Dossier

Scientific contributions for a deep history of the Amazon

Aportes científicos para una historia profunda de la Amazonía
Contribuições científicas para uma história profunda da Amazônia

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Abstract: This article presents a selection of the most recent findings in the fields of geology and archelogy of the Amazon and discusses how current scientific research can be useful in the production of environmental histories of the Amazon Forest. From the Miocene, around 20 million years ago, when the west of the forest was a wetland, to the Holocene, roughly 11 thousand years ago, when humans moved into the forest, the fields of Amazon geology and Amazon archaeology have shed light on the deep past of the region. Contributions of both fields can assist environmental historians to paint a fuller picture of the Amazon's deep past.

Keywords: Amazon geology, Amazon archeology, Amazon environmental history.

Resumen: Este artículo presenta una selección de los hallazgos más recientes en los campos de la geología y la arqueología de la Amazonía y discute cómo la investigación científica actual puede ser útil en la producción de historias ambientales de la Selva Amazónica. Desde el Mioceno, hace unos 20 millones de años, cuando el oeste de la selva era un humedal, hasta el Holoceno, hace aproximadamente 11 mil años, cuando la humanidad se trasladó la selva, los campos de la geología amazónica y la arqueología amazónica han arrojado luz sobre el pasado profundo de la región. Las contribuciones de ambos campos pueden ayudar a las historiadoras ambientales a pintar una imagen más completa del pasado profundo de la Amazonía.

Palabras clave: geología amazónica, arqueología amazónica, historia ambiental amazónica.

Resumo: Este artigo apresenta uma seleção das descobertas mais recentes nas áreas de geologia e arqueologia da Amazônia e discute como a pesquisa científica atual pode ser útil na produção de histórias ambientais da Floresta Amazônica. Desde o Mioceno, há cerca de 20 milhões de anos, quando o oeste da floresta era um pantanal, até o Holoceno, há cerca de 11 mil anos, quando humanos passaram a habitar a floresta, os campos da geologia amazônica e da arqueologia amazônica tem lançado luz sobre o passado profundo da região. As contribuições de ambos os campos podem ajudar historiadoras ambientais a pintar um quadro mais completo do passado profundo da Amazônia.

Palavras-chave: geologia amazônica, arqueologia amazônica, história ambiental amazônica.

Geology and Archelogy of the Amazon: layers of the deep past of the forest

Famous explorers of the Amazon – from Francisco de Orellana to Teddy Roosevelt – would be shocked to read the most recent science about the forest. Their narratives, like the vast majority of historical accounts, deemed the forest pristine and eternal, immobile in its ancient ways and nearly untouched by human hands, so vast as to dwarf any marks left by our actions. Now, the Amazon is being portrayed in new scientific light that shows the dynamism of the region through deep time, as well as ancient human presence and management of the forest. Recently, several fields of science have contributed novel interpretations to the deep past of the forest, based on new methods and quickly evolving technology. The latest geological research reveals the increased likelihood of an ancient Amazonian Sea, connected to the Caribbean sometime during the Miocene Epoch (23.03 to 5.33 million years ago), a hypothesis long suspected and still debated amongst geologists. In a different field of science, Amazon archeologists have been pushing back the date of human occupation of the forest, now believed to have been inhabited for more than 11,000 years. The forest itself, paleo-scientists of all stripes say, is much more domesticated than previously thought.

These new findings help establish the many layers of natural and human history buried within the largest rainforest in the world.[1] In tandem, recent geological and archeological discoveries offer a new vision of the forest, one that can help answer long-asked questions, such as the main drivers for the vast biodiversity of the region (which holds one tenth of the world's species) and how long humans have inhabited the forest. The deep history of the Amazon, however, has not yet been the subject of environmental historians. While there are many excellent environmental history works about the region, they largely focus on the last five centuries, with the majority having a more modern focus, such as the 19th and 20th century forest occupation and destruction (Dean, 1987; Grandin, 2009; Garfield, 2013; Acker, 2017). With themes centered on the boom and bust of the rubber trade, failed attempts of global enterprises at installing industrial and cattle ranching ventures in the forest, and the many efforts to "colonize" the forest, these important works of Amazon environmental history do not fully engage with the history the Amazon Forest itself, focusing instead on how modern humans worked to transform the forest. While some attention has been given to the more ancient times of the Amazon Forest (Pádua, 2000), a more detailed historical account of the deep past of the forest is still missing. So far, the earlier days of the Amazon, and of its human inhabitants have been the sole preserve of geologists, archeologists, and other paleo-scientists.

