area surrounding the Amazon biome was populated by hunter-gatherers (Figure 3).

The most accepted model for human colonization of the Americas is that of coastal migration, with movement and settlement within broad ecological zones, when human groups would have moved most rapidly southward along the coast of the Pacific Ocean (Dixon, 2001). However, Araújo (2004) suggested that, instead of the route having been only along the Pacific coast, human populations followed two paths: one by the Atlantic and the other by the Pacific, with occupation of the interior occurring later.

The first human evidence in the Amazon has been recorded in several regions, including at the mouth of the Tapajós River – Pedra Pintada cave, in Monte Alegre (PA), where evidence associated with the Pleistocene-Holocene transition was found (Roosevelt, 2013).

Figure 3 – Models of settlement routes to South America and sites within the Amazon biome, including physical aspects of the terrain.



Sources: Dixon (2001) and de Wade (2017).
Adaptation by the authors.

The expansion and settlement of the Americas was probably marked by more than one migratory wave. Although the evidence discovered so far is not sufficient to establish more precise human trajectories, anthropogenic indicators embedded in the ecological structure can compensate for possible gaps.

Archaeological indicators in prehistoric Brazilian Amazonia

Archaeological data demonstrate that human colonization in the Amazon resulted in the formation of ecological patterns in the rainforest related to prehistoric human groups, which forged later agricultural societies (Magalhaes, 2016).

Neves (2006) stated that the Amazon has been occupied for more than 10,000 years, in some cases by populations of thousands. This assumes that the current forest, which covers archaeological sites, has, in addition to a natural history, a cultural history.

Strong evidence of human activity in the Amazon is the so-called Cultural, Anthropogenic, or Domesticated Forests. These forests are indicators that suggest a high degree of domestication. Examples include forests with high concentrations of Brazil nuts, inga, abiu, and cacoa located in the interfluves of the Purus and Madeira rivers, in the Carajás Mountains, and in the middle and lower Amazon River (Levis et al., 2017).

Based on archaeobotanical evidence in the Pedra Pintada cave (in Monte Alegre, Pará), Roosevelt et al. (1996) state that the Amazon Forest was a dynamic anthropic formation. The first human impacts were changes in the composition of forest species by the dispersal of useful plants, such as in the southwestern and eastern Amazon and the southern Carajás Mountains (Magalhães, 2016).

Other anthropic transformations are recorded in the Indian terra preta (TPI). Prehistoric societies formed extensive anthropogenic soils in these spaces, such as the Marajó plains, the middle and lower Amazon River, and some tributaries (e.g., Madeira, Tapajós, Xingu), (Costa et al., 2009). TPI is the result of waste deposits and field and forest management practices, which form cultural and nutrient-rich soil (Roosevelt, 2013). Between Santarém and Manaus, there are many TPIs, some dating around 2,500 years BP, whose sites occupy river and lake edges (Prous, 2006). According to Clement et al. (2015), almost 1% of the Amazonian soil is composed of TPI, where approximately 83 native species grow with some degree of domestication.

Other indications have been used as anthropic evidence, such as the occurrence of large settlements, the construction of mounds and geometrically shaped earth structures (geoglyphs) (Eriksen, 2011). Mounds represent anthropogenic reliefs, built to elevate surfaces, for residential, defensive, or agricultural purposes. In the Marajó Archipelago (PA), more than 400 mounds have been identified, mostly dating from 400 to 1300 AD (Schaan, 2007).

Roosevelt (2013) notes that geoglyphs constitute monuments different from other prehistoric evidence, representing artificial constructions on dry land and non-flooded land, which date to the early Christian era. Such landforms extend from Acre to the vicinity of the border with Bolivia, following eastward and reaching western Rondônia, as well as the river plains of the Amazon River and its tributaries (Schaan, 2007).

Other occupations reveal early evidence of pottery production and intense human intervention in Amazonian ecosystems, associated with faunal, lithic, and ceramic evidence. Among these indicators are the Taperinha sambaquis in the lower Amazon (7.5 thousand and 4 thousand years BP), of the Xingu River (5 thousand and 3 thousand years BP) (Schaan, 2009), and the coast of Pará (5 thousand years BP) (Roosevelt et al., 1996).

Socio-spatial events and periodization of human expansion in the Amazon

Evidence in the northern Amazon (~11,000 to 8,000 years BP) verifies the presence of human groups in the lower Amazon River, possibly through routes that began in the northern Guiana Plateau, entering Brazil through tributaries of the Amazon and the savanna corridor of the lower Amazon (Bueno; Dias, 2015).

Based on archaeological evidence, five socio-productive phases (Paleo-indigenous, Archaic, Formative, Decomplexification, and Diversification) and three historical periods (Pre-Colonial, Colonial, and Post-Colonial) were established in the Brazilian Amazon.

Pre-Colonial Period: from hunter-gatherers to environmental diversity

The first hunter-gatherer groups played a fundamental role in establishing routes in the Amazon Forest, facilitating future migratory processes and the evolutionary relationship with increasingly less unknown landscapes – the Paleo-indigenous phase. In the Amazon, evidence associated with these groups includes the presence of palm and chestnut trees at the Cave of Pedra Pintada site, in Monte Alegre (PA) (Roosevelt et al., 1996), charcoal particles at the Curuçá lagoon, on the Pará coast (~10,000 years BP), lithic points at the Dona Stela site (AM) (9,000 years BP) (Neves, 2006), and fossilized vegetables in the Carajás Mountains (PA) (9,000 years BP) (Magalhães, 2016).

The settlement process of the Amazon may have been facilitated by the valleys of the great rivers and triggered rapid displacements of hunter-gatherers. According to Magalhães (2016), starting 7,000 years BP, humans had already spread to different parts of the Amazon basin, initiating a new socio-productive context – the Archaic phase.

