What, when, who and how? A review of peatland research in Amazonia

Cristina Malpica-Piñeros, Alexandra Barthelmes, Hans Joosten

Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Germany

SUMMARY

Amazonia is believed to harbour the world's most extensive tropical peatlands, storing significant amounts of carbon and having high value for biodiversity conservation, climate regulation and human welfare. However, a comprehensive assessment is hampered by fragmentary knowledge of the locations of peat-covered areas and this, in turn, prevents their protection and restoration in the face of ongoing anthropogenic destruction. The study reported here reviewed research activities on peatlands in Amazonia, which started with ecological studies in the 1950s. We found a broad and significant thematic increase since 2009, with growing focus first on carbon accumulation and greenhouse gas fluxes then, after 2017, on degradation and conservation, along with a spatial imbalance in favour of the Peruvian lowlands. Hitherto, very little scientific attention has been directed towards the peatlands of western Brazil, the Bolivian lowlands and the Guianas. Most research in Amazonia has been conducted by international institutions with, in recent times, increasing contributions from local institutes and research groups. Nevertheless, research on Amazonian peatlands is still in its early stages, and several scientific questions remain unanswered. Advancing the knowledge base with respect to various scientific disciplines (e.g., ecology, biology, geography, social sciences and economics) is, therefore, essential for understanding how and where peatlands developed, how they are used, which ecosystem services they provide, how climate change will affect them and, finally, what would be the most appropriate conservation, restoration and sustainable use strategies for safeguarding the wellbeing of both peatlands and people.

KEY WORDS: Amazon Basin, bibliometrics, mire, peat

INTRODUCTION

Peatlands are ecosystems that accumulate and store dead organic matter (peat) under waterlogged conditions (cf. UNEP 2022). Peatlands are widespread and cover 3.8 % of the global land area (UNEP 2022). Most of the world's known peatlands are situated in the northern (sub)arctic, boreal and temperate zones (Page *et al.* 2006), where their location and extent are well established, probably because of the early importance of peat as an energy source (Huber & Zinck 2011). Extensive peatland assessments have been carried out in Europe, North America and Asian Russia. In contrast, peatland assessments have remained fragmentary in the Southern Hemisphere with a bias towards specific land use potentials, e.g., resource extraction or agriculture.

Compared to the Northern Hemisphere and Southeast Asia, peatland research in South America is severely underdeveloped and notable research efforts have only begun to take shape in the last decade (UNEP 2022). Amazonian peatlands have so far been described mostly from the extensive lowlands, but many higher-altitude peatlands occur in the Andes and the Guiana Shield (UNEP 2022). Lähteenoja *et al.* (2009) reported the most extensive Amazonian peatland known hitherto, in the Pastaza-Marañón foreland basin in Northwest Peru. For other parts of Amazonia the spatial distribution, functioning, carbon storage capacity and other ecosystem services of peatlands remain obscure (Santofimio-Tamayo & Benavides 2019), even though this knowledge is critical to understanding the role of Amazonian peatlands in the global climate system (UNEP 2022). It is essential to identify and fill knowledge gaps to facilitate the conservation, restoration and sustainable use of Amazonian peatlands.

This study characterises peatland research in Amazonia over time, while tracing the locations and geographical distribution of research activities and study sites, the thematic research foci, and the countries involved.

METHODS

Study area

Amazonia is the world's largest rainforest and river system, containing 10 % of the world's species (Charity *et al.* 2016). Located in tropical South America, Amazonia extends over nine countries, with most (59 %) of the area belonging to Brazil (BRA) and the remainder to Bolivia (BOL), Colombia (COL), Ecuador (ECU), French Guiana (GUF), Guyana (GUY), Peru (PER), Suriname (SUR) and Venezuela (VEN) (Charity *et al*. 2016). The boundaries of Amazonia vary depending on the definition used and the purpose of delineation, i.e., the hydrological basin or the biome. In order to have clear standardised boundaries for our analyses we used the limits proposed by Eva & Huber (2005), who combine hydrographical, biogeographical and ecological criteria.

To accommodate the high diversity of Amazonian ecosystems that may host peatland, we divided Amazonia into four ‘peatscapes’ along an altitudinal gradient (Figure 1). The coastal peatscape includes all coastal and brackish regions up to 50 m a.s.l. It covers the estuarine areas of the Amazon Delta in Brazil, coastal areas in Guyana, French Guiana and Suriname, and the south-eastern flank of the Orinoco Delta in Venezuela. Coastal peatland types include mangrove swamps, fresh and brackish grass swamps and swamp forests (UNEP 2022). The lowland peatscape has an altitudinal range of 50–500 m a.s.l. and harbours *Mauritia flexuosa* palm swamps, *Platycarpum loretense* pole forests, herbaceous swamps and flooded forest (Draper *et al*. 2014, Householder & Wittmann 2016, Hastie *et al*. 2022). The upland peatscape encompasses altitudes between 500 and 1500 m a.s.l. in three main regions, namely the lower part of the Andean Cordillera, the Guiana Shield and the Brazilian Shield, where peatlands

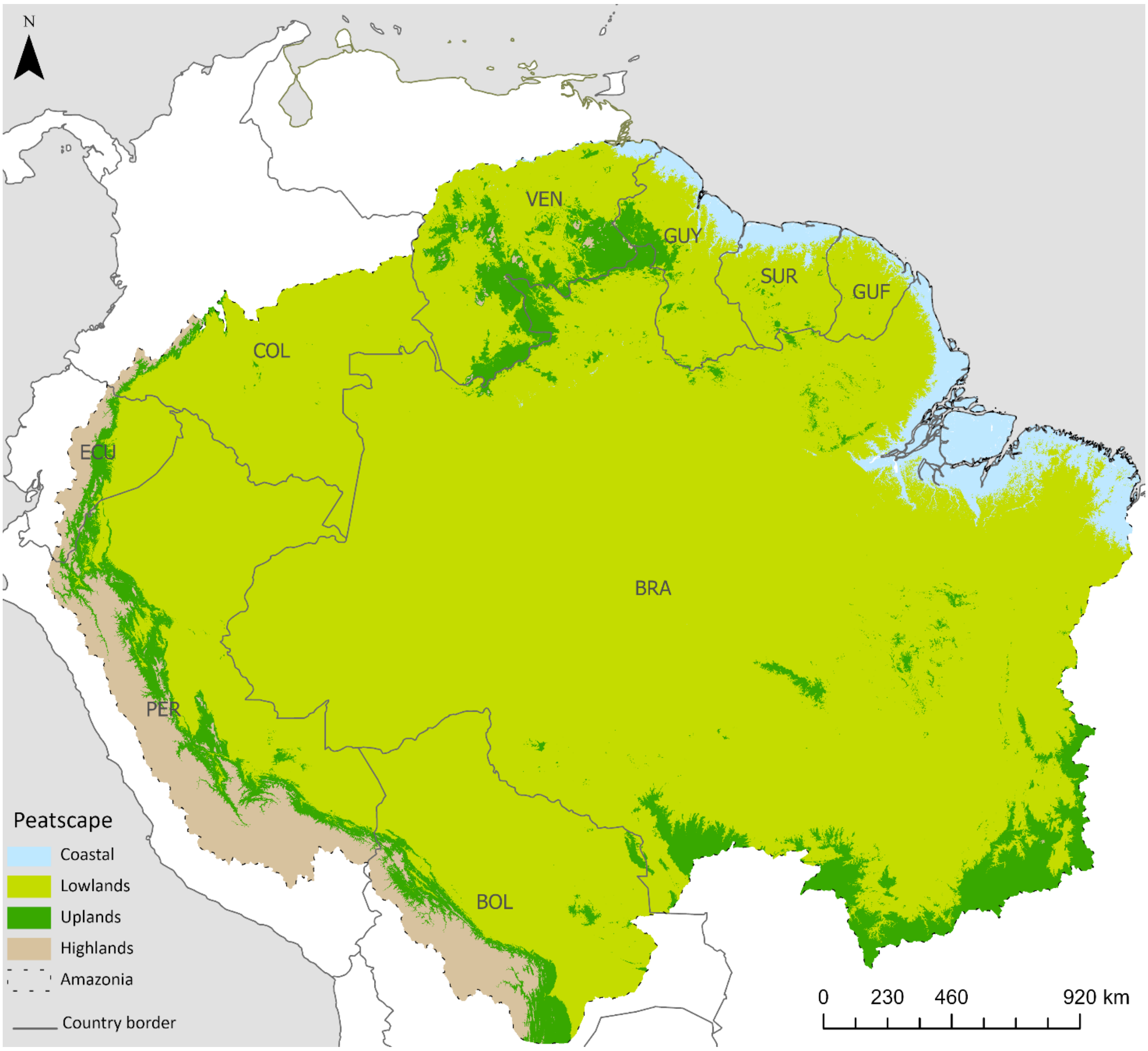

Figure 1. Peatscapes of Amazonia by country following an altitudinal gradient. Countries are labelled with their ISO codes (see Appendix 1). Limits of Amazonia follow Eva & Huber (2005).

may be present as Chusquea-dominated ecosystems in sub-Andean areas and as *M. flexuosa* swamps in the Guiana and Brazilian Shields (UNEP 2022). The highland peatscape contains all areas above 1500 m a.s.l. and is limited to the Andean Cordillera and the Table Mountains of the Guiana Shield in Venezuela (Mesetas). In the Andes, peatlands are characterised by a wide variety of vegetation including cushion plants, *Sphagnum* mosses, páramo and Chusquea (mountain bamboo) (UNEP 2022). The tops of the sandstone-quartzite Mesetas host tepuian meadows with *Acopanea* sp., shrublands dominated by *Stegolepis* and *Bonnetia*, and grasslands (Huber 1988, Zinck & Huber 2014).

Data collection and classification

We collected data from scientific publications, reports, governmental sources, and national and international organisations, up to 31 December 2022. We gathered this information using a range of sources and databases including Web of Science, JSTOR, Scielo, the digital archive of the Global Peatland Database and the "PENCIL" peatland library (https://greifswaldmoor.de/databases.html). We conducted searches in English, Spanish, Portuguese, French and Dutch. We selected sources that refer to the occurrence of 'peat', 'peatland' or 'Histosol' (in any of the above-mentioned languages) within Amazonia as delineated by Eva & Huber (2005; Figure 1). We excluded all peatland maps with global or tropical scope in order to focus on primary sources. The total number of studies retrieved and analysed was 188 (see Appendix 3). The studies were sorted by country, peatscape (cf. Figure 1), year of publication, type of publication, and eight research categories including ecology, soil science, palaeoecology, peatland coverage (including maps and estimates of extent), carbon stocks, greenhouse gas (GHG) fluxes, degradation and conservation. Studies addressing additional topics were grouped as 'other'. We also noted the country affiliation of the first and last author of each peer reviewed article. If the author was associated with more than one institution, we considered the first-placed affiliation only.

RESULTS

Geographical and temporal distribution

Distribution across peatscapes and countries

Overall, we found striking differences in number of studies amongst peatscapes and countries. Nearly twice as many studies were conducted in the lowland peatscape than in the others (Figure 2). More than 30 % of the studies originated from Peru, and 80 % of those from the lowlands of that country; the latter figure representing 24 % of all peatland studies from Amazonia. The country with the second highest number of studies was Venezuela (19 % of all studies), followed by Ecuador with 13 % (Figure 2).