This article presents a selection of the most recent findings in the fields of geology and archelogy of the Amazon and discusses how current scientific research can be useful in the production of environmental histories of the Amazon Forest. On the one hand, historians gain different perspectives from reading cutting-edge scientific work. Just like learning a new language, being able to engage with current science production opens up new avenues of research, with novel themes and hypotheses, as it multiplies the sources available to us, far beyond the archives. On the other hand, the hard sciences have much to gain by the engagement of historians. Historians are more mindful of some varieties of nuance and detail, as we are used to dealing with shorter spans of time and can help temper some of the more sweeping claims made by scientists.

Closing seas and rising mountains: the geological past of the Amazon

One of the greatest scientific questions that is yet to be fully answered about the Amazon is the root causes of its astonishing biodiversity. For hundreds of years, naturalists like Alexander von Humboldt and other

explorers of the Amazon marveled at the vast diversity of plant and animal species of the region (Humboldt & Bonpland, 1815). More recently, 20th-century modern science has continued to search for explanations for its ecological uniqueness. For several decades, scientists looked at climate, soil, and biological dispersal, going back a couple million years to investigate the evolutionary routes taken by Amazon species and to try to explain the sheer variety of life forms present within the forest. Meanwhile, geologists working in the Amazon were independently making discoveries and producing models that could aid in this endeavor with their ability to produce, read, and interpret deep-time data from rock cores and fossil samples. But geological research, concerned with a much deeper past, spanning tens or hundreds of million years, had little to do with these ecological debates (McDermott, 2021; Hoorn et al., 2022).

The first dominant paleoecological theory for the biodiversification of the Amazon was formulated in 1969 by German ornithologist Jürgen Haffer and prevailed up until the early 1990s (Haffer, 1969). Known as the Amazon Refugia hypothesis, it stated that, over the last 2.6 million years, the forest had evolved as several distinct patches with no connection to one another, akin to island settings like the Galapagos. This would explain the incredibly high biodiversity found in the currently continuous expanse of the Amazon (Rocha & Kaefer, 2019).[2] Cracks in this theory were already appearing when geological research offered insight into the much deeper past of the forest that could debunk the idea of isolated patches, at the same time as it offered new explanations for the potential drivers of the long debated biodiversification of the Amazon. Geologists' main hypothesis was: water, lots and lots of water.

The most recent findings of geological works in the Amazon all point to the same broad conclusion: between 10 and 20 million years ago (a much longer span than the 2.6 million years that had been the earlier threshold for paleoecological investigation), the western side of the Amazon was a vast wetland. Not only that, but also probably at times a saltwater sea, with connections to the Caribbean Sea, which may have flooded the area with some regularity. So far, geologists have not hammered down the details, but it seems that they are finally getting closer to more definitive proof of this long-proposed hypothesis. Geological finds of fossils of marine and mangrove species (both animals and plants) in the heart of the forest, thousands of miles away from the nearest ocean have long puzzled geologists. A vast wetland in western Amazonia, with connections to the ocean, would help explain this. This mix of intermittent marine and freshwater environments may aid in solving other Amazonian ecological mysteries, such as the strong presence of typically marine animals in its rivers, which feature a number of dolphins, sharks, stingrays, and manatees, who have likely evolved to adapt to the change of environment, from salt to freshwater (Lovejoy et al., 2006).