The Archaic phase is characterized by the beginning of ceramic production. The oldest ceramic remains on the American continent were found in the lower Amazon (8,000 years BP), as well as on the coast of Pará, the Middle Amazon, the Carajás Mountains (PA), the Jamari River basin (RO), and the Lower Negro River (AM) (Roosevelt et al., 1991).

For Magalhães (2016), the Archaic phase constituted an entropy in the social organization of the pioneer hunter-gatherer cultures, which intensified the management of selected plants (e.g., Brazil nut, cassava). Around 5,000 years BP, some inhabitants began to prioritize forest horticulture, initiating the Formative phase (Roosevelt, 2013).

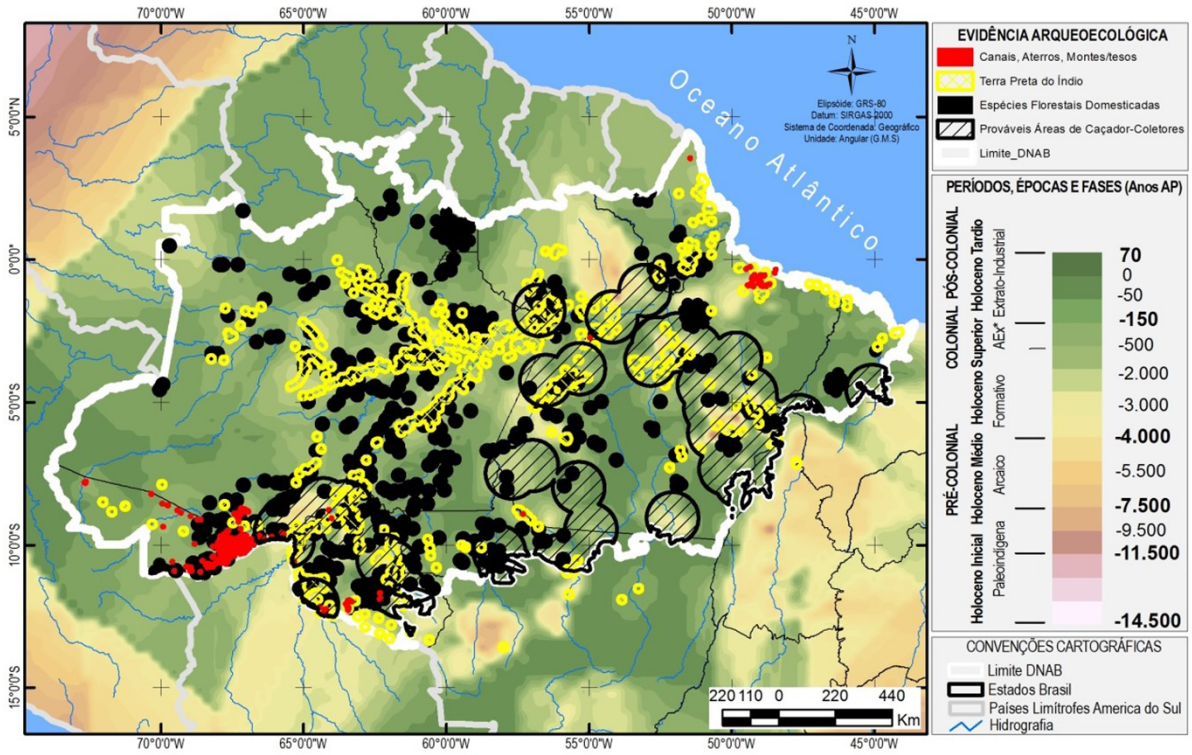
The Formative phase corresponds to approximately four millennia prior to European colonization and is characterized by the consolidation of sedentarism, population densification in the Amazon River channel, a socio-technological revolution, and agricultural expansion – phenomena that intensified the transformation of landscapes. Clear indicators of these ecological transformations are the sambaquis and the TPI formations.

The sambaquis are distributed discontinuously from the island of São Luís (MA) to the Guaporé River valley (RO), passing through northeastern Pará, the Marajó Archipelago, the coast of Ampara, the lower Xingu, the mouth of the Tapajós River, and the city of Itapiranga (AM) (Neves, 2006; Schaan, 2009). Along plains and terraces of the Amazon River and its tributaries, a high concentration of TPI soils indicate occupation by pre-colonial societies. Clement et al. (2015) point to the agricultural evidence associated with TPI (~2,000 years BP), such as at the headwaters of the Xingu and Madeira rivers.

In the Marajó Archipelago, the origin of pottery culture is related to the agglomeration, between 3500 and 500 years BP, of small villages with different ethnic groups (Magalhães, 2016), spreading along the Amazon River and its main tributaries (Neves, 2006).

At the beginning of the Christian era, artificial embankments were built in flood environments of the Marajó Archipelago, to allow human permanence, during flood seasons. Around 500 AD, these mounds multiply, along the main rivers and around the great Arari Lake, associated with TPI (Prous, 2006; Schaan, 2009). Figure 4 presents the spatialization of anthropogenic evidence, associated with the Pre-Colonial period.

Figure 4 – Anthropogenic evidence in the Pre-Colonial Brazilian Amazon



Red = Canals, Landforms, Mounds/ridges; Yellow = Indian black earth; Solid black = Domesticated Forest Species; slanted lines = Probable hunter-gather areas; White= Limit of NDBA.

Sources: Schaan (2007), Costa et al. (2009), McMichael et al. (2014), Clement et al. (2015), Levis et al. (2017) and Iphan ([n.d.]), with data compressed and made available in shapefile format.

Compiled by the authors.