Among all peatscapes, only coastal and highlands were represented by at least one study in all relevant countries (Figures 1 and 2). Most (16) of the coastal studies were conducted in Suriname, followed by French Guiana (9), Guyana (5), Brazil (2) and Venezuela (1). More than half (56) of the studies assigned to the lowland peatscape took place in Peru, followed by Colombia and Brazil (16 each) and the rest of the coastal countries with one study each (Figure 2). Despite the broad distribution of the upland peatscape across Amazonia, studies referring to peatlands in this zone were found for just three countries (Figures 1 and 2, Table 1); Venezuela was

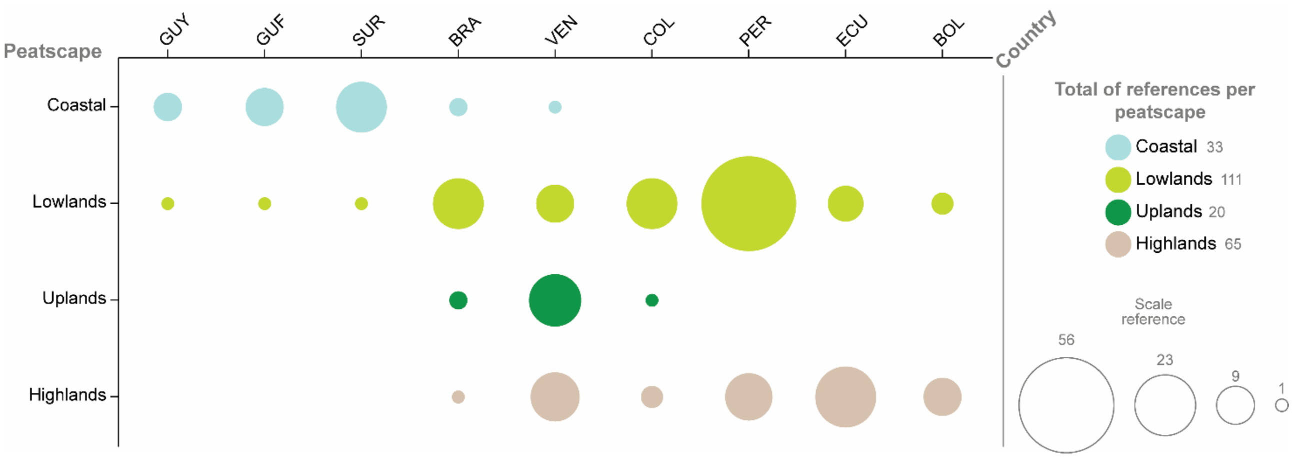

Figure 2. Geographical distribution of peatland studies across the peatscapes of Amazonia (cf. Figure 1).

the largest contributor with 18 studies. In contrast, all countries that overlap with the highland peatscape have produced peatland studies, of which most (35 %) stem from Ecuador (23), followed by Venezuela (15), Peru (14), Bolivia (9), Colombia and Brazil (1 each).

Distribution through time

Peatland research in Amazonia started in the coastal peatscape during the early 1950s, and coastal studies dominated the field for approximately 30 years. We found an obvious hiatus with almost no studies between 1995 and 2008. Research in the lowland peatscape began sporadically in the 1960s, building to regular investigations by the late 1980s and rising to a maximum frequency and number (10) of studies in 2022 (Figure 3a).

Regular research in the upland peatscape started later than in the other peatscapes, with most studies conducted and published between 2009 and 2016; while research in the highland peatscape started ten years earlier, increased after 2002 and peaked between 2008 and 2011. Peatland research increased across all peatscapes of Amazonia after 2009. After 2017, there was a slight drop in all peatscapes.

The first decade of peatland research in Amazonia was monopolised by Suriname, which was the country with most studies until the mid-1980s (Figure 3b). Peatland studies in Guyana and French Guiana followed in the 1960s. In Guyana they stopped in the early 1970s until 2021; but in French Guiana, a few later studies were conducted over these years. By the end of the 1980s, peatland studies were being conducted in most Amazonian countries, yet it took five more years to finally see research from Colombia and Peru. After this, a steady increase can be observed in most Amazonian countries until the mid-2010s. After 2017, peatland research showed a dramatic decline for most countries, but notably not for Peru.

Geo-political affiliations

International affiliations

First and last authors were found to be affiliated with 23 countries in total and 15 countries outside Amazonia. The distribution was similar if only first authors were considered (Figure 4, Appendix 2).

Most institutions with research in Amazonia were European (53 %). Most (26 %) of first authors were affiliated with institutions in the United States (USA), 2 % of first and last authors with Indonesia (IND), and 1 % of first and last authors with Cameroon (CMR) and Trinidad and Tobago (TTO) (Figure 4).

Within Europe, the United Kingdom (GBR) showed most affiliations (13 %), with 84 % of the research effort directed at Peru, producing 29 % of all peer-reviewed papers on Peru. GBR also undertook studies in Colombia, Ecuador, and French Guiana. The total number of authors affiliated with British institutions increased to 15 % when considering last author affiliation, in that case with the study locations also including Bolivia and Venezuela.

Spain (ESP) contributed 10 % of all research effort in Amazonia based on first author contribution, making it the second-largest European contributor, but this number decreased to 5 % for last author. All Spanish studies focused exclusively on Venezuela.

Germany (DEU) was ranked third with 8 % of first author affiliations. 58 % of German research effort focused on Ecuador, followed by Brazil (25 %) and Peru (17 %). Considering last author affiliation, the score increased to 10 %, without change in research area focus.

Table 1. Peatscapes of Amazonia by country. ● indicates that the peatscape is present in the country.

Countries		Peatscapes			
		Coastal	Lowland	Upland	Highland
Guyana	GUY	●	●	●	
French Guiana	GUF	●	●	●	
Suriname	SUR	●	●	●	
Brazil	BRA	●	●	●	●
Venezuela	VEN	●	●	●	●
Colombia	COL		●	●	●
Peru	PER		●	●	●
Ecuador	ECU		●	●	●
Bolivia	BOL		●	●	●

Figure 3. Temporal distributions of the reviewed studies: (a) across Amazonian peatscapes; (b) across the countries of Amazonia; and (c) according to the research type. Only years with at least one study are shown.

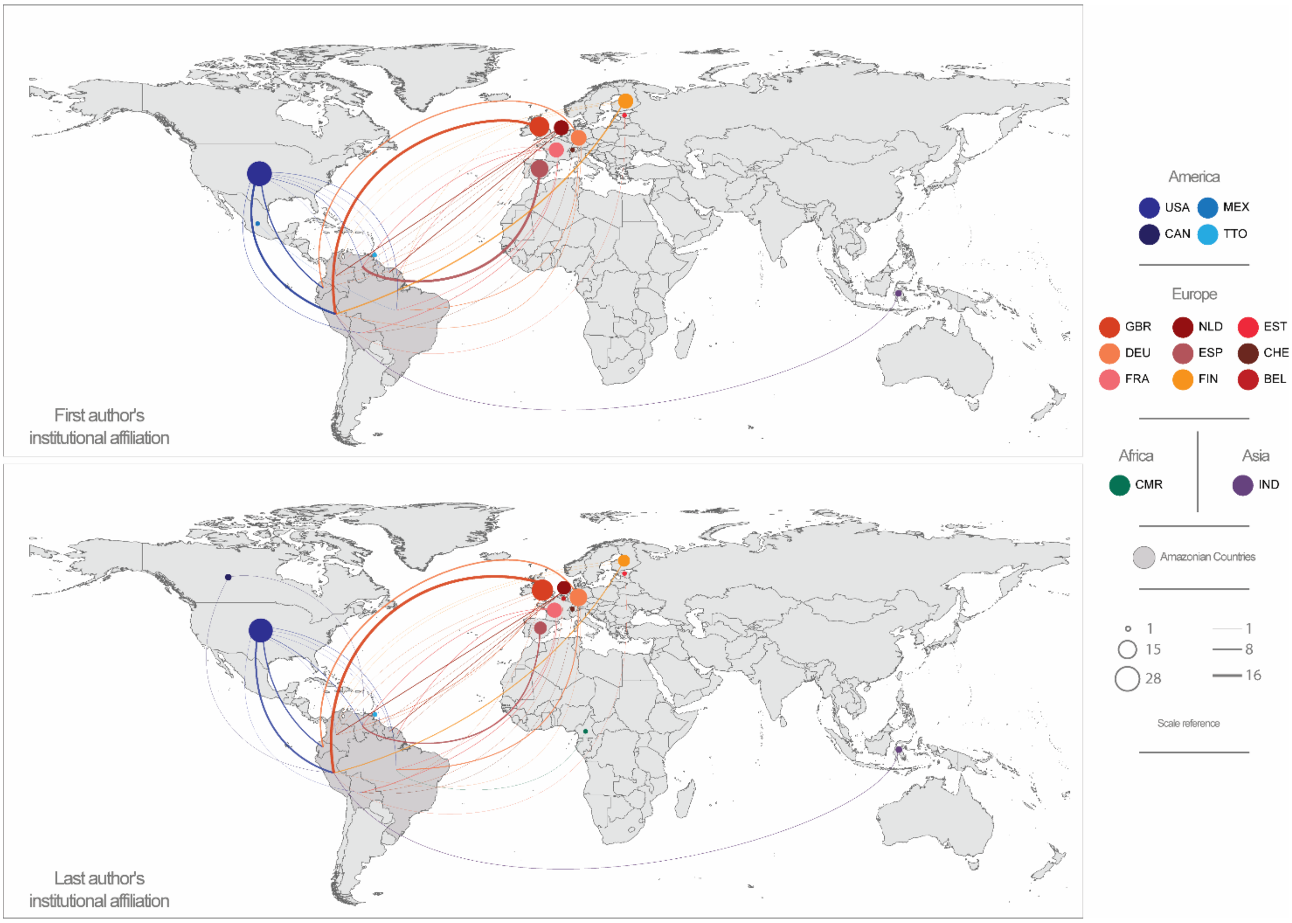

Figure 4. The proportion of research activities on Amazonian peatlands carried out by foreign institutions and the country where the research was conducted. The sizes of the circles refer to the total number of scientific articles on Amazonian peatlands according to country of the author's institutional affiliation (but note that institutional affiliations within Amazonian countries are not included). Different line thicknesses reflect the total number of scientific articles on Amazonian peatlands from that country which concern peatlands in the country of implementation. The names of the countries are in ISO code (see Appendix 1).

The Netherlands (NLD), Finland (FIN) and France (FRA) ranked fourth with 8 % each; Finland concentrating on Peru (73 %), The Netherlands on Suriname and Colombia (36 % each), and France on Bolivia and Venezuela (27 % each).

The remaining European first authors were from Switzerland and Estonia, while 1 % of last authors were affiliated to Belgium.

The USA was the country with most research in Amazonia, 47 % of which was conducted in Peru and 23 % in Ecuador. The total number of affiliations to US American organisations decreased from 20 % to 19 % when considering the last author. The USA has undertaken research in all Amazonian countries except French Guiana. Mexico (MEX), Canada (CAN) and Trinidad and Tobago (TTO) each accounted for 1 % of the author affiliations.

The American continent as a whole provided 22 % and 21 % of the total first and last author affiliations, excluding the ones from the Amazonian countries themselves.

Affiliations within Amazonian countries

22 % of first and last authors were affiliated with Amazonian countries. All Amazonian countries apart from French Guiana have contributed research either in their home country or in another Amazonian country. Brazil and Peru were the only Amazonian countries where the first and last authors were simultaneously affiliated with national institutions (Figure 5, Tables A1 and A2).