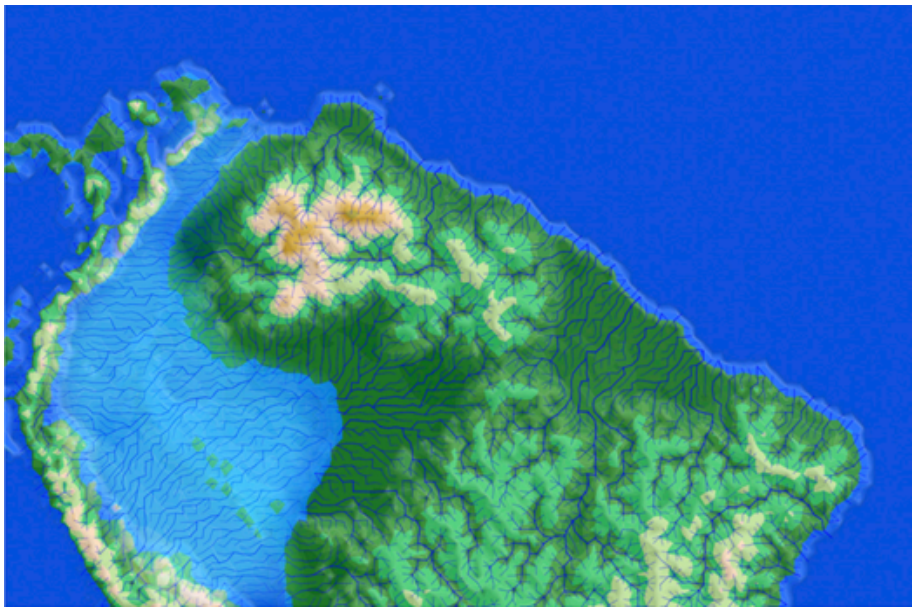

FIGURE 1
Geophysical modelling of a western Amazonian Sea in the Miocene
Amy McDermott (2021). "A sea in the Amazon", Proceedings of the
National Academy of Sciences V 118 - N 10 doi:10.1073/pnas.2102396118

Added to that, the Amazonian Sea hypothesis also provides a plausible explanation for the immense amount of water that presently constitutes the forest's vast river system. Geologists today agree that an ancient version of the Amazon River once flowed westward, from the proto-Congo River system present in Gondwana, the supercontinent once linking Africa and South America. Gondwana started breaking apart around 150 million years ago, in the Late Jurassic, opening the Atlantic Ocean. After breakage, this river system ended up on the northern portion of South America and continued to flow west mostly unimpeded for many geological epochs. The Andes range had not fully formed yet, although mountains existed in the west. This ancient river likely emptied its waters in the proto-Caribbean Sea, which had opened up around 160 to 180 million years ago. Even then, some of the water would have started pooling in the west of the Amazon.

Around 10 to 15 million years ago, the tectonic collision of the South American Plate with the Nazca Plate produced another spurt in the long series of mountain-building events known as Andean orogeny (Orme, 2014). The latest episode caused the quick rise of the complex range of tall mountains in the Miocene Epoch, the most consequential time for the formation of the vast inland sea (Jaramillo et al., 2017). Suddenly (at least in geological terms), the ancient river had a massive barrier, resulting in widespread flooding of the area, which gradually turned into inland sea, then a freshwater marsh or swampy lake – or in some geological models, an intermittent mix of those. Around 4 million years later, the waters of this wetland had worked through the sandstone sediments of the area until the river system finally started flowing east, as it still does today. According to this model, the river's meandering and its many tributaries are thought to be key in the formation and spread of the Amazon Forest as we know it (Figueiredo et al., 2019).