Agricultural settlements spread throughout the southwestern Amazon between 400 years and 100 years BC, in which earthwork constructions – geoglyphs – began to dot the landscape of northern Acre (Eriksen, 2011). However, ceramics dated between 2,000 and 2,600 years BP have shown that humans had already mastered agriculture, since such occupations coincide with the chestnut groves in the region (Nicoli et al., 2001, p. 661 apud Costa et al., 2009, p. 24).

Colonial Period: socio-spatial retraction and territorial expropriation

Before the colonizers arrived in the region (15th century), the Amazon basin was densely occupied by different indigenous peoples with diverse lifestyles. Some groups lived in settlements, which later became cities (e.g., Santarém (PA), Manaus (AM), and Tefé (AM)) (Neves, 2006).

Reports about the European contact with indigenous Amazonian societies describe population agglomerations with groups of one to ten thousand people in the Upper Xingu, at the mouth of the Tapajós River, and in the savannas of Marajó (Clement et al., 2015). Approximately five million people occupied the Amazon basin in 1492 (Denevan, 2003). These estimates are more considered more conservative than the more progressive projections, with estimates approaching eight million (Neves, 2006).

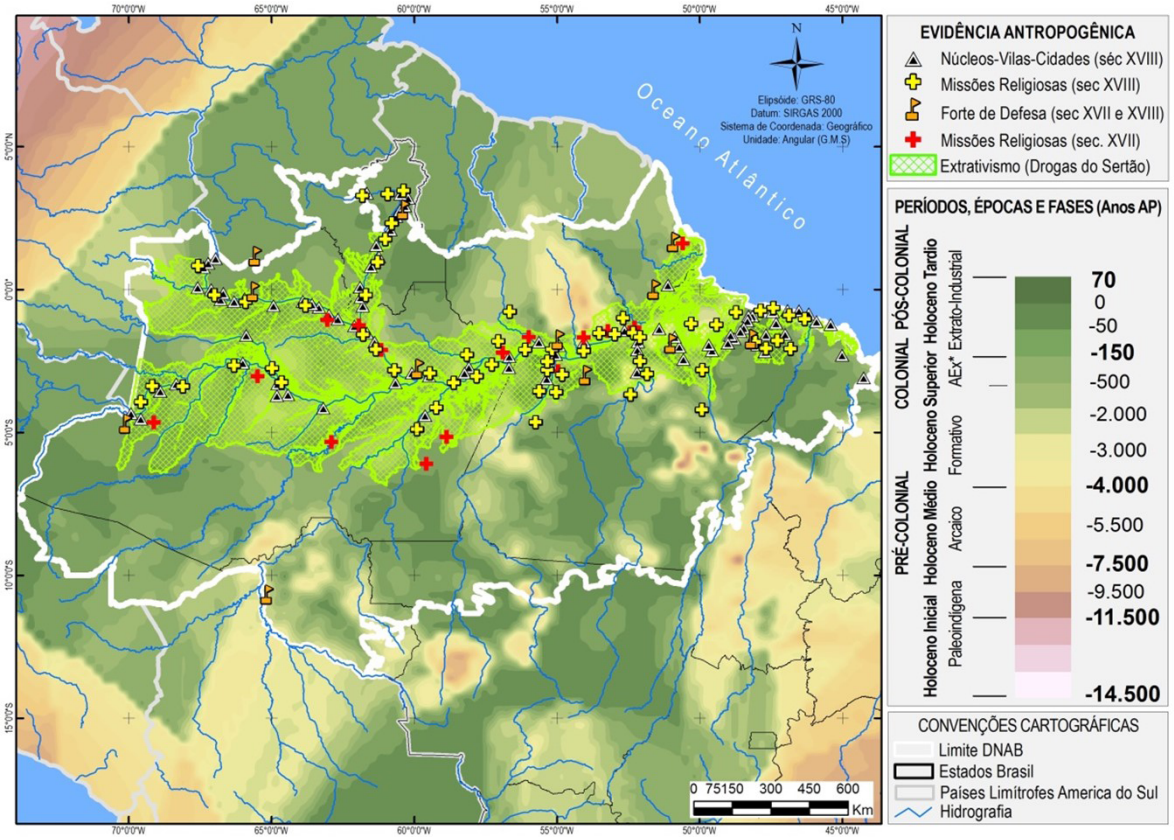
Contact with Europeans affected the prevailing socio-cultural organization and the number of inhabitants, due to the imposition of a different way of life and exposure to diseases spread by the colonizers (Roosevelt, 2013). The estimated population suffered a significant reduction of about 90% by 1650. In 1750, including Indians, Europeans, and slaves, there were only 30% of the inhabitants that lived there in 1492 (Denevan, 2003).

The settlement of the region followed the interests of European mercantilism through the vegetal extraction centers linked to the export economy ¬– Drogas do Sertão (Figure 5).

In this phase of interior colonization, also driven by Jesuit missions, several cities were founded on the margins of the lower and middle courses of the Amazon River, such as Gurupá (PA) (1639), Santarém (PA) (1661), São Gabriel da Cachoeira (AM) (1690), Manaus (AM) (1699), and Tefé (AM) (1709) (Miranda, 2007). In addition to missionary occupations, the Portuguese Crown also decided to combat French incursions in the northern Amazon region, resulting in the conquest of the Negro, Branco, and Solimões rivers (Guzmán, 2008).

In the second half of the eighteenth century, the political actions of Portugal's Secretary of State, Marquis of Pombal, in the Amazon are the first indications of state intervention in the regional economy, in search of regional and national integration (Guzmán, 2008).

Figure 5 - Anthropogenic evidence in the Colonial Brazilian Amazon



Black triangle = Centers, Villages, Cities (XVIII century); yellow crosses = Religious Missions (XVIII century); Orange flags = Defensive forts (XVII and XVIII centuries); Red crosses = Religious Missions (XVII century); Green lines = Extractivism.