Peru was responsible for 21 % of the first-author research carried out on its own territory and 29 % of last-author publications; and Venezuela for 16 % of

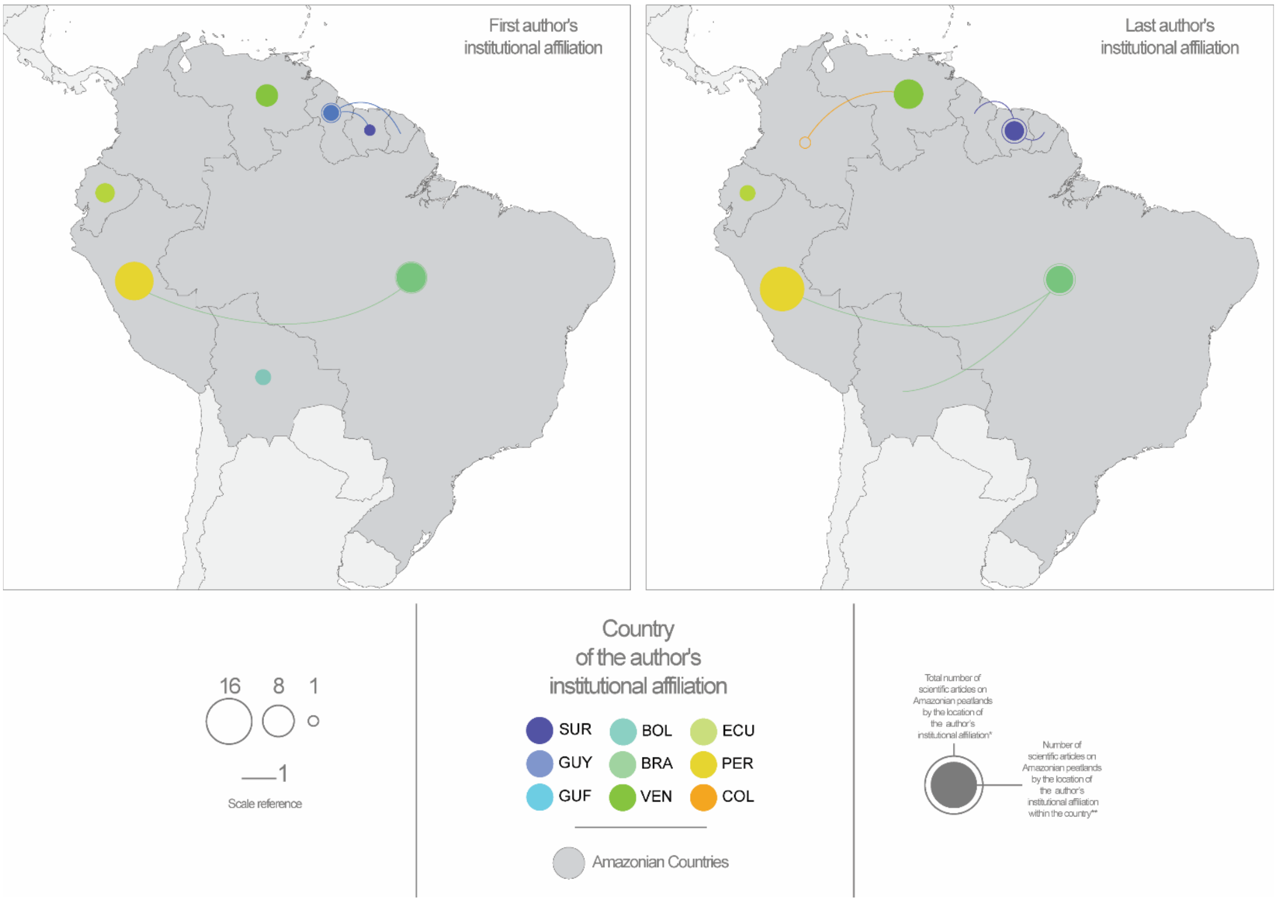

Figure 5. Connection between the location of the author's institutional affiliation and the Amazonian country where research was conducted. Sizes of the circles refer to total numbers of scientific articles on Amazonian peatlands according to the location of the author's institutional affiliation. Different line thicknesses reflect differences in the total number of scientific articles on Amazonian peatlands from the country of the author's institutional affiliation that relate to the country of implementation. If a circle has no connecting line, all scientific articles about Amazonian peatlands located within that country have authors whose institutional affiliations are within the same country. If there is no inner circle, all scientific research on Amazonian peatlands conducted by authors affiliated to an institution within a particular country took place outside that country. The names of the countries are in ISO code (see Appendix 1).

first-author and 28 % of last-author. Scientific papers associated with Brazil were 44 % authored (first and last authors) by researchers affiliated with that country, i.e., these authors generated 5 % of the total number of articles we analysed for Amazonia. Brazilian first and last authors were also responsible for 2 % of the research conducted in Peru and 11 % of that in Bolivia. Ecuador conducted 15 % of first-author studies within its boundaries, but this number decreased to 10 % when the research activity of last authors was included. Bolivia and Suriname were responsible for 1 % of the scientific articles we reviewed overall, but no last author was affiliated with a Bolivian institution. Surinamese research activity increased to 3 % when last-author affiliations were included, with 2 % of the studies within its boundaries and the remainder equally distributed between Guyana and French Guiana. 1 % of the research in Amazonia was carried out by a last author affiliated with Colombia, but these studies were not executed within Colombia.

Temporal and geopolitical research focus

Peru and Brazil were the only countries with at least one study in each research category (Figure 6). Peatland research in most countries focused on ecology, soil sciences and palaeoecology. Peru had around 42 % of all ecological studies, followed by Colombia. Concerning research on soil science, Suriname had most studies reporting peatlands (29 %), followed by French Guiana (25 %), Peru (14 %) and Brazil (11 %). Venezuela dominated palaeoecological studies for the region (30 %), Ecuador was second (22 %) and Peru third (18 %).

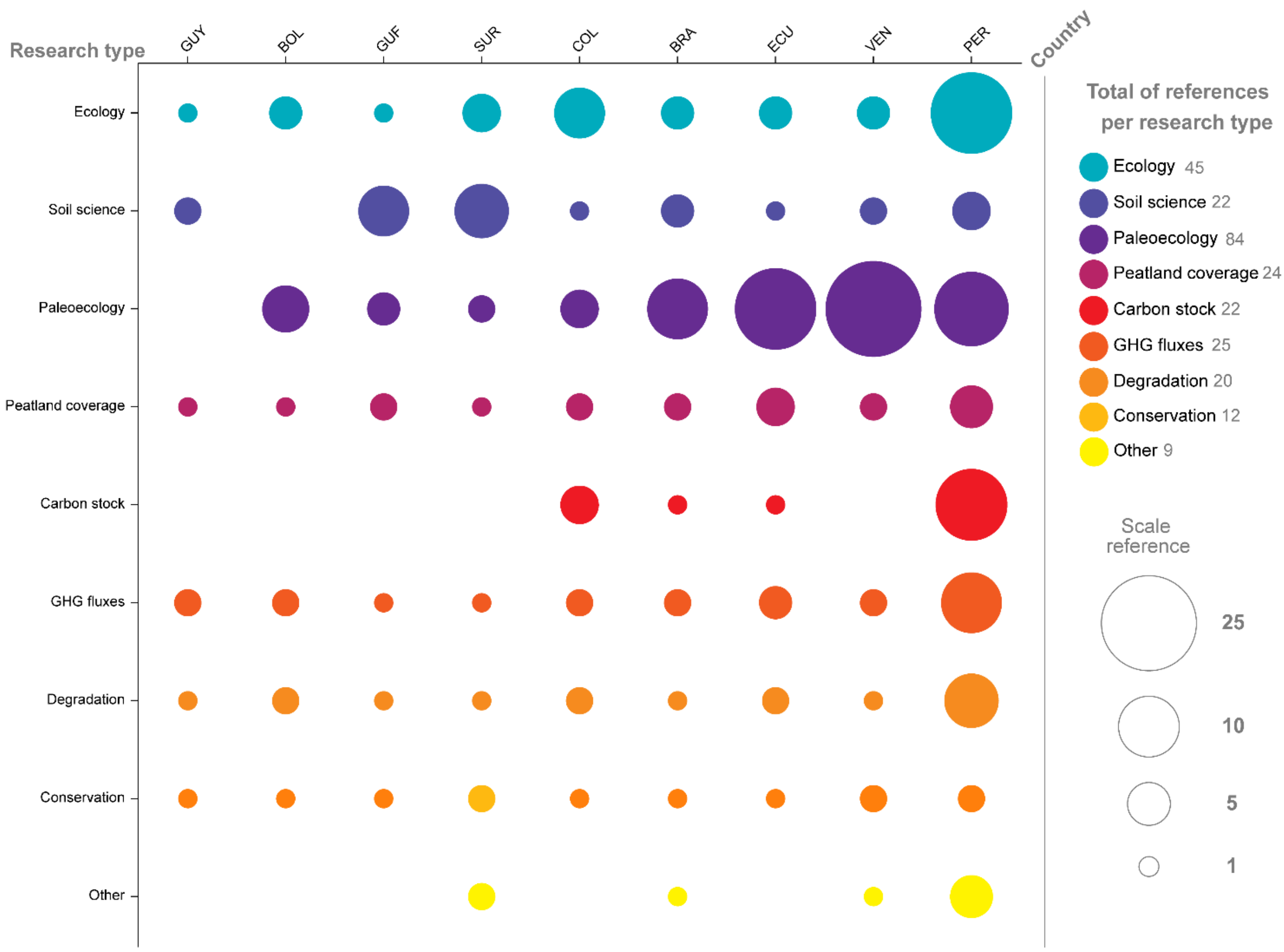

Figure 6. Geographical distribution of the research foci.

Peru was the country with most research activity on carbon stocks (70 %), followed by Colombia (20 %), Brazil and Ecuador. Every country had at least one publication mentioning peatland coverage, GHG fluxes, degradation and conservation.

As a general trend, the variety of research categories increased over time. 32 % of the studies were palaeoecological, 17 % were ecological, and the next most important category was soil science (11 %).

The first study we found reporting on peatlands was an ecological study (Figure 3c). The number of studies belonging to this type increased from 2009 to 2016 and peaked in 2014. After this date, they slowly decreased. Regarding soil sciences, peatland reports began at the end of the 1950s and started to decline by the end of the 1990s, whereas work on peatland coverage slowly increased after 2013. Palaeoecological studies showed a steady increase over time with a peak in 2013. Whereas these declined as of 2018, studies relating to carbon accumulation, GHG fluxes, degradation and conservation are now increasing.

Publication categories by language and country

Our analysis showed that most of the publications identified were peer-reviewed articles (84 %), of which more than 94 % were in English (Figure 7). The results were similar when analysed by country: Bolivia 91 % of which 90 % were in English; Brazil 80 % and 88 %; Peru 84 % and 96 %; and Ecuador 66 %, of which all were in English. The picture was different for Colombia, French Guiana and Suriname, where at least half of the information came from grey literature or from peer-reviewed articles in other languages. Around 8 % of the studies were reported in books. Grey literature made up 20 % of the studies compiled, comprising 6 % reports and the remainder distributed among theses, maps, and other sources. Overall, the language most commonly found in our study was English (84 %), followed by Spanish (11 %), French (3 %), and Portuguese and Dutch (1 % each).

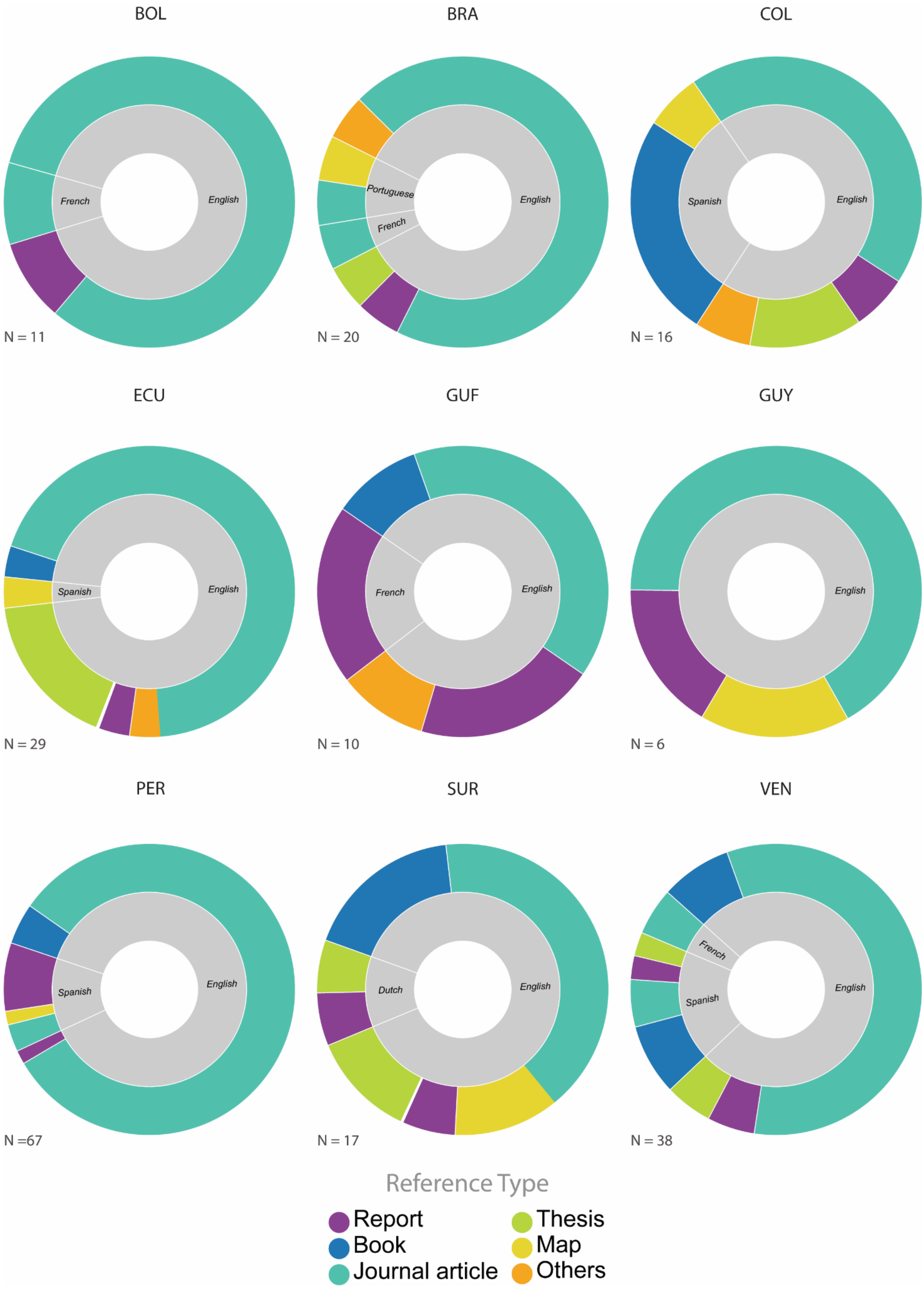

Figure 7. Distributions of research types according to language, per country.