The deep geological history of the Amazon Forest is still being researched and written. New models displaying this vast wetland in western Amazon, named the Pebas System, have given rise to new hypotheses for the biodiversification of the Amazon (Hoorn et al., 2022). Sediments, fossils, and palynology studies of western Amazonia lend weight to the hypothesis of a vast water environment during the Miocene, between 10 and 20 million years ago. With some imagination, it is possible to envision the Pebas as a vast, glistening wetland, visible from the Andean peaks, that spanned from Paraguay to Venezuela when it reached

a maximum size of over one million square kilometers. The Pebas is only now being described and it sounds like it was teeming with aquatic life:

> The Pebas consists of an association of deltaic plains; forested plains; low-energy wetlands with swamps, ponds, and channels; shallow freshwater lacustrine systems; and episodic, short-lived marine events. The Pebas underwent at least two short-lived marine incursion events, the first during the early Miocene, and the second during the middle Miocene, that may have influenced some components of the extant Amazonian floristic composition. (Gomes et al., 2021, p.1)

From this description, the Pebas sounds like a tropical wonderland of gharials, caimans, dolphins, manatees, and other ancient aquatic creatures, not to mention the incredible variety of plant life, inside and around this vast sea.

Put together, these new findings and models suggest that, beyond than the climate and the soils of 2.6 million years ago, the current biodiversity of the Amazon Forest may have a lot more to do with the deeper geological movements of mountain-building and sea closing, dating back tens of millions of years. The wetland model has a simple basic assumption: water was at the center of the rise of biodiversification. This vast and varied wetland system may be an important piece of the biodiversity puzzle. The latest model geologists have proposed is a

> scenario in which the Pebas System is a permeable biogeographical system. (...) This dynamic landscape favored biotic exchange at the interface of (1) aquatic and terrestrial, (2) brackish and freshwater and (3) eutrophic to oligotrophic conditions. In addition, the intermittent connections between western Amazonia and the Caribbean Sea, the Andes and eastern Amazonia favored two-way migrations. Therefore, biotic exchange and adaptation was probably the norm, not the exception, in the Pebas System. The myriad of environmental conditions contributed to the Miocene Amazonian wetland system being one of the most species-rich systems in geological history. (Hoorn et al., 2022, p. 25)

Humans in the Amazon Forest: not that pristine after all

While the ancient geological movements of western Amazonia provide new insight into the issue of biodiversification of the forest, another important question that has puzzled scientists for several decades may also be getting new answers: the extent and impact of human occupation of the forest. The Amazon had long been seen as a vast, mostly empty expanse of land, only sparsely inhabited by tribal peoples who didn't build or develop anything worthy of notice. These biased beliefs permeated the interactions between modern human outsiders and the forest from colonial times to the 21st century. From "green hell" to "land without men, for men without land"[3], the Amazon Forest has been consistently portrayed as both inhospitable and largely uninhabited.

Current scientific findings show such assumptions could not be further from the truth. A collection of recent archeological studies about the presence of humans in the forest portray the Amazon as much more anthropic and domesticated than we knew just a few years ago. Based on findings from multi-proxy interdisciplinary approaches that include carbon and nitrogen isotopic data, high resolution lake sediment records, phytolith analysis, artefact residues, Lidar, and satellite imaging – among other emerging technologies and techniques – archeologists and paleo-scientists are producing a large, and constantly growing, body of work that attests to intense human management and domestication across the Amazon Forest throughout the Holocene, an 11,700-year span to the present (de Souza et al., 2018; Hermenegildo at al., 2017; Piperno et al., 2021).

The Amazon was home to several human-nature entanglements over deep time that are being revealed by new research methods. Like their geological peers, archeologists of the Amazon are uncovering evidence and producing models that may revolutionize our current understanding of the forest. While historically seen as a patch of nature mostly untouched by human hands, now the forest seems to have been home to variety of human groups over several millennia. The forest may have sustained many more people, in larger groups, much more widely spread out than previously thought. This is a particularly novel understanding and leads

to new interpretations of human occupation and management of the forest. Scientists are excited about their findings. Most works include at least a couple of sentences devoted to debunking the 'pristine myth', that is the idea of an untouched region of the world. The forest, these scientists claim, was a highly cultivated garden, with large swaths of Amazonian Dark Earths (ADEs) now known to be anthropic soils, managed by ancient humans to enhance soil fertility, and potentially 85 domesticated hyperdominant plant species to prove it (Bongers et al., 2017). Some go so far as to ask:

> Can any Amazonian landscapes be considered natural? (Bush et al., 2015, p. 2284)

A recent survey of 81 Late Pre-Columbian sites in the Upper Tapajos Basin, in southwest Amazonia, for example, found 104 earthworks in the area, which suggests the presence of palisaded villages, fortified settlements enclosed by ditches, connected by causeways and capable of sustaining low-density urban-like populations of thousands. Other such structures have been uncovered in different parts of the forest, while many more are likely still hidden by forest cover. The discovery of these structures has implications for the development and spread of interconnected earth-building cultures, their languages, practices, and customs. The calibrated carbon dates of the earthworks in the study fall between AD 1410 and 1460, just a few decades prior European arrival on the continent. The projected human density is anywhere between half to a million people in an area described as a "periphery of the Amazon Basin". All this evidence, scientists suggest, shines a light on how these societies might have lived in pre-contact times, as they "appear to have been organized in regionally integrated peer-polity systems", recasting Amazonian dwellers as large, settled earth-building communities, rather than small nomadic bands of hunters-gatherers who left little or no imprint in the forest (de Souza et al., 2018).[4]

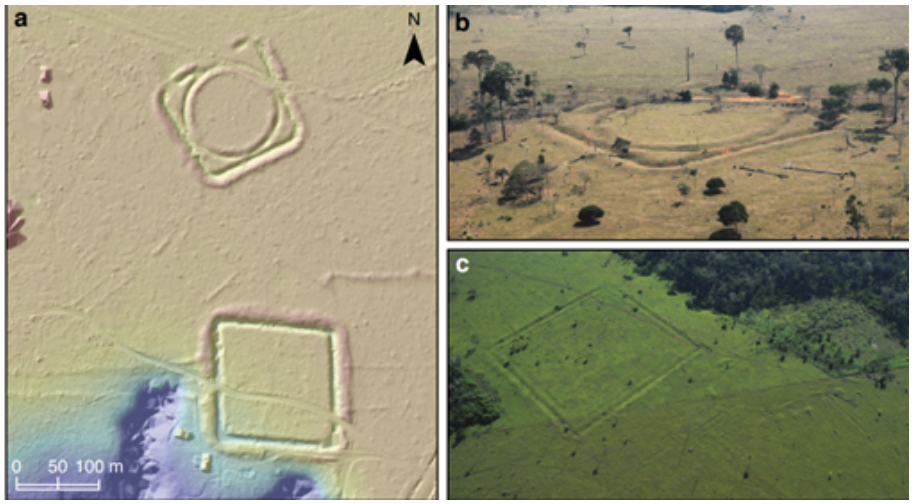

FIGURE 2
A selection of newly identified geoglyphs and mounded ring villages
de Souza, J.G., Schaan, D.P., Robinson, M. et al. (2018). Pre-Columbian earth-builders settled along the entire southern rim of the Amazon. Nat Commun 9, 1125. https://doi.org/10.1038/s41467-018-03510-7

These current advances and new evidence are uncovering many stories about Amazonia's past peoples, their spread across the forest and just how much they impacted the biophysical world around them (Palace et al., 2017). The focus on food production has been a central theme in the scientific conversation. Because of the uneven soil fertility – with western, younger soils being more fertile than the older, more settled and weathered soils of the east – one of the dominant aspects of the Amazonian past is the presence of Amazonian Dark Earths. These enhanced soils, called terras pretas in Portuguese, get their name due to the charcoal content mixed with the earth, darkening its color. Initially thought to be remnants of early settlements – because the soils were also mixed with bone and ceramic pieces – today, the terras pretas are recognized

to be human-made soils, manufactured intentionally to improve soil quality, by communities living as far back as 3000 BCE (Clement et al., 2017). Of the many plant domestications currently under investigation, established ones include peanuts, manioc, and Brazil nuts (Watling et al., 2018). Another strong candidate is the now famous açaí.