Sources: Pfafstetter (1989), Arruda (1991), Araújo (2004), Chaves and Pena (2013) and IBGE (2017a), with data compressed and made available in shapefile format) and IBGE (2017c).

Compiled by the authors.

Post-Colonial Period: Socio-spatial diversification and landscape suppression

The Post-Colonial period can be divided into two: from 1850 to 1950 and from 1950 to the present. In the first, there is an intensification of extractive activity, inherited from the previous period and enhanced in the current one. The second is characterized by agro-industrial activity, with emphasis on mineral extraction and the expansion of urban infrastructure and agricultural structures. Both cycles intensified anthropic intervention in the region's natural resources, forging the Diversification phase.

The extraction of latex from rubber trees for its commercial production drove the occupation of floodplains to the headwaters of rivers (e.g., Acre), participating as the third product of Brazilian exports (Homma, 2001). Homma highlights, as a consequence of this activity, the construction of the port of Manaus (1907), to support the collection and export of rubber, and the Belém-Bragança (1883-1908), Madeira-Mamoré (1907-1912), and Tucuruí (1905-1944) railroads to occupy areas of drier lands and facilitate transport.

With the end of the Rubber Cycle and the population increase (in the first half of the twentieth century), the region began and economic decline (Lui; Molina, 2009). The decline of latex extraction reduced migration to the region, which resulted in the search for new productive strategies in the Amazon, such as jute and mallow extraction.

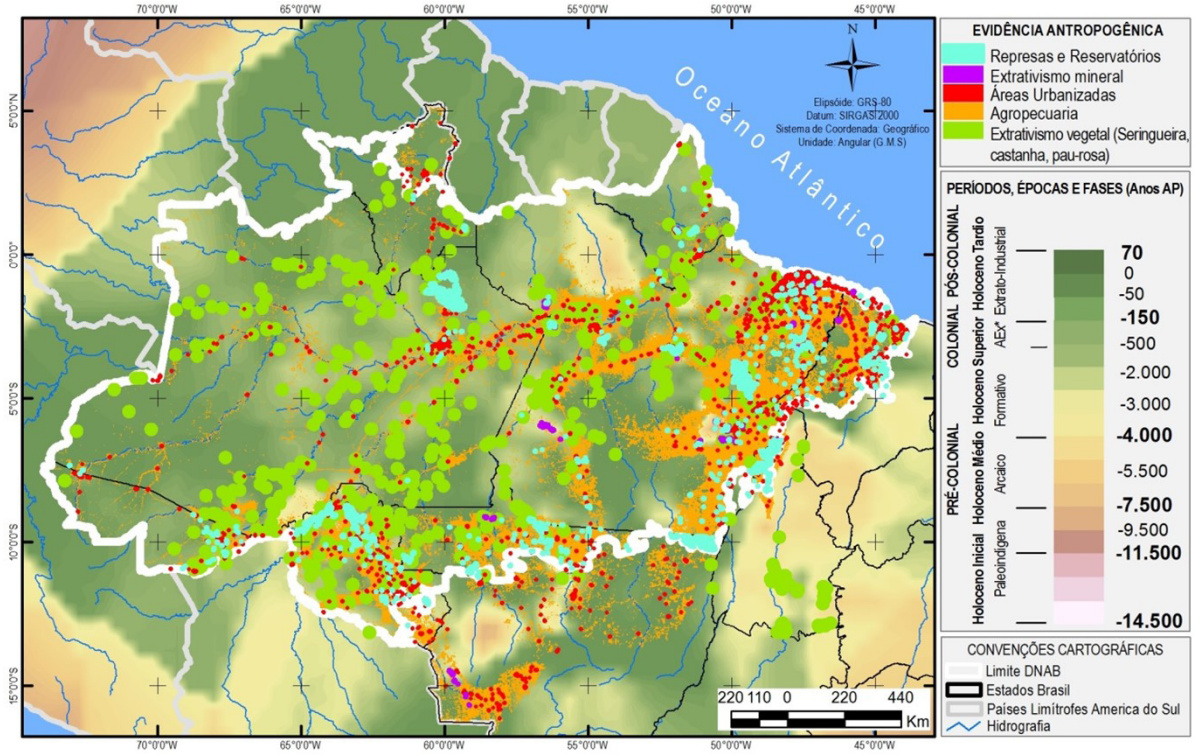
Japanese immigration established the jute culture in the Amazon floodplains, initially in the state of Amazonas and later in northeastern Pará, and it was mainly helped by the availability of labor from the diminishing rubber plantations. In northeastern Pará, this activity was almost simultaneous with the expansion of black pepper cultivation, boosting agriculture in the region (Homma, 2001), as well as the extraction, on dry land of rosewood and Brazil nuts (Leite et al., 1999).

Starting in the second half of the 20th century, the Amazon experienced a set of public policies that redirected production in the region, such as the creation of the Superintendency Plan for Economic Development of the Amazon (Castro; Campos, 2015). Such policies represented a paradigm shift in the NDBA, establishing a "new" socio-spatial dynamic between the plains and depressions, toward the forest interior.

In the 1970s, the Brazilian government assigned a new political-ideological conception to the Amazon, starting from the discussion that the region was an extensive demographic void that should be occupied. To this end, the federal government was responsible for the implementation of large-scale colonization and "development" projects in the region, such as the National Integration Program (PIN) (1970), the Agricultural and Agri-mineral Poles of the Amazon Program (Polamazônia) (1974), and the Great Carajás Project (PGC) (1980).

The Amazon became coveted by national and international markets, which caused a negative impact on the environment, due to fragmentation and destruction of landscapes (Figure 6).