DISCUSSION

Temporal and geographical trends

International research

Amazonia has recently gained international attention in the climate change and biodiversity debate through the research of Malhado *et al.* (2014), which is the first comprehensive study on the spatio-temporal aspects of peatland research in that region. For the last 70 years, Amazonian peatland research has varied in distribution and research focus and has become increasingly global, while most research (77 %) has been performed by institutions located in the Northern Hemisphere. This phenomenon may be termed 'colonial' and, in some cases, 'helicopter' research; the former referring to studies conducted in countries during their colonial periods and the latter being area-specific publications written mainly by international researchers (Minasny *et al.* 2020). Helicopter research often favours scientists from developed nations and may have negative aspects such as unequal partnerships, ignoring ownership and national priorities, lack of sustainability, etc. (Minasny *et al.* 2020, Seidler *et al.* 2021). However, in the tropics, notable instances of fruitful collaborations between international and local researchers in various projects have yielded enduring advantages for both scientists and local communities (Seidler *et al.* 2021).

The Netherlands was the first country to perform peatland research in Amazonia, which is attributable to its long history of peatland research (the world's oldest scientific book on peatlands stems from that country) and its colonist tradition. A similar situation has been observed in Indonesia, where peatland research started while the country was under the control of The Netherlands (Joosten 2016). The colonial connection could also explain the rapid decline in studies after 1977, when Suriname became a sovereign state. Nevertheless, research conducted by The Netherlands in other Amazonian countries continued. In contrast, the United Kingdom, with an equally established colonist tradition and known effort on peatland research, did not have studies in Guyana. Nonetheless, peatland research performed by GBR in Amazonia has increased over time. A similar situation has been observed in France; whereas peatland research has indeed been conducted in French Guiana, which remains politically linked to France, the majority of French peatland research has focused on other Amazonian nations. It is worth mentioning that the level of engagement in collaborations between international and local scientists and with local communities may vary significantly between projects, and evaluating the particular situation for each of the studies we reviewed was out of scope for this research.

A second important influence is globalisation. The presence of national incentives, access to funding and the search for 'globally significant' topics are key factors in driving the internationalisation of research (Woldegiyorgis *et al.* 2018). The USA and European Union (EU) countries have several national and regional initiatives to promote international research collaboration (Woldegiyorgis *et al.* 2018). Also, the USA, GBR, Germany and France are four of the six countries that account for 82 % of the world's multinational publications. Hence, it is no surprise that these countries are the main contributors to peatland research in Amazonia, also considering that GBR, the USA, Germany and The Netherlands are currently the top producers of peatland knowledge at global level (van Bellen & Larivière 2020). Furthermore, studies incorporating a foreign study site (relative to the authors' country of affiliation) receive more citations than those utilising only domestic study sites (van Bellen & Larivière 2020). International interest in Amazonia was possibly awakened after the publication by Lähteenoja *et al.* (2009) announcing their discovery of the largest known peatland complex in this region, which may have facilitated collaborative research and attracted researchers striving to find topics with global relevance.

Institutional affiliation may also explain the presence of some countries, as in the case of the University of Turku in Finland, which has a long history of research in Amazonia (Malhado *et al.* 2014) or the University of Göttingen with peatland research in four Amazonian countries. The involvement of organisations with multiple headquarters, both national and international, can also play a role in diversifying the countries conducting research in Amazonia, as is the case with CIFOR in Indonesia or ORSTOM, the French 'Overseas Scientific and Technical Research Office', which had offices in France, Mexico and Cameroon. In addition, international organisations such as the United Nations have contributed to the promotion of cross-national research by integrating research into their development assistance packages for developing countries (Woldegiyorgis *et al.* 2018). The United Nations Environmental Programme (UNEP) recently developed a Global Peatlands Assessment, giving information on the location and status of peatlands and recommendations for their sustainable management on a global scale (UNEP

2022). This assessment is the most up-to-date source of peatland information for some countries in Amazonia.

The influence of individual researchers on knowledge production patterns may have been shaped by their contributions to biological collections as well as by training students and founding research groups (Malhado *et al.* 2014). Also, international research collaboration has been significantly enhanced by the international mobility of graduate researchers and faculty members (Woldegiyorgis *et al.* 2018). In Amazonia, an example of this pattern is the work of Dr. Valentí Rull (ESP) and his research group, who are responsible for 60 % of the peatland research articles published for Venezuela.

National research

Our results show that research from institutions based in Amazonian countries has grown and diversified over time. However, more than half of the Amazonian countries (Bolivia, Colombia, Ecuador, Guyana and French Guiana) have low or zero peatland research efforts either within their own boundaries or in other Amazonian countries.

Peru is the country with most domestic peatland research effort, followed by Brazil. Peru has consistently carried out peatland research on its territory and is amongst the Amazonian countries with the highest research productivity (Malhado *et al.* 2014). In addition to its domestic research, Brazil has financed studies in Peru and Bolivia, invested in scientific research and infrastructure, and increased its peatland research efforts since 2007 (Stocks *et al.* 2008, van Bellen & Larivière 2020).

Previous studies have observed a positive relationship between a country's population and its total scientific productivity including number of publications produced by in-country scientists (Stocks *et al.* 2008). Also, the gross domestic product (GDP) of a country correlates positively with its scientific productivity. Countries like Guyana, French Guyana and Suriname generally have a small number of scientific institutions and low research productivity (Malhado *et al.* 2014), which could explain their low peatland research effort. Linguistic, cultural and practical barriers may also disadvantage Amazonian researchers, compared to authors affiliated with northern institutions, in performing as lead authors (Malhado *et al*. 2014) and publishing in prestigious journals rather than working on collaborative articles (Meneghini *et al.* 2008). However, we did not consider the nationalities of authors, so it may be the case that authors from Amazonian countries are affiliated to institutions located outside of Amazonia.

It is important to mention that peatlands in South America are poorly characterised and not widely recognised. In most cases, the respective countries do not have specific peatland policies (UNEP 2022). The knowledge gap regarding distribution, extent, ecosystem services and cultural values of peatlands, as well as the lack of policies to ensure their protection, may explain the lack of effort devoted to peatland research for most Amazonian countries.

Distribution of peatland research

The contrast between the large number of studies on lowland peatlands compared to the small number in other peatscapes is interesting, although hardly any scientific attention has been paid to the lowland peatlands of Western Brazil, Bolivia and the Guianas. Reasons for the disproportionate attention may be that most peatlands are located in the lowlands (Page *et al.* 2011); that fieldwork on other peatlands is more difficult and expensive (Lawson *et al.* 2015); and that research sites tend to cluster according to accessibility (along major rivers and close to urban areas), facilities and logistics (e.g., infrastructure, security) and the availability of background or baseline information (dos Santos *et al.* 2015). Furthermore, the greater diversity of species and ecosystems may make larger countries more attractive to foreign researchers (Stocks *et al*. 2008).

Changes in peatland research focus

Our study demonstrates that the peatland research focus in Amazonia has shifted over time. Studies started with ecological investigations in Suriname in 1953, publishing the results of scientific expeditions carried out during the late 1940s. Peat soil research rapidly followed, probably influenced by earlier colonial soil studies in Suriname, which is the Amazonian country with the most soil studies. Historical colonial soil studies were frequently driven by the exploitation of natural resources (Minasny *et al.* 2020). Furthermore, there were local investigations within the frameworks of national soil inventories for resource assessment. Palaeoecological studies have also long been a constant field of research in Amazonia. Despite being primarily supported by scientific institutions, the oil industry in Venezuela has been involved in palynological studies since the mid-1930s (Hopping 1967). Brazil was the first - and to our knowledge the only - country to make a peatland inventory for commercial exploitation purposes (Suszczynski 1984). Some soil inventories have mentioned the presence of peat or Histosols in their analyses, as was the case for Guyana in 1964. However, interest in mapping peatland occurrence in Amazonia did not start formally until the early 1990s.

As a general trend, peatland research in Amazonia has shown a significant thematic increase since the discovery of the largest peatland complex in the area (Lähteenoja *et al.* 2009), with a growing focus on carbon accumulation, GHG fluxes, degradation, and conservation after 2017. The latter may have been triggered by the increasing global attention to peatlands in the Climate Convention (Joosten 2011, Joosten *et al.* 2012, IPCC 2014, Joosten *et al.* 2016), the Paris Agreement (Horowitz 2016), and the devastating peatland fires in Indonesia in 2015 (IPCC 2014, Horowitz 2016, Atwood *et al.* 2016), which all underlined the importance of peatland conservation and restoration for climate change mitigation. Another important finding is that, whereas research on carbon stocks and GHG fluxes is thriving at global level (van Bellen & Larivière 2020), this type of information is still lacking for most countries in Amazonia, the only available data having been published in the Global Peatlands Assessment. Such research is critical to elucidate the role that Amazonian peatlands play in global GHG fluxes and climate change (UNEP 2022). However, the increase in studies in Amazonia is encouraging, as they are crucial for developing effective strategies to mitigate climate change and protect the vulnerable ecosystems in the region.

Language and publication trends

Our results show that most studies are peer-reviewed papers, predominantly in English. However, our study also highlights the peculiarities of non-English-speaking countries such as Colombia, French Guiana and Suriname, where at least half of the peatland information comes from grey literature or peer-reviewed articles in other languages (see Appendix 3). Also, Pitman *et al.* (2007) found that most literature on tropical biology and conservation in Madre de Dios (PER) consisted of grey literature, books or papers written in Spanish and published in journals that were mostly inaccessible outside Peru, and that 90 % of texts authored by Peruvians were written in Spanish. Researchers with limited proficiency in English may face difficulties in having their work published in international journals, and thus be impeded in connecting with the international audience (Montgomery 2004).

Language-specific search is key when searching for literature across multiple languages (Amano *et al.* 2021). Literature search often neglects non-English-language journals and grey literature (Pitman *et al.* 2007, Amano *et al.* 2021). Ignoring non-English and grey literature would have reduced our data considerably and would have portrayed countries with little peatland-related information as having even less. Even though we searched in (all) relevant languages and considered grey literature, we may have missed significant amounts of peatland-related information for Amazonia that is not publicly online due to its age, internal policies, or lack of capacity at pertinent institutions to make it internationally available. Thus, further (local) searches for grey and non-English literature may help to reduce the knowledge gap in some Amazonian countries. Another reason for missing relevant studies could be that they termed their own focus as 'Andean peatlands' with no mention that they were also located in Amazonia, meaning the literature search systems could have missed them. We did identify and review some articles of this type, but a specific search on Andean peatlands was out of scope for this study.

Recommendations

Even though peatland research is increasing in Amazonia, it is still at an early stage and several questions remain unanswered. Overall, we have been able to identify some trends in research effort along with their causes. Our study also highlights the importance of addressing the knowledge gaps and challenges in peatland research in Amazonia. It is essential to realise that the lack of data on location and extent of peatlands in Amazonia and on the services they provide frustrates policies to guarantee their protection and sustainable use. Therefore, research should urgently fill these geographical and subject-related knowledge gaps to address the challenges of preserving peatlands in the region while balancing economic development.