Domesticated food production radically changes ideas about hunter-gatherers in small and isolated groups. It also informs other recent findings and hypotheses. With more food and population in the region, it is possible to envision a dynamic network of settled communities connected through trade (and occasionally war) all the way to the Andes. Current estimates are that there were around 5 to 6 million people living in the Amazon at the time of European arrival. This number, however, might well increase in the future, given that so much evidence still needs to be unearthed and studied. The vastness of the Amazon means that there are several large swaths of forest that have not been the focus of scientific investigation yet.

Fruit orchards and large settled villages in the Amazon would nevertheless look quite wild to an external observer. Because forest dwellers did not develop metalwork, most of the land clearing and maintenance was done with fire – which would not necessarily give a 'civilized' aspect to Amazonian vegetable patches. Unlike cutting down trees, fire leaves traces scientists can pick up from sediments and phytoliths, making fire management, food production and large settlements currently the hottest topics of pre-contact Amazon research. As it is, the present picture of the deep human past in the Amazon includes active presence and traces dating back to the beginning of the Holocene (11,700 years ago), with some studies pushing the earlier dates as far back as 13,000 BCE (Roosevelt, 2013). Scientific evidence points to settled communities around 4,000 years ago engaging in soil enhancement (ADEs) and plant domestication, with clear choices of crops that, to this day, are hyperdominant species in the forest.

Miocene, Holocene, and Anthropocene in the forest: contributions for a deep Environmental History of the Amazon

So, what does all this new information about the deep past of the Amazon mean for environmental historians? While scientists are skilled in producing data from a wide array of methods, including rock core sampling, archeological digs, remote sensing, and a myriad of lab techniques that scrutinize geological and archeological materials, with ever more precise dating and details of all kinds, they do not have the training historians receive throughout our careers. Some of their historical accounts are very rudimentary, based on outdated concepts, and lack the nuance that professional historical analysis typically brings to the studies of past human groups. The evidence produced in scientific research still needs to receive a more elegant historical narrative than the ones so far being written by natural scientists. A bit of historical rigor would be beneficial to curb the new claims that the Amazon is entirely human-made. Also, including a historian in the large research teams may help avoid time scale imprecisions. Simply stating that pre-Columbian anthropogenic impacts happened 'in the Holocene' (as some scientists do) is still not quite as precise as historians would like – we are used to much shorter spans than nearly 12 thousand years.

Ultimately, the ideal scenario would be one where historians are part of the scientific teams that produce new data, as this would certainly enhance the qualitative analysis and interpretation of such data. Historians can assist with fine tuning of periodization, bring in knowledge of human societies and modes of organization, and make inferences and connections to other human groups across time and space. This is expertise that is particular to our field of specialization, while largely absent from scientific training. Historical thinking has the power to dislodge the model-thinking paradigm, which is the general norm in the natural sciences. As it is, historians can start by paying closer attention to scientific production that is already out there – as many environmental historians already do – and work on building bridges across disciplines for future efforts.

Lastly, another cohort of scientists working on the Amazon have issued dire warnings about the future of forest. In 2016, Earth systems scientist Carlos Nobre and his team formulated the not-without-controversy idea of an Amazon tipping point, a moment when mass-scale deforestation would cause the biome to collapse and become dry savanna-style grasslands (Nobre et al., 2016). According their models, two main drivers may lead to the tipping point: a 4 °C temperature increase and the loss of more than 40% of forest cover. So far, the region has seen a 1°C temperature increase over the last 60 years and current deforestation amounts to just below 20%. Such numbers made waves in the scientific community but failed to move wider audiences, who largely still subscribe to the long-established rhetoric of the Amazon as mostly untouched (and somehow indestructible). Then, in August 2019, a never-before-seen extreme event happened in Brazil that brought this scientific finding to the national conversation: a thick cloud of smoke descended on the country's largest city, São Paulo. The skies darkened to deep, dark grey, and day turned into night at 3 o'clock in the afternoon. It quickly became clear that it was the smoke from forest fires in the Amazon, nearly three thousand miles away, that had darkened the skies of São Paulo. Suddenly a hypothesis out of a scientific article seemed so much closer, like the beginning of catastrophe movie, where scientific warnings go unheard until it is too late.