Figure 6 – Anthropogenic evidence in the Post-Colonial Brazilian Amazon



Mint green = dams and reservoirs; Purple = mineral extractivism; Red = urban areas; Orange = Agriculture; Green = vegetable extractivism.

sources: MapBiomas (1985, 2019), Leite et al. (1999), Thomas et al. (2014), Homma (2014), IBGE (2017a), Latrubesse et al. (2017), Inpe (2018), and ANA (2019), with data compacted and made available in shapefile format.

Compiled by the authors.

The construction of extensive highways and vicinal roads, such as the Cuiabá-Porto Velho (BR-364) (in 1968), Transamazônica (BR-230) (in 1972), and Cuiabá-Santarém (BR-163) (in 1973), resulted in the creation of two occupation poles: Sudam cattle ranching projects (southeast of Pará and north of Mato Grosso) and Incra settlements (Rondônia and Transamazônica) (Castro et al., 2014). In southern Pará, the PA-150 highway stands out, which became a gateway for loggers and cattle ranchers (Homma, 2001).

Between 1960 and 2000, large extractive and infrastructure projects consolidated the role of the Amazon in the national and international contexts, as well as the socioeconomic dynamics, especially around the mineralogical projects, such as Icomi (in Serra do Navio (BP)), Serra Pelada (in Curionópolis (PA)), Vale do Rio Doce/Vale (in Parauapebas (PA)), Rio do Norte Mineralization (in Oriximiná (PA)), Albrás-Alunorte (in Barcarena (PA)), Alcoa (in Juruti (PA)), and Hidro-bauxita (in Paragominas (PA)).

Figure 6 illustrates the Amazon River channel and the north-south axis of eastern Amazonia, east-west of southern Amazonia, central-south of central Amazonia, connecting Santarém to northern Mato Grosso, and north-south of western Amazonia, connecting the states of Roraima, Amazonas, and Rondônia.

Based on the archaeological evidence, a periodization of the occupation process of the Amazon is proposed (Table 2).

Table 2 – Period, epoch, phase, and socio-spatial events in the Holocene Amazon

period	epoch (years BP)	phase/ production	Social group(s)	socio-spatial event	location/region
Pre-colonial	Early Holocene (11,500–7,500)	Paleo-indigenous extractivism (preceramic)	Paleoindian hunter-gatherer	arrival of the humans and initial dispersion in the Amazon, lithic technology	Upper Madeira River, Upper Teles Pires River (Parecis plateau), Xingu plateau
	Middle Holocene Médio (7,500-4,000)	Archaic: extractivism (preagricultural)	hunter-gatherer-fisher	beginning of ceramic production, diversity of human groups, and horticulture	Coast of Pará, Lower-Middle Amazon, Carajás Mountains
	Upper Holocene (4,000-150)	Formative: Extractivism-agricultural	gatherer-fisher-farmer	population expansion, ceramic-agricultural societies, and sedentary	Amazon coast, channel of the Amazon River and tributaries (Tocantins, Tapajós)
Colonial		Complexity: commercial extractivism and rustic cultivation	gatherer, fisher, missionary, settler	population reduction, expropriation, and simplification	Amazon coast, channel of the Amazon River and mouth of tributaries
Post-colonial	Late Holocene (>= 150)	Technical-scientific diversification, agroindustry	state, industries, finance	population increase, urbanization, degradation	Amazon coast, eastern Amazon, plains and plateaus, northern and southern highlands

Sources: Roosevelt et al. (1996), Lui and Molina (2009), and Costa et al. (2009).
Compiled by the authors.

Processes of occupation and anthropogenic advancement, within natural systems

Anthropogenic evidence, associated with the Paleo-indigenous phase, can be found on the Upper Madeira (Ji-Paraná-Aripuanã Plateau), the Upper Teles Pires (Parecis and Uatumã-Jari Plateaus), the dissected plateau of the Xingu, among others. This phase encompasses an anthropogenic area estimated at 760 thousand km2, equivalent to 20% of the study area.

In the Sedimentary Depressions domain, the first occupations of the interfluves occurred in the Interplanar Depression of the Phyto-pluvial Tablelands at Monte Alegre (e.g., Pedra Pintada Cave), the lower Xingu (e.g., Cachoeira Jericoá site) and the lower Tapajós (e.g., N. Sra. de Lourdes site). In the Southern Marginal Phyto-Transitional Depression (e.g., Upper Madeira), moderate occupation was detected. In this domain, the area of anthropogenic occurrence can reach about 15%. As for the natural systems, the Interplanaltic Depression of the Phyto-pluvial

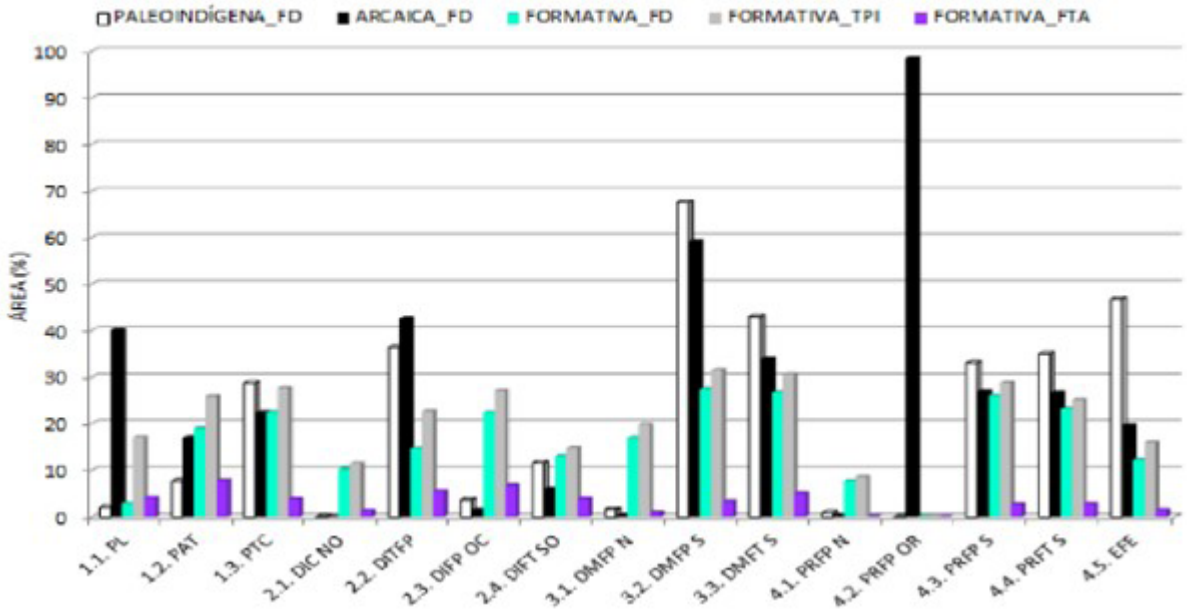
Tablelands (36%) and the Southwest Southwestern Interplanaltic Phyto-pluvial Depression (11%) stand out (Figure 7).