Also, we recommend considering the accessibility of information, especially for non-English-speaking countries, to guarantee that knowledge and research findings are effectively translated into policy and management decisions. International collaboration could strengthen the professional relationships of local researchers and invest in their capacity through the exchange of knowledge, expertise, and information. In most cases, local researchers have the better understanding of the area, local communities and the possibilities and constraints for generating adequate management plans or implementing research projects.

It is essential to promote collaborative work to help extinguish helicopter research, address local priorities, and establish long-term benefits for scientists and local communities. By increasing research effort, improving accessibility and strengthening collaboration, peatland research in Amazonia can work towards sustainable management, conservation, and informed decision-making in the region.

ACKNOWLEDGEMENTS

The authors are deeply grateful to everyone who contributed to this research, especially all members of the Global Peatland Database. Also, we extend our heartfelt thanks to the *Mires and Peat* reviewers and editors, whose constructive critiques and valuable suggestions during the peer review process greatly improved the final manuscript. Finally, we acknowledge the financial support provided to Cristina Malpica Piñeros by the Bogislaw Scholarship from the University of Greifswald, which played a crucial role in facilitating the execution of this study.

AUTHOR CONTRIBUTIONS

CM-P collected, classified and analysed the data, and wrote the first draft. AB and HJ provided data from the Global Peatland Database and the "PENCIL" peatland library, supervised the project, and provided critical feedback and revisions to the manuscript.

REFERENCES

Amano, T., Berdejo-Espinola, V., Christie, A.P., Willott, K. and 59 others (2021) Tapping into non-English-language science for the conservation of global biodiversity. *PLoS Biology*, 19(10), e3001296, 29 pp.

Atwood, E.C., Englhart, S., Lorenz, E., Halle, W., Wiedemann, W., Siegert, F. (2016) Detection and characterization of low temperature peat fires during the 2015 fire catastrophe in Indonesia using a new high-sensitivity fire monitoring satellite sensor (FireBird). *PloS ONE*, 11(8), e0159410, 16 pp.

Charity, S., Dudley, N., Oliveira, D., Stolton, S. (eds.) (2016) *Living Amazon Report 2016: A Regional Approach to Conservation in the Amazon*. WWF Living Amazon Initiative, Brasilia and Quito, 112 pp.

dos Santos, J.G., Malhado, A.C.M., Ladle, R.J., Correia, R.A., Costa, M.H. (2015) Geographic trends and information deficits in Amazonian conservation research. *Biodiversity and Conservation*, 24(11), 2853–2863.

Draper, F., Roucoux, K.H., Lawson, I.T., Mitchard, E.T.A., Honorio Coronado, E.N., Lähteenoja, O., Torres Montenegro, L., Valderrama Sandoval, E., Zaráte, R., Baker, T.R. (2014) The distribution and amount of carbon in the largest peatland complex in Amazonia. *Environmental Research Letters*, 9, 124017, 12 pp.

Eva, H.D., Huber, O. (eds.) (2005) *Una propuesta para la definición de los límites geográficos de la Amazonía* (*A Proposal for Defining the Geographical Boundaries of Amazonia*). EUR 21808-ES, Office for Official Publications of the European Communities, Luxembourg, 38 pp. (in Spanish).

Hastie, A., Honorio Coronado, E.N., Reyna, J., Mitchard, E.T.A. and 24 others (2022) Risks to carbon storage from land-use change revealed by peat thickness maps of Peru. *Nature Geoscience*, 15, 369–374.

Hopping, C.A. (1967) Palynology and the oil industry. *Review of Palaeobotany and Palynology*, 2, 23–48.

Horowitz, C.A. (2016) Paris Agreement. *International Legal Materials* (*ILM*), 55(4), 740–755.

Householder, E., Wittmann, F. (2016) Floristic diversity of *Mauritia flexuosa* wetlands in the Brazilian Amazon. In: Lasso, C., Colonnello, G., Moraes, M. (eds.) *Morichales, cananguchales y otros palmares inundables de Suramérica: Parte II* (*Morichales, Cananguchales and Other Flood-Prone Palm Groves in South America: Part II*), Hydrobiological and Continental Fisheries Resources of Colombia XIV, Alexander von Humboldt Biological Resources Research Institute, Bogotá, 241–251.

Huber, O. (1988) Guayana Highlands versus Guayana Lowlands, a reappraisal. *Taxon*, 37(4), 595–614.

Huber, O., Zinck, J.A. (2011) Introduction. In: Zinck, J.A., Huber, O. (eds.) *Peatlands of the Western Guayana Highlands, Venezuela*, Springer, Berlin, 1–4.

IPCC (2014) *2013 Supplement to the IPCC 2006 Guidance for Greenhouse Gas Inventories: Wetlands*. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Jamsranjav, B., Fukuda, M., Troxler, T. (eds.), International Panel on Climate Change (IPCC), Switzerland.

Joosten, H. (2011) Sensitising global conventions for climate change mitigation by peatlands. In: Tanneberger, F., Wichtmann, W. (eds.) *Carbon Credits from Peatland Rewetting*, Schweizerbart, Stuttgart, 90–94.

Joosten, H. (2016) Changing paradigms in the history of tropical peatland research. In: Osaki, M., Tsuji, N. (eds.) *Tropical Peatland Ecosystems*, Springer Japan, Tokyo, 33–48.

Joosten, H., Tapio-Biström, M., Susanna, T. (eds.) (2012) *Peatlands: Guidance for Climate Change Mitigation through Conservation, Rehabilitation and Sustainable Use*. Mitigation of Climate Change in Agriculture 5, FAO, Rome, 114 pp.

Joosten, H., Sirin, A., Couwenberg, J., Laine, J., Smith, P. (2016) The role of peatlands in climate regulation. In: Bonn, A., Allott, T., Evans, M., Joosten, H., Stoneman, R. (eds.) *Peatland Restoration and Ecosystem Services: Science, Policy and Practice*, Cambridge University Press/ British Ecological Society, Cambridge, 63–76.

Lähteenoja, O., Ruokolainen, K., Schulman, L., Oinonen, M. (2009) Amazonian peatlands: an ignored C sink and potential source. *Global Change Biology*, 15, 2311–2320.

Lawson, I.T., Kelly, T.J., Aplin, P., Boom, A., Dargie, G., Draper, F.C.H., Hassan, P.N.Z.B.P., Hoyos-Santillan, J., Kaduk, J., Large, D., Murphy, W., Page, S.E., Roucoux, K.H., Sjögersten, S., Tansey, K., Waldram, M., Wedeux, B.M.M., Wheeler, J. (2015) Improving estimates of tropical peatland area, carbon storage, and greenhouse gas fluxes. *Wetlands Ecology and Management*, 23, 327–346.

Malhado, A.C.M., de Azevedo, R.S.D., Todd, P.A., Santos, A.M.C., Fabré, N.N., Batista, V.S., Aguiar, L.J.G., Ladle, R.J. (2014) Geographic and temporal trends in Amazonian knowledge production. *Biotropica*, 46, 6–13.

Meneghini, R., Packer, A.L., Nassi-Calò, L. (2008) Articles by Latin American authors in prestigious journals have fewer citations. *PloS ONE*, 3(11), e3804, 4 pp.

Minasny, B., Fiantis, D., Mulyanto, B., Sulaeman, Y., Widyatmanti, W. (2020) Global soil science research collaboration in the 21st century: Time to end helicopter research. *Geoderma*, 373, 114299, 4 pp.

Montgomery, S. (2004) Of towers, walls, and fields: perspectives on language in science. *Science*, 303(5662), 1333–1335.

Page, S.E., Rieley, J.O., Wüst, R. (2006) Lowland tropical peatlands of Southeast Asia. In: Martini, I., Martínez Cortizas, A., Chesworth, W. (eds.) *Peatlands: Evolution and Records of Environmental and Climate Changes*, Developments in Earth Surface Processes 9, Elsevier, Amsterdam and Oxford, 145–172.

Page, S.E., Rieley, J.O., Banks, C.J. (2011) Global and regional importance of the tropical peatland carbon pool. *Global Change Biology*, 17(2), 798–818.

Pitman, N.C.A., Del Azáldegui, M.C.L., Salas, K., Vigo, G.T., Lutz, D.A. (2007) Written accounts of an Amazonian landscape over the last 450 years. *Conservation Biology*, 21(1), 253–262.

Santofimio-Tamayo, G.A., Benavides, J.C. (2019) Carbon accumulation patterns in soils of tropical peatlands from fluvial origin (Caquetá, Colombia). *Wetland Science & Practice*, 36(3), 171.

Seidler, R., Primack, R.B., Goswami, V.R., Khaling, S. and 18 others (2021) Confronting ethical challenges in long-term research programs in the tropics. *Biological Conservation*, 255, 10893, 10 pp.

Stocks, G., Seales, L., Paniagua, F., Maehr, E., Bruna, E.M. (2008) The geographical and institutional distribution of ecological research in the tropics. *Biotropica*, 40(4), 397–404.

Suszczynski, E.F. (1984) The peat resources of Brazil. In: *Proceedings of the 7th International Peat Congress*, Volume 1, IPS, Dublin, 468–492.

UNEP (2022) *Global Peatlands Assessment - The State of the World's Peatlands: Evidence for Action Toward the Conservation, Restoration, and Sustainable Management of Peatlands*. United Nations Environment Programme (UNEP), Nairobi, 425 pp.

van Bellen, S., Larivière, V. (2020) The ecosystem of peatland research: A bibliometric analysis. *Mires and Peat*, 26, 15, 30 pp.

Woldegiyorgis, A.A., Proctor, D., de Wit, H. (2018) Internationalization of research: Key considerations and concerns. *Journal of Studies in International Education*, 22(2), 161–176.

Zinck, J.A., Huber, O. (2014) Turberas tepuyanas (Tepuian mires). In: Lasso, C.A., Rial, A., Colonnello, G., Machado-Allison, A., Trujillo, F. (eds.) *Humedales de la Orinoquia* (*Wetlands of the Orinoco*), Hydrobiological and Continental Fisheries Resources of Colombia XI, Alexander von Humboldt Biological Resources Research Institute (IAvH), Bogotá, 249–251 (in Spanish).

Submitted 28 Jun 2023; final revision 05 Mar 2024
Editor: Olivia Bragg

Author for correspondence: Cristina Malpica-Piñeros, Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Soldmannstrasse 15, 17487, Germany.
Tel: +4915772727226; E-mail: crismalpica@gmail.com

Appendix 1: List of ISO abbreviations used in this article for Amazonian and non-Amazonian countries.

	Abbreviation	Country
Amazonian	BOL	Bolivia
	BRA	Brazil
	COL	Colombia
	ECU	Ecuador
	GUF	French Guiana
	GUY	Guyana
	PER	Peru
	SUR	Suriname
	VEN	Venezuela
Non-Amazonian	BEL	Belgium
	CAN	Canada
	CHE	Switzerland
	CMR	Cameroon
	DEU	Germany
	ESP	Spain
	EST	Estonia
	FIN	Finland
	FRA	France
	GBR	United Kingdom of Great Britain and Northern Ireland
	IND	Indonesia
	MEX	Mexico
	NLD	The Netherlands
	TTO	Trinidad and Tobago
	USA	United States of America

Appendix 2

Table A2.1. Total number of scientific articles on Amazonian Peatlands from the location of the first author's institutional affiliation to the country of implementation.

	Country of the first author's institutional affiliation																		
Country of implementation	BOL	BRA	CHE	DEU	ECU	ESP	EST	FIN	FRA	GBR	GUY	IND	NLD	PER	SUR	TTO	USA	VEN	MEX
BOL	2		1						3				1				2		
BRA		7		3				1	2								2		1
COL								1		1			4				1		
ECU				7	3			1	1	1							7		
GUF									2	1	1								
GUY											1		1			1	1		
PER		1		2			1	8		16		2		12			14		
SUR											1		4		1		1		
VEN						15			3				1				2	4	

Table A2.2. Total number of scientific articles on Amazonian Peatlands from the location of the last author's institutional affiliation to the country of implementation.