But it is not too late for the Amazon. Between a recent change in government policies and more attention from the international community,[5] the Amazon (not only the large Brazilian part, but the whole forest biome) still has a chance of survival. Conservation and future-looking initiatives will only benefit from more knowledge about the deep past (geological and human) of the forest. The peril in which the Amazon rainforest finds itself currently is entirely human-engineered. The solutions will be too. Humans have earned our own geological epoch, the Anthropocene. But history unfolds before and beyond humanity. Deep history, in the very long-durée, spanning thousands or millions of years, layering multiple eras of natural activity and human entanglements in the forest can help shape and inform new and necessary visions for the future of the Amazon. Miocene, Holocene, and Anthropocene are millions of years apart and yet are integral parts of the Amazon as we know it today. Understanding the forest's deep past is essential for its future survival.

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Notes

[1] Here I will use the terms Amazon Forest and Amazonia interchangeably. These terms are not indicative of the present territorial divisions of national states, not reflecting the nine countries currently encompassed by the Amazon Forest biome. This analysis centers on expanded timeframes, of 10 to 20 million years for geological evidence and up to 13,000

years for archaeological research, long before South American countries came into existence. On occasion, research might indicate specific areas, particularly archaeological sites. But in the text, it matters less in which country they are located, than what role they can play in a history that extrapolates present political lines to investigate the deep past of the whole biome.

[2] "Around mid-20th century, many biologists believed the only mechanism of species differentiation was geographic isolation of populations, which reduced gene flow. Therefore, it was challenging to explain how vast contiguous tropical forests could be so diverse. One common assumption was that extant differentiated forms that currently overlap distributions had been spatially separated in the past (Vuilleumier, 1971). In that context, Livingstone's (1967) and Moreau's (1963) studies provided evidence of considerable past climate and vegetational changes in Africa and the consequential effects on faunal diversification (Moreau, 1966). Jürgen Haffer's famous Science paper (1969) applied the same logic to propose that climate and vegetation changes were the main drivers for the Amazonian high species diversity." IN: Rocha & Kaefer, 2019, p. 4303.

[3] The slogan of a 1970 campaign for the occupation of the forest, an important project of the Brazilian miliary dictatorship era.

[4] "Ethnohistoric evidence speaks in favour of such connections. Historically, the southern periphery of the Amazon was occupied by a chain of Arawak-speaking populations. They shared a common ethos of settled village life, ranked social organisations, macro-regional integration, and inter-community exchange. At the same time, regions such as southwestern Amazonia were home to one of the highest diversities of language families within Amazonia, and the multi-ethnic/multilinguistic nature of regional systems is exemplified by the Upper Xingu. The belt of Arawak and other groups along the [Southern Rim of the Amazon] SRA has been hypothesised to constitute a formative supra-regional system that was present from late Pre-Columbian times. If true, this connection would suggest an uninterrupted distribution of earthworks along 1800 km east–west in the SRA and a more intense Pre-Columbian human impact in the forests of this region than previously postulated". IN: de Souza et al., 2018, p.3.

[5] From 2019 to 2022, Brazil's government radically shifted several policies that protected the forest and its inhabitants, paving the way to record deforestation, pollution, and invasion of protected areas, mainly for mining and cattle ranching. This also led to a large divestment of international conservation efforts, who stood in disagreement of these practices. In January 2023, former president Luiz Inácio Lula da Silva was inaugurated as president for a third term, with the promise of reverting the previous policies and working with international partners to halt the destruction of the forest. Marina da Silva, a major leader in the grassroots environmental movement in Brazil, was reinstated as minister for the environment and several foreign investors have agreed to renew financial support for the conservation of the Brazilian Amazon. While there is renewed hope for the future of the forest, the current situation of lawlessness in the forest and abandonment of its dwellers will require years of concentrated efforts to revert its harmful effects.