The Crystalline Depressions presents significant human remains. In the Southern Marginal Phyto-pluvial Depression of the natural system, the relevant presence of anthropogenic evidence was observed in eastern interfluves (e.g., Tocantins and Xingu rivers), as well as in the Southern Marginal Phyto-transitional Depression, which has evidence of occupation in central interfluves (e.g., between the Iriri and Tapajós rivers) and in the southwest (e.g., Upper Madeira). In the northern portion of this domain in the Northern Marginal Phyto-pluvial Depression, a possible absence of human occupation was detected, probably due to the ecological determinism imposed by the dense forest and the rugged reliefs. The Crystalline Depressions domain presents moderate evidence (33%), highlighting the Southern Marginal Phyto-pluvial Depression (67%) and the Southern Marginal Phyto-transitional Depression (43%).

The Plateaus and Montane Reliefs presented a discrete occurrence of anthropogenic evidence, with emphasis on the natural systems in the Southern Residual Phyto-pluvial Plateau (e.g., Carajás Mountains) and Southern Residual Phyto-transitional Plateau (e.g., Chapadas do Cachimbo), both with an anthropogenic increment of approximately 34% (Figure 7).

In the Archaic phase, concurrent with the advent of horticulture, ceramic production begins, considered an embryonic productive technique of agricultural societies. This is especially evidenced in the Pará coast (e.g.: Guará and Viseu sambaquis), the Lower-Middle Amazon (Paituna and Taperinha sites), the Jamari River (Pedra Pintada), the Negro River (Iranduba), the Upper Madeira, and the Carajás Mountains (Rio Verde).

Figure 7 – Anthropogenic increase of the natural systems of the Pre-Colonial period phases



Compiled by the authors.

Note: The X-axis of the graph represents the natural systems described in Figure 1 and Table 1. Anthropogenic evidence: domesticated forest (FD), Terra Preta do Indio (TPI), domesticated forest + Indian Terra Preta + landfill (FTA).

The evidence of the Archaic phase is in an area of 700 thousand km2, equivalent to 19% of NDBA, distributed predominantly over the Coastal Plain, the Interplanaltic Tableland Depression, the Southern Marginal Phyto-pluvial Depression, the Southern Marginal Phyto-transitional Depression, and the Eastern Residual Plateau (Figure 7).

These increments denote a significant spatial diversity, especially in the southwestern portion (Rondônia and Acre) and in eastern Amazonia (Lower Tocantins, northern periphery of the southern cratonic domains, Pará coast, and Lower Amazonas), probably due to socio-organizational evolution and greater adaptability to ecological conditions.

The anthropogenic evidence associated with the Formative phase is found in several natural domains, highlighting domesticated forest species and TPI. The socio-spatial dynamics of this phase is marked by expressive occupational processes as the Amazon Plains and the Sedimentary Depressions, highlighting the eastern portion – current state of Maranhão (Pindaré River and tributaries), the Lower-Middle Amazon and tributaries (Xingu, Tapajós, Madeira, and Negro rivers) and the extreme southwest of the NDBA (Upper Madeira River).

The occurrence of anthropogenic evidence in this phase, estimated to be around 45% of the NDBA, highlights the natural systems Alluvial Terrace Plain, Interplanaltic Depression of the Phyto-pluvial Tablelands, Western Interplanaltic Phyto-pluvial Depression, Southern Marginal Phyto-pluvial Depression, and Southern Marginal Phyto-transitional Depression.

In this context, geomorphological evidence is represented by formations and/or by morphological changes in relief such as channels and landforms/mounds over the Southwestern Interplanaltic Phyto-pluvial Depression (present-day Acre State) and the Marajó Island plains, totaling an area around 38 thousand km2, equivalent to 1% of NDBA.

The spatial distribution of domesticated forest species and the occurrence of TPI show a cause-and-effect relationship, suggesting that the socio-productive base of these societies was agricultural cultivation and forest management.