	Country of the last author's institutional affiliation																			
Country of implementation	BEL	BRA	CAN	CHE	CMR	COL	DEU	ECU	ESP	EST	FIN	FRA	GBR	IND	NLD	PER	SUR	TTO	USA	VEN
BOL	1	1		1								3	1						2	
BRA		6			1		5					2							2	
COL											1		1		4				1	
ECU							9	2			1		1						7	
GUF												3					1			
GUY															1		1	1	1	
PER		1	1				1			1	5		17	2	1	16			11	
SUR															3		3		1	
VEN			1			1			8			3	2						3	7

Appendix 3: Publications included in the analysis, by country.

Note: If a study covered more than three countries, the reference is assigned to the category 'Amazonia'.

Amazonia

Dias, R.M., Tófoli, R.M., Lopes, T.M., Alves, G.H.Z. (2021) Amazon peatlands in peril: a warning for global warming. *Oecologia Australis*, 25, 1–6.

Melack, J.M., Basso, L.S., Fleischmann, A.S., Botía, S., Guo, M., Zhou, W., Barbosa, P.M., Amaral, J.H., MacIntyre, S. (2022) Challenges regionalizing methane emissions using aquatic environments in the Amazon Basin as examples. *Frontiers in Environmental Science*, 10, 866082, 26 pp.

Ruokolainen, K., Schulman, L., Tuomisto, H. (2001) On Amazonian peatlands. *International Mire Conservation Group Newsletter*, 4, 8–10.

UNEP (2022) *Global Peatlands Assessment - The State of the World's Peatlands: Evidence for Action Toward the Conservation, Restoration, and Sustainable Management of Peatlands*. United Nations Environment Programme (UNEP), Nairobi, 425 pp.

Bolivia

Cochi Machaca, N., Condori, B., Rojas Pardo, A., Anthelme, F., Meneses, R.I., Weeda, C.E., Perotto-Baldivieso, H.L. (2018) Effects of grazing pressure on plant species composition and water presence on bofedales in the Andes mountain range of Bolivia. *Mires and Peat*, 21, 15, 15 pp.

Declerck, S.A.J., Coronel, J.S., Legendre, P., Brendonck, L. (2011) Scale dependency of processes structuring metacommunities of Cladocerans in temporary pools of High-Andes wetlands. *Ecography*, 34, 296–305.

Escobar-Torrez, K., Ortuño, T., Bentaleb, I., Ledru, M.-P. (2018) Cloud dynamic contribution to high-elevation peatland growth during the Holocene (Escalerani, Central Andes, Bolivia). *The Holocene*, 28, 1334–1344.

Gouze, P., Ferhi, A., Fontes, J., Roche, M. (1987) Composition isotopique (180) de la matière organique des tourbières actuelles et holocènes en Bolivie: Résultats préliminaires et perspectives d'application en paléoclimatologie (Isotopic composition (180) of organic matter from current and Holocene peatlands in Bolivia: Preliminary results and prospects for application in palaeoclimatology). *Géodynamique*, 2, 113–116 (in French).

Graf, K. (1981) Palynological investigations of two post-glacial peat bogs near the boundary of Bolivia and Peru. *Journal of Biogeography*, 8, 353–368.

Ledru, M.-P., Jomelli, V., Bremond, L., Ortuño, T., Cruz, P., Bentaleb, I., Sylvestre, F., Kuentz, A., Beck, S., Martin, C., Paillès, C., Subitani, S. (2013) Evidence of moist niches in the Bolivian Andes during the mid-Holocene arid period. *The Holocene*, 23, 1547–1559.

Maezumi, S.Y., Power, M.J., Mayle, F.E., McLauchlan, K.K., Iriarte, J. (2015) Effects of past climate variability on fire and vegetation in the cerrãdo savanna of the Huanchaca Mesetta, NE Bolivia. *Climate of the Past*, 11, 835–853.

Mourguiart, P., Ledru, M.-P. (2003) Last Glacial Maximum in an Andean cloud forest environment (Eastern Cordillera, Bolivia): Comment and Reply. *Geology*, 31, 195–198.

Quenta, E., Molina-Rodriguez, J., Gonzales, K., Rebaudo, F., Casas, J., Jacobsen, D., Dangles, O. (2016) Direct and indirect effects of glaciers on aquatic biodiversity in high Andean peatlands. *Global Change Biology*, 22, 3196–3205.

Brazil

Barberi, M., Salgado-Labouriau, M.L., Suguio, K. (2000) Paleovegetation and paleoclimate of "Vereda de Águas Emendadas", central Brazil. *Journal of South American Earth Sciences*, 13, 241–254.

Behling, H., Cohen, M., Lara, R.J. (2001) Studies on Holocene mangrove ecosystem dynamics of the Bragança Peninsula in north-eastern Pará, Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 167, 225–242.

Buessecker, S., Sarno, A.F., Reynolds, M.C., Chavan, R., Park, J., Fontánez Ortiz, M., Pérez-Castillo, A.G., Panduro Pisco, G., Urquiza-Muñoz, J.D., Reis, L.P., Ferreira-Ferreira, J., Furtunato Maia, J.M., Holbert, K.E., Penton, C.R., Hall, S.J., Gandhi, H., Boëchat, I.G., Gücker, B., Ostrom, N.E., Cadillo-Quiroz, H. (2022) Coupled abiotic-biotic cycling of nitrous oxide in tropical peatlands. *Nature Ecology & Evolution*, 6, 1881–1890.

da Silva Meneses, M.E.N., da Costa, M.L., Behling, H. (2013) Late Holocene vegetation and fire dynamics from a savanna-forest ecotone in Roraima state, northern Brazilian Amazon.

Journal of South American Earth Sciences, 42, 17–26.

Dubroeucq, D., Volkoff, B. (1988) Évolution des couvertures pédologiques sableuses à podzols géants d'Amazonie (Evolution of sandy soil coverings with giant podzols in the Amazon). *Cahiers de l'ORSTOM série Pédologie*, 24, 191–214 (in French).

Dubroeucq, D., Volkoff, B. (1998) From Oxisols to Spodosols and Histosols: evolution of the soil mantles in the Rio Negro basin (Amazonia). *CATENA*, 32, 245–280.

Guimarães, J.T.F., Cohen, M.C.L., França, M.C., Alves, I.C.C., Smith, C.B., Pessenda, L.C.R., Behling, H. (2013a) An integrated approach to relate Holocene climatic, hydrological, morphological and vegetation changes in the southeastern Amazon region. *Vegetation History and Archaeobotany*, 22, 185–198.

Guimarães, J.T.F., Cohen, M.C.L., França, M.C., Pessenda, L.C.R., Behling, H. (2013b) Morphological and vegetation changes on tidal flats of the Amazon Coast during the last 5000 cal. yr BP. *The Holocene*, 23, 528–543.

Hermanowski, B., da Costa, M.L., Behling, H. (2012a) Environmental changes in southeastern Amazonia during the last 25,000yr revealed from a paleo-ecological record. *Quaternary Research*, 77, 138–148.

Hermanowski, B., da Costa, M.L., Carvalho, A.T., Behling, H. (2012b) Palaeoenvironmental dynamics and underlying climatic changes in southeast Amazonia (Serra Sul dos Carajás, Brazil) during the late Pleistocene and Holocene. Palaeogeography, *Palaeoclimatology, Palaeo-ecology*, 365–366, 227–246.

IBGE (2006) *Solos 1:5.000.000, Brazil* (*Soils 1:5,000,000, Brazil*) (in Portuguese). Online at: https://geoftp.ibge.gov.br/informacoes_ambientais/pedologia/vetores/brasil_5000_mil/

Lähteenoja, O., Flores, B., Nelson, B. (2013) Tropical peat accumulation in central Amazonia. *Wetlands*, 33, 495–503.

Laine Borges, S., Ludivine, E., Belloni Schmidt, I., Sena Barradas, A., Almeida dos Santos, I. (2016) Manejo do fogo em veredas: novas perspectivas a partir dos sistemas agrícolas tradicionais no Jalapão (Fire management in veredas: new perspectives from traditional agricultural systems in the Jalapão). *Ambiente & Sociedade*, 19, 275–300 (in Portuguese).

Ledru, M.-P., Bertaux, J., Sifeddine, A., Suguio, K. (1998) Absence of last glacial maximum records in lowland tropical forests. *Quaternary Research*, 49, 233–237.

Oliveira, P., Marquis, R. (eds.) (2002) *The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna*. Columbia University Press, New York, 367 pp.

Salgado-Labouriau, M.L., Barberi, M., Ferraz-Vicentini, K.R., Parizzi, M.G. (1998) A dry climatic event during the late Quaternary of tropical Brazil. *Review of Palaeobotany and Palynology*, 99, 115–129.

Suszczynski, E.F. (1984) The peat resources of Brazil. In: *Proceedings of the 7th International Peat Congress*, International Peat Society, Dublin, 468–492.

Volkmer-Ribeiro, C. (1992) The freshwater sponges in some peat-bog ponds in Brazil. *Amazoniana*, 12, 317–335.

Colombia

Behling, H., Berrío, J.C., Hooghiemstra, H. (1999) Late Quaternary pollen records from the middle Caquetá River basin in central Colombian Amazon. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 145, 193–213.

Duivenvoorden, J., Lips, J.M. (1993) *Ecologia del paisaje del medio Caqueta: Memoria explicativa de los mapas* (*Ecology of the Middle Caqueta Landscape: Explanatory Memoir to the Maps)*. Publication No. 3, Tropenbos Colombia, Bogota, 301 pp. (in Spanish).

Hoorn, C. (1994) Fluvial palaeoenvironments in the intracratonic Amazonas Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 109, 1–54.

IGAC (2014) *Mapa Nacional de Unidades Cartográficas de Suelos 2014* (*National Map of Cartographic Soil Units 2014*). Instituto Geografico Agustin Codazzi (IGAC), Bogota (in Spanish). Online at: https://geoportal.igac.gov.co/es/contenido/datos-abiertos-cartografia-y-geografia, accessed 06 Dec 2023.

Lasso, C.A., Rial, A., González-B., V. (eds.) (2013) *Morichales y cananguchales de la Orinoquia y Amazonia: Colombia y Venezuela, Parte I* (*Morichales and Cananguchales of the Orinoquia and Amazonia: Colombia and Venezuela, Part I*). Hydrobiological and Continental Fisheries Resources of Colombia VII, Alexander von Humboldt Biological Resources Research Institute (IAvH), Bogotá, 344 pp. (in Spanish).

Lasso, C.A., Rial, A., Colonnello, G., Machado-Allison, A., Trujillo, F. (eds.) (2014) *Humedales de la Orinoquia (Colombia-Venezuela)* (*Wetlands of the Orinoquia (Colombia-Venezuela)*).

Hydrobiological and Continental Fisheries Resources of Colombia XI, Alexander von Humboldt Biological Resources Research Institute (IAvH), Bogotá, 301 pp. (in Spanish).

Lawson, I.T., Honorio Coronado, E.N., Andueza, L., Cole, L., Dargie, G.C., Davies, A.L., Laurie, N., Okafor-Yarwood, I., Roucoux, K.H., Simpson, M. (2022) The vulnerability of tropical peatlands to oil and gas exploration and extraction. *Progress in Environmental Geography*, 1, 84–114.

Marchant, R., Behling, H., Berrio, J.-C., Cleef, A., Duivenvoorden, J., Hooghiemstra, H., Kuhry, P., Melief, B., Schreve-Brinkman, E., van Geel, B., van der Hammen, T., van Reenen, G., Wille, M. (2002) Pollen-based biome reconstructions for Colombia at 3000, 6000, 9000, 12 000, 15 000 and 18 000 14 C yr ago: Late Quaternary tropical vegetation dynamics. *Journal of Quaternary Science*, 17, 113–129.

Santofimio-Tamayo, G.A. (2018) *Carbon Accumulation Patterns in Soils of Tropical Peatlands from Alluvial Origin (Caquetá, Colombia)*. Dissertation, Pontificia Universidad Javeriana, Bogotá, 37 pp.

Santofimio-Tamayo, G.A., Benavides, J.C. (2019) Carbon accumulation patterns in soils of tropical peatlands from fluvial origin (Caquetá, Colombia). *Wetland Science & Practice*, 36(3), 171.

van Andel, T.R. (1992) *Characterization and Classification of a Floodplain Forest of the River Caqueta, Amazonas, Colombia*. Master´s dissertation, University of Amsterdam, 31 pp.

van der Hammen, T., Urrego, L.E., Espejo, N., Duivenvoorden, J.F., Lips, J.M. (1992) Late glacial and Holocene sedimentation and fluctuations of river water level in the Caquetá River area (Colombian Amazonia). *Journal of Quaternary Science*, 7, 57–67.

Ecuador

Bech, J., Sokolovska, M., Petrova, L., Tonon, L., Lansac, A. (2002) Humus nature of the soils in the upper Western Andes (Southern Ecuador). Paper no. 1572 in: *Abstracts Volume 1: Symposia 01–12*, 17th World Congress of Soil Science, Kasetsart University, Bangkok, Thailand, 219.

Behling, H. (2008) Tropical mountain forest dynamics in the Mata Atlantica and northern Andean biodiversity hotspots during the late Quaternary. In: Gradstein, S.R., Homeier, J., Gansert, D. (eds.) *The Tropical Mountain Forest: Patterns and Processes in a Biodiversity Hotspot*, Volume 2, Biodiversity and Ecology Series, Universitätsverlag Göttingen, 25–33.

Brunschön, C. (2010) *Late Quaternary Landscape Dynamics in the Podocarpus National Park Region in the Southeastern Andes of Ecuador*. Dissertation, Georg August University Göttingen, Göttingen, 204 pp.

Brunschön, C., Behling, H. (2009) Late Quaternary vegetation, fire and climate history reconstructed from two cores at Cerro Toledo, Podocarpus National Park, southeastern Ecuadorian Andes. *Quaternary Research*, 72, 388–399.

Chimner, R., Karberg, J. (2008) Long-term carbon accumulation in two tropical mountain peatlands, Andes Mountains, Ecuador. *Mires and Peat*, 3, 04, 10 pp.

Frost, I. (1988) A Holocene sedimentary record from Anañgucocha in the Ecuadorian Amazon. *Ecology*, 69, 66–73.

Jantz, N. (2013) *Patterns of Mountain Vegetation Dynamics and their Responses to Environmental Changes in the South Ecuadorian Andes*. Dissertation, Georg-August-Universität Göttingen, Göttingen, 239 pp.

Ledru, M.-P., Jomelli, V., Samaniego, P., Vuille, M., Hidalgo, S., Herrera, M., Ceron, C. (2013) The Medieval Climate Anomaly and the Little Ice Age in the eastern Ecuadorian Andes. *Climate of the Past*, 9, 307–321.

MAG-SIGTIERRAS (2015) Mapa de órdenes de suelos del Ecuador (Map of the soil orders of Ecuador). Ministry of Agriculture and Livestock - Sigtierras, Quito (in Spanish). Online at: http://www.sigtierras.gob.ec/mapa-de-ordenes-de-suelos/

Niemann, H. (2008) *Late Quaternary Vegetation, Climate and Fire Dynamics in the Podocarpus National Park Region, Southeastern Ecuadorian Andes*. Dissertation, Georg-August-Universität Göttingen, Göttingen, 178 pp.

Niemann, H., Behling, H. (2008) Past vegetation and fire dynamics. In: Beck, E., Bendix, J., Kottke, I., Makeschin, F., Mosandl, R. (eds.) *Gradients in a Tropical Mountain Ecosystem of Ecuador*, Ecological Studies 198, Springer-Verlag, Berlin / Heidelberg, 101–112.

Niemann, H., Behling, H. (2009) Late Pleistocene and Holocene environmental change inferred from the Cocha Caranga sediment and soil records in the southeastern Ecuadorian Andes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 276, 1–14.

Niemann, H., Behling, H. (2010) Late Holocene environmental change and human impact inferred from three soil monoliths and the Laguna Zurita multi-proxi record in the southeastern Ecuadorian Andes. *Vegetation History and Archaeobotany*, 19, 1–15.

Pitman, N.C.A., Andino, J.E.G., Aulestia, M., Cerón, C.E., Neill, D.A., Palacios, W., Rivas-Torres, G., Silman, M.R., Terborgh, J.W. (2014) Distribution and abundance of tree species in swamp forests of Amazonian Ecuador. *Ecography*, 37, 902–915.

Rodríguez, F., Behling, H. (2011) Late Holocene vegetation, fire, climate and upper forest line dynamics in the Podocarpus National Park, southeastern Ecuador. *Vegetation History and Archaeobotany*, 20, 1–14.

Rodríguez Rosero, L.F. (2012) *Reconstruction of Late Quaternary Landscape Dynamics in the Podocarpus National Park Region Southern Andes of Ecuador*. Master´s dissertation, Georg-August-Universität Göttingen, Göttingen, 101 pp.

Sánchez, M., Chimner, R.A., Hribljan, J.A., Lilleskov, E.A., Suárez, E. (2017) Carbon dioxide and methane fluxes in grazed and undisturbed mountain peatlands in the Ecuadorian Andes. *Mires and Peat*, 19, 20, 18 pp.

Suárez, E., Chimbolema, S., Chimner, R.A., Lilleskov, E. (2021) Root biomass and production by two cushion plant species of tropical high-elevation peatlands in the Andean páramo. *Mires and Peat*, 27, 18, 9 pp.

Villota Villafuerte, A.S. (2014) *Studies on Mountain Vegetation, Plant Diversity, Fire and Forest Line Dynamics of the Southeastern and Central Ecuadorian Andes During the Late Quaternary*. Dissertation, Georg August University Göttingen, Göttingen, 158 pp.

Villota, A., Behling, H. (2013) Late quaternary vegetation, climate, and fire dynamics: Human impact and evidence of past *Polylepis* populations in the northern Andean Depression inferred from the El Cristal record in southeastern Ecuador. *Ecotropica*, 19, 39–58.

Villota, A., Behling, H. (2014) Late glacial and Holocene environmental change inferred from the páramo of Cajanuma in the Podocarpus National Park, southern Ecuador. *Caldasia*, 36, 345–364.

Weng, C., Bush, M.B., Athens, J. (2002) Holocene climate change and hydrarch succession in lowland Amazonian Ecuador. *Review of Palaeobotany and Palynology*, 120, 73–90.

French Guiana

Boye, M., Cruys, H. (1961) New data on the coastal sedimentary formations in French Guiana. In: *Proceedings of the Fifth Inter-Guiana Geological Conference* (Georgetown, British Guiana, 28 Oct to 06 Nov 1959), Geological Survey Department, Georgetown, British Guiana, 145–160.

Brinkman, R., Pons, L.J. (1968) *A Pedo-Geomorphological Classification and Map of the Holocene Sediments in the Coastal Plain of the Three Guianas*. Soil Survey Papers 4, Soil Survey Institute of the Netherlands (Stichtung voor Bodemkartering), Wageningen, 40 pp.

Charles-Dominique, P., Blanc, P., Larpin, D., Ledru, M.-P., Riéra, B., Sarthou, C., Servant, M., Tardy, C. (1998) Forest perturbations and biodiversity during the last ten thousand years in French Guiana. *Acta Oecologica*, 19(3), 295–302.

Cubizolle, H., Mayindza Mouandza, M., Muller, F. (2013) Mires and Histosols in French Guiana (South America): new data relating to location and area. *Mires and Peat*, 12, 03, 10 pp.

Granville, J.J., Cremers, G. de, Hoff, M., Lescure, J., Tastain, O. (1993) *Les zones humides de la Guyane: numero special de nature guyanaise* (*The Wetlands of French Guiana: Special Issue of* Nature Guyanaise). SEPANGUY, Cayenne, French Guiana, 17 pp. (in French).

Iriarte, J., Power, M.J., Rostain, S., Mayle, F.E., Jones, H., Watling, J., Whitney, B.S., McKey, D.B. (2012) Fire-free land use in pre-1492 Amazonian savannas. *Proceedings of the National Academy of Sciences of the United States of America* (*PNAS*), 109, 6473–6478.

Prost, M.T., Lointier, M. (1986) *Sedimentologie et stratigraphie des formations holocenes - de la plaine cotiere de la Guyane Francaise* (*Sedimentology and Stratigraphy of the Holocene Formations of the French Guiana Coastal Plain*). Report, Project 201, International Programme for Geological Correlation, ORSTOM Centre, Cayenne, 83 pp. (in French).

Prost, M.T., Lointier, M. (1987) Sedimentology and stratigraphy of the Holocene formations of the French Guiana coastal plain. *Proceedings of the IGCP Project 201*, Mérida, Venezuela, 55–83.

Prost, M.T., Baltzer, F., Rudant, J.P., Dechambre, M. (1994) Using Sarex and Erasme imagery for coastal studies in French Guiana: example of the Kaw Swamp. In: Wooding, M., Attema, E. (eds.) *Proceedings of the South American Radar Experiment (SAREX-92) Final Results Workshop*, WPP 76, European Space Agency (ESA), Paris, 223–231.

Guyana

Arneaud, L.L. (2021) Preserving *Mauritia flexuosa* L.f. (Arecaceae) ecosystems during Guyana's first oil boom. *Brazilian Journal of Biology*, 82, 1–3.

Braun, E., Derting, J. (1964) Map for the reconnaissance soil survey of northwest British Guiana. FAO, Rome. Online at: https://esdac.jrc.ec.europa.eu/images/Eudasm/latinamerica/images/maps/download/PDF/gy13002_1so.pdf.

Brinkman, R., Pons, L.J. (1968) *A Pedo-Geomorphological Classification and Map of the Holocene Sediments in the Coastal Plain of the Three Guianas*. Soil Survey Papers 4, Soil Survey Institute of the Netherlands (Stichtung voor Bodemkartering), Wageningen, 40 pp.

Eisma, D., van der Marel, H. (1971) Marine muds along the Guyana Coast and their origin from the Amazon Basin. *Contributions to Mineralogy and Petrology*, 31, 321–334.

Peru

Alva Hurtado, J.E., Meneses Loja, J.F., Chang Chang, L.A., Lara Montani, J.L., Nishimura, T. (1992) Efectos en el terreno ocasionados por los sismos del Alto Mayo en Perú (Effects on the ground caused by the Alto Mayo earthquakes in Peru). IX National Congress of Civil Engineering, Ica, 14 Sep 1992 (in Spanish).

Baker, T.R., del Castillo Torres, D., Honorio, E., Lawson, I., Martinez, M., Montoya, M., Roucoux, K. (2019) The challenges for achieving conservation and sustainable development within the wetlands of the Pastaza-Marañon. In: Chirif, A. (ed) Perú: Deforestation in times of climate change, IWGIA, Lima, 155–174.

Bhomia, R.K., van Lent, J., Rios, J.M.G., Hergoualc'h, K., Coronado, E.N.H., Murdiyarso, D. (2019) Impacts of *Mauritia flexuosa* degradation on the carbon stocks of freshwater peatlands in the Pastaza-Marañón river basin of the Peruvian Amazon. *Mitigation and Adaptation Strategies for Global Change*, 24, 645–668.

Bourgeau-Chavez, L.L., Grelik, S.L., Battaglia, M.J., Leisman, D.J., Chimner, R.A., Hribljan, J.A., Lilleskov, E.A., Draper, F.C., Zutta, B.R., Hergoualc'h, K., Bhomia, R.K., Lähteenoja, O. (2021) Advances in Amazonian Peatland discrimination with multi-temporal PALSAR refines estimates of peatland distribution, C stocks and deforestation. *Frontiers in Earth Science*, 9, 1–19.

Brañas, M., Núñez Pérez, C., Fabiano, E., Del Águila Villacorta, M., Schulz, C., Laurie, N., Sanjurjo Vilchez, J., Davies, A., Roucoux, K., Lawson, I., Andueza, L. (2019) *Urarina: Identidad y memoria en la cuenca del Río Chambira* (*Urarina: Identity and Memory in the Chambira River Basin*). Instituto de Investigaciones de la Amazonia Peruana (IIAP), Iquitos, 74 pp. (in Spanish).

Branch, N.P., Kemp, R.A., Silva, B., Meddens, F.M., Williams, A., Kendall, A., Pomacanchari, C.V. (2007) Testing the sustainability and sensitivity to climatic change of terrace agricultural systems in the Peruvian Andes: a pilot study. *Journal of Archaeological Science*, 34, 1–9.

Buessecker, S., Sarno, A.F., Reynolds, M.C., Chavan, R., Park, J., Fontánez Ortiz, M., Pérez-Castillo, A.G., Panduro Pisco, G., Urquiza-Muñoz, J.D., Reis, L.P., Ferreira-Ferreira, J., Furtunato Maia, J.M., Holbert, K.E., Penton, C.R., Hall, S.J., Gandhi, H., Boëchat, I.G., Gücker, B., Ostrom, N.E., Cadillo-Quiroz, H. (2022) Coupled abiotic-biotic cycling of nitrous oxide in tropical peatlands. *Nature Ecology & Evolution*, 6, 1881–1890.

Chepstow-Lusty, A.J., Bennett, K.D., Fjeldså, J., Kendall, A., Galiano, W., Herrera, A.T. (1998) Tracing 4,000 years of environmental history in the Cuzco area, Peru, from the pollen record. *Mountain Research and Development*, 18, 159–172.

Chepstow-Lusty, A., Frogley, M.R., Bauer, B.S., Bush, M.B., Herrera, A.T. (2003) A late Holocene record of arid events from the Cuzco region, Peru. *Journal of Quaternary Science*, 18, 491–502.

Chepstow-Lusty, A.J., Frogley, M.R., Bauer, B.S., Leng, M.J., Boessenkool, K.P., Carcaillet, C., Ali, A.A., Gioda, A. (2009) Putting the rise of the Inca empire within a climatic and land management context. *Climate of the Past*, 5, 375–388.

Cooper, D.J., Wolf, E.C., Colson, C., Vering, W., Granda, A., Meyer, M. (2010) Alpine peatlands of the Andes, Cajamarca, Peru. *Arctic, Antarctic, and Alpine Research*, 42(1), 19–33.

Correa-Metrio, A., Cabrera, K.R., Bush, M.B. (2010) Quantifying ecological change through discriminant analysis: a paleoecological example from the Peruvian Amazon. *Journal of Vegetation Science*, 21, 695–704.

Crnobrna, B., Llanqui, I.B., Cardenas, A.D., Panduro Pisco, G. (2022) Relationships between organic matter and bulk density in Amazonian peatland soils. *Sustainability*, 14, 12070, 14 pp.

del Aguila-Pasquel, J., Doughty, C.E., Metcalfe, D.B., Silva-Espejo, J.E., Girardin, C.A., Chung Gutierrez, J.A., Navarro-Aguilar, G.E., Quesada, C.A., Hidalgo, C.G., Reyna Huaymacari, J.M., Halladay, K., del Castillo Torres, D., Phillips, O., Malhi, Y. (2014) The seasonal cycle of productivity, metabolism and carbon dynamics in a wet aseasonal forest in north-west Amazonia (Iquitos, Peru). *Plant Ecology & Diversity*, 7, 71–83.

Draper, F., Roucoux, K.H., Lawson, I.T., Mitchard, E.T.A., Honorio Coronado, E.N., Lähteenoja, O., Torres Montenegro, L., Valderrama Sandoval, E., Zaráte, R., Baker, T.R. (2014) The distribution and amount of carbon in the largest peatland complex in Amazonia. *Environmental Research Letters*, 9, 124017, 12 pp.

Draper, F.C., Honorio Coronado, E.N., Roucoux, K.H., Lawson, I.T., A. Pitman, N.C., A. Fine, P.V., Phillips, O.L., Torres Montenegro, L.A., Valderrama Sandoval, E., Mesones, I., García-Villacorta, R., Arévalo, F.R.R., Baker, T.R. (2018) Peatland forests are the least diverse tree communities documented in Amazonia, but contribute to high regional beta-diversity. *Ecography*, 41, 1256–1269.

FAO (2021) *Perú y las turberas: Necesidades y brechas de conocimiento* (*Peru and Peatlands: Knowledge Needs and Gaps*). Technical Report, Food and Agriculture Organization of the United Nations (FAO), Rome, 41 pp. (in Spanish). Online at: https://www.fao.org/3/CB7684ES/CB7684ES.pdf, accessed 06 Dec 2023.

Finn, D.R., Ziv-El, M., van Haren, J., Park, J.G., del Aguila-Pasquel, J., Urquiza-Muñoz, J.D., Cadillo-Quiroz, H. (2020) Methanogens and methanotrophs show nutrient-dependent community assemblage patterns across tropical peatlands of the Pastaza-Marañón Basin, Peruvian Amazonia. *Frontiers in Microbiology*, 11, 1–15.

Flores Llampazo, G., Honorio Coronado, E.N., Del Aguila-Pasquel, J., Cordova Oroche, C.J., Díaz Narvaez, A., Reyna Huaymacari, J., Grandez Ríos, J., Lawson, I.T., Hastie, A., Baird, A.J., Baker, T.R. (2022) The presence of peat and variation in tree species composition are under different hydrological controls in Amazonian wetland forests. *Hydrological Processes*, 36, e14690. 14 pp.

Freitas Alvarado, L., Otárola Acevedo, E., del Castillo Torres, D., Linares Bensimón, C., Martínez Dávila, P., Adolfo Malca Salas, G. (2006) *Servicios ambientales de almacenamiento y secuestro de carbono del ecosistema aguajal en la Reserva Nacional Pacaya Samiria, Loreto - Perú* (*Carbon Storage and Sequestration Ecosystem Services of the Aguajal Ecosystem in the Pacaya Samiria National Reserve, Loreto - Peru)*) . Technical Document No. 29, Instituto de investigaciones de la Amazonía peruana (IIAP), Iquitos, 62 pp. (in Spanish).

Garcia Soria, D., Honorio Coronado, E.N., Del Castillo, D. (2012) Determinación del stock de carbono en aguajales de la cuenca del río Aguaytía, Ucayali - Perú (Determination of the carbon stock in aguajales of the Aguaytía river basin, Ucayali - Peru). *Folia Amazónica*, 21, 153–160 (in Spanish).

Griffis, T.J., Roman, D.T., Wood, J.D., Deventer, J., Fachin, L., Rengifo, J., Del Castillo, D., Lilleskov, E., Kolka, R., Chimner, R.A., del Aguila-Pasquel, J., Wayson, C., Hergoualc'h, K., Baker, J.M., Cadillo-Quiroz, H., Ricciuto, D.M. (2020) Hydrometeorological sensitivities of net ecosystem carbon dioxide and methane exchange of an Amazonian palm swamp peatland. *Agricultural and Forest Meteorology*, 295, 1–15.

Hastie, A., Honorio Coronado, E.N., Reyna, J., Mitchard, E.T.A. and 24 others (2022) Risks to carbon storage from land-use change revealed by peat thickness maps of Peru. *Nature Geoscience*, 15, 369–374.

Hergoualc'h, K., Gutiérrez-Vélez, V.H., Menton, M., Verchot, L.V. (2017) Characterizing degradation of palm swamp peatlands from space and on the ground: An exploratory study in the Peruvian Amazon. *Forest Ecology and Management*, 393, 63–73.

Hergoualc'h, K., Dezzeo, N., Verchot, L.V., Martius, C., van Lent, J., del Aguila-Pasquel, J., López Gonzales, M. (2020) Spatial and temporal variability of soil N_2O and CH_4 fluxes along a degradation gradient in a palm swamp peat forest in the Peruvian Amazon. *Global Change Biology*, 26, 7198–7216.

Hidalgo Pizango, C.G., Honorio Coronado, E.N., Del Águila-Pasquel, J., Flores Llampazo, G. and 19 others (2022) Sustainable palm fruit harvesting as a pathway to conserve Amazon peatland forests. *Nature Sustainability*, 5, 479–487.

Honorio Coronado, E.N., Hergoualc'h, K. (2021) *Informe sobre los análisis y resultados de las emisiones de CO_2 debido a la deforestación y degradación de turberas en la Amazonía peruana*. (*Report on the Analysis and Results of CO_2 Emissions due to Deforestation and Peatland Degradation in the Peruvian Amazon*). Center for International Forestry Research (CIFOR), Bogor, 29 pp. (in Spanish).

Honorio Coronado, E.N., Vega, J.E., Corrales, M.N. (2015) Diversidad, estructura y carbono de los bosques aluviales del noreste peruano (Diversity, structure and carbon in the alluvial forests of north-eastern Peru). *Folia Amazónica*, 24, 55–70 (in Spanish).

Honorio Coronado, E.N., Hastie, A., Reyna, J., Flores, G. and 25 others (2021) Intensive field sampling increases the known extent of carbon-rich Amazonian peatland pole forests. *Environmental Research Letters*, 16, 1–15.

Householder, J.E., Wittmann, F., Tobler, M.W., Janovec, J.P. (2015) Montane bias in lowland Amazonian peatlands: Plant assembly on heterogeneous landscapes and potential significance to palynological inference. *Palaeogeography, Palaeoclimatology, Palaeo-ecology*, 423, 138–148.

Kalliola, R., Puhakka, M., Salo, J., Tuomisto, H., Alle, R. (1991) The dynamics, distribution and classification of swamp vegetation in Peruvian Amazonia. *Annales Botanici Fennici*, 28, 225–239.

Kelly, T.J., Baird, A.J., Roucoux, K.H., Baker, T.R., Honorio Coronado, E.N., Ríos, M., Lawson, I.T. (2014) The high hydraulic conductivity of three wooded tropical peat swamps in northeast Peru: measurements and implications for hydrological function. *Hydrological Processes*, 28, 3373–3387.

Kelly, T.J., Lawson, I.T., Roucoux, K.H., Baker, T.R., Jones, T.D., Sanderson, N.K. (2017) The vegetation history of an Amazonian domed peatland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 468, 129–141.

Kelly, T.J., Lawson, I.T., Roucoux, K.H., Baker, T.R., Honorio-Coronado, E.N., Jones, T.D., Rivas Panduro, S. (2018) Continuous human presence without extensive reductions in forest cover over the past 2500 years in an aseasonal Amazonian rainforest. *Journal of Quaternary Science*, 33, 369–379.

Lähteenoja, O., Page, S. (2011) High diversity of tropical peatland ecosystem types in the Pastaza-Marañón basin, Peruvian Amazonia. *Journal of Geophysical Research*, 116, 1–14.

Lähteenoja, O., Roucoux, K.H. (2010) Inception, history and development of peatlands in the Amazon Basin. *PAGES News*, 18, 27–29.

Lähteenoja, O., Ruokolainen, K., Schulman, L., Alvarez, J. (2009a) Amazonian floodplains harbour minerotrophic and ombrotrophic peatlands. *CATENA*, 79, 140–145.

Lähteenoja, O., Ruokolainen, K., Schulman, L., Oinonen, M. (2009b) Amazonian peatlands: an ignored C sink and potential source. *Global Change Biology*, 15, 2311–2320.

Lähteenoja, O., Reátegui, Y.R., Räsänen, M., Torres, D.D.C., Oinonen, M., Page, S. (2012) The large Amazonian peatland carbon sink in the subsiding Pastaza-Marañón foreland basin, Peru. *Global Change Biology*, 18, 164–178.

Lawson, I.T., Jones, T.D., Kelly, T.J., Coronado, E.N.H., Roucoux, K.H. (2014) The geochemistry of Amazonian peats. *Wetlands*, 34, 905–915.

López Gonzales, M., Hergoualc'h, K., Angulo Núñez, O., Baker, T.R., Chimner, R.A., Del Águila Pasquel, J., del Castillo Torres, D., Freitas Alvarado, L., Fuentealba Durand, B., García Gonzales, E., Honorio Coronado, E.N., Kazuyo, H., Lilleskov, E., Málaga Durán, N., Maldonado Fonkén, M.S., Martín Brañas, M., Vargas, T., Planas Clarke, A.M., Roucoux, K., Vacalla Ochoa, F. (2020) *What do we Know About Peruvian Peatlands?* Occasional Paper 210, Center for International Forestry Research (CIFOR), Bogor, 16 pp.

Maldonado Fonkén, M.S. (2015) An introduction to the bofedales of the Peruvian High Andes. *Mires and Peat*, 15, 05, 13 pp.

MINAM (2018) Mapa de suelos (Soils Map): Shapefile. GEO GPS Perú, Lima (in Spanish). Online at: https://www.geogpsperu.com/2018/02/mapa-de-suelos-shapefile-memoria.html, accessed 06 Dec 2023.

Oyague Passuni, E., Maldonado Fonkén, M.S. (2015) Relationships between aquatic invertebrates, water quality and