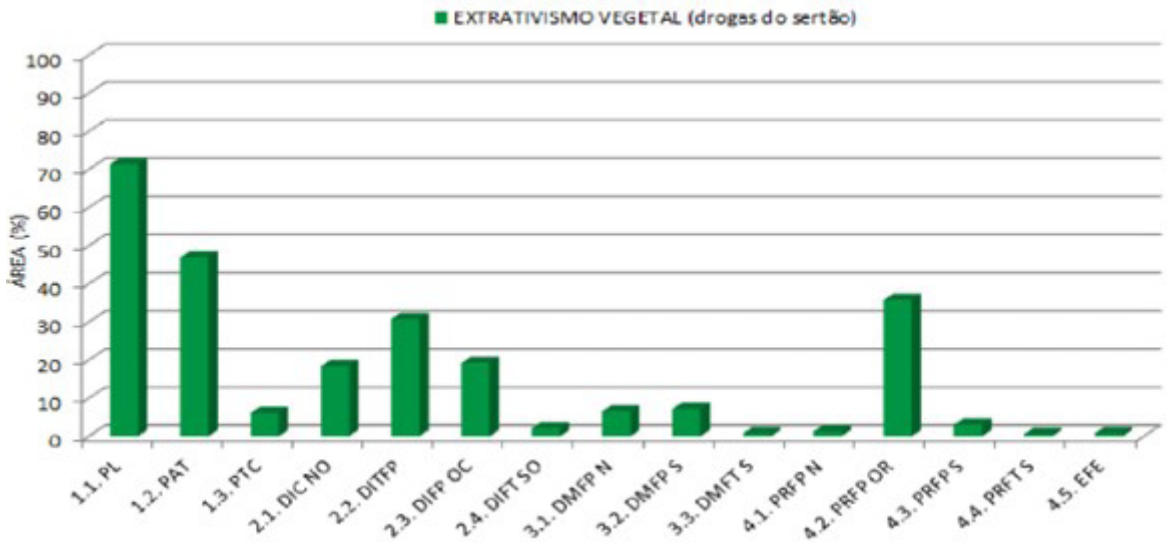
The spatial diversity of this evidence demonstrates a high geographic variability, dispersed over several natural systems, constituting evidence that corroborates the hypotheses of significant occupation of the Amazon prior to the arrival of the Europeans.

In the Decomplexification phase, of the Colonial Period, the socio-spatial dynamics first occurred in the Amazon River plains, site of the first religious missions.

The anthropogenic evidence of this phase had a major increase in the Plains and Sedimentary Depressions (Figure 8), located between the Amazon coast (northwestern Maranhão, northeastern Pará, and Amapá coast) and the Amazon River channel (lower and middle courses) and several tributaries.

Figure 8 shows that the extractive activity was predominantly restricted to the Amazon Plains and partially to Sedimentary Depressions, which surround the Amazon River channel. Here the percentage of anthropogenic increase occurred more sensitively in the natural systems of the Coastal and Alluvial-Terracial plains and in the Interplanaltic Depression of the Phyto-pluvial Tablelands and the Western Interplanaltic Phyto-pluvial Depression.

Figure 8 – Anthropogenic increase of natural systems in the Colonial Period related to Vegetal Extractivism.



Compiled by the authors.
Note: The X-axis of the graph represents the natural systems described in Figure 1 and Table 1.

The Colonial period was marked by the retreat of previous occupational processes and by timid expansions of new occupations. As a reflex of this occupation process, the spatial dynamics decelerated, the socio-cultural (evangelization) and productive (collection of forest products) organizations simplified, new producing agents were incorporated (missionaries and settlers), and the indigenous societies endured deterritorialization.

In the Diversification phase of the Post-Colonial period, the Amazon went through profound environmental changes, due to extractive activity (19th century) and, later on, by the advent of new socio-productive factors.

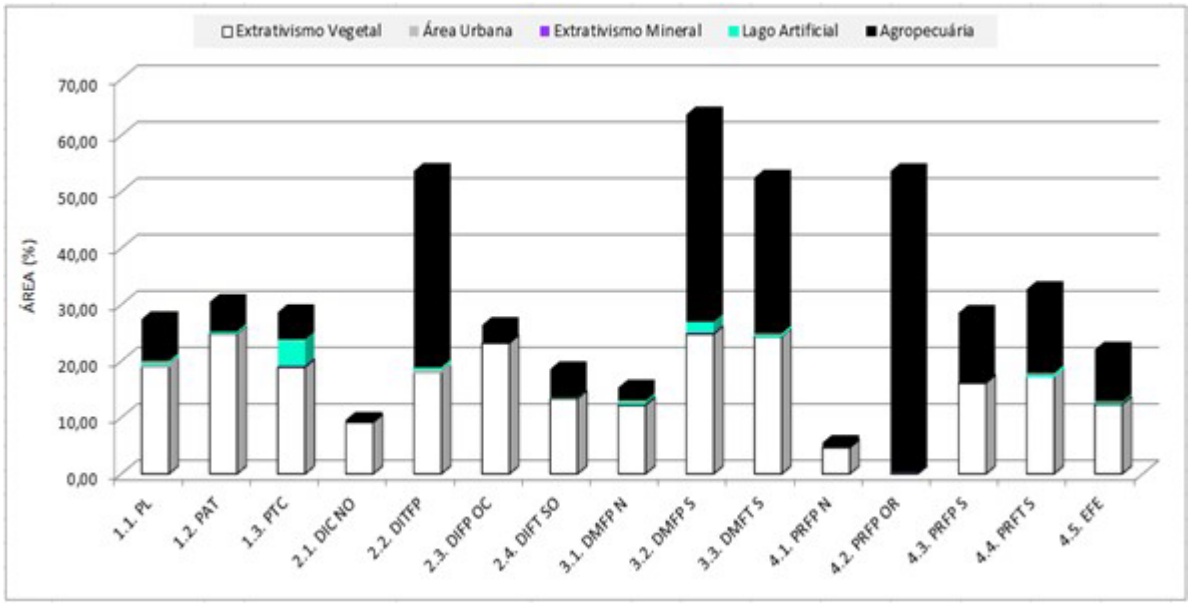
Beginning in the second half of the 20th century, the Amazonian economy started to experience a new production cycle, based on mineral extraction and agriculture, especially cattle raising. The implementation of a new production matrix in the region, initially driven by governmental initiative and followed by private interests, triggered a complex and varied set of emerging factors, forging several levels of anthropogenization.

The projects implemented in the Amazon beginning in the 1960s, such as colonization through Incra agricultural settlements, the agricultural undertakings financed by Sudam, the mineralogical poles, and more recently, the monoculture of oil palm and the mechanized cultivation of grains, have contributed to environmental diversification.

The anthropogenic evidence of the Post-Colonial period presents a spatial amplitude, expanding throughout the NDBA. However, it is most concentrated in the eastern part, along the Amazon River channel and its main tributaries, and on the central-south axes.

The socio-spatial dynamics of the Post-Colonial period has been characterized by intense occupational processes. In the Amazon Plains domain, the natural systems Coastal Plain, Alluvial-Terrain Plain, and in Crystalline Terrain Plain stand out, the latter comprising a good part of the tributaries of the Amazon River and high elevations of plains on the northern and southern cratons (Figure 9).

Figure 9 – Anthropogenic increase of natural systems in the Post-Colonial period



White = Vegetal extractivism; gray = urban area; purple = mineral extractivism; mint green = artificial lake; black = agriculture
Compiled by the authors.
Note: The X-axis of the graph represents the natural systems described in Figure 1 and Table 1.

The Diversification phase had a strong presence of actors (e.g., Indians, quilombolas, traditional communities) and little developed activities (e.g., rudimentary agriculture, extractivism) inherited from their ancestors. These aspects give the Amazon a fragmented socio-productive scenario, where divergent actors and activities have occurred concomitantly in time and space, with serious environmental impacts.

In the Sedimentary Depressions domain, an exponential and generalized expansion of occupation was detected in the Interplanaltic Depression of the Phyto-pluvial Tablelands, a significant and continuous expansion in the Western Interplanaltic Phyto-pluvial Depression, mainly, in its eastern portion and, more discretely, in its western portion, as well as in the Southwestern Interplanaltic Phyto-pluvial Depression (Acre).

In the Crystalline Depressions, extensive occupation was observed, mainly in the southern and northern marginal depressions, where constant expansion of agricultural activities and mineral extraction could already be detected. The occupation of the Plateaus and Montane Reliefs domain followed a slow and gradual speed, mainly by mineral extraction.

Anthropogenic evidence, not very spatially expressive, occurred including urban structure, mineral extraction, and artificial lakes. Urbanized areas stand out in the eastern portion of the Interplanaltic Depression of the Phyto-Pluvial Tablelands and along the Coastal and Alluvial-Terrain plains. Mineral extraction occurred predominantly in depressions and crystalline plateaus, mainly in the Southern Amazonian domain. Most of the artificial lakes are reservoirs for electrical energy generation and dams to support agricultural activities, located predominantly in transition zones between the crystalline and Sedimentary depressions, highlighting those in the southern

(e.g., Tocantins, Araguaia, Xingu, Jamanxim, Madeira) and eastern (e.g. Capim, Gurupi, Pindaré rivers) portions (Figures 6 and 9). Despite the low areal occurrence, the artificial lakes are anthropogenic evidence with broad environmental impacts, imposing deep decharacterizations on geomorphic processes, landscapes, and socio-spatial dynamics.

The anthropogenic increase shows that the dynamics of use of the main activities (vegetal extractivism and agriculture) permeate all natural systems, particularly vegetal extractivism. This panorama demonstrates the great extractive potential of the region, especially of the plains and some sedimentary depressions.

Although agriculture is a recent activity in the region, it has had an accelerated growth and wide spatial occurrence, and is present in all natural systems, to a greater or lesser extent, especially in the Interplanaltic Depression of the Phyto-pluvial Tablelands and the Marginal Depressions of the southern Amazon.

The set of anthropogenic evidence suggests that aspects intrinsic to the ecological potential and/or limitations of the natural domains of the Amazon had and still have a great influence on the dynamics of occupational processes in the Amazon.

The holistic and cumulative perspectives of human actions on natural systems allowed an evolutionary perception of anthropogenic pressure. The most anthropogenized natural systems include the Interplanaltic Depression of the Phyto-pluvial Tablelands, with an accumulated anthropic load around 206%, the Southern Marginal Phyto-pluvial Depression, with approximately 259%, and the Southern Marginal Phyto-Transitional Depression, with an accumulative percentage around 192%.

Final considerations

The anthropogenic evidence presents a close relationship with the conditioning factors of the surrounding environment. However, this evidence ends up feeding each other, either by the natural evolution of biodiversity or by the diversification of anthropogenic landscapes, driven by the way humans have managed these natural resources.

It is assumed that over time these groups have become familiar with the natural characteristics of the region and better understand the dynamics of its ecosystems, consequently selecting plant species and ecosystems with greater utilitarian potential for their livelihood.

The analysis about the dynamics of socio-spatial events demonstrate that humans have always established relationships with nature through their organizational and productive capacities, the latter conditioned by the available technology. As human beings have interacted with Amazonian nature, they have reached higher levels of knowledge and mastery, enhancing the conditions that facilitate socio-productive stabilization.

The attempted retrospective of the arrival and human adaptation to NDBA has made it possible to raise and systematize a range of evidence about the human relationship with regional landscapes, helping to conjecture, quantify, and qualify socio-spatial events. The mosaic of evidence demonstrates the wide temporal-spatial variety and the evolution of human relationships with natural resources in the region.

The dynamics of the processes of occupying the Brazilian Amazon implied a diversity of human macrosystems in the region, inherited and recently processed, which coexist and suggest that its natural domains present a significant level of anthropogenization, with a territorial extension of around 64%. However, if we consider the accumulation of this evidence throughout the Holocene, this percentage rises to 150%, that is, it extrapolates the study area by 50%, which indicates repeated occupation and extensive management of landscapes, favorable to the evolution of humans within the NDBAs.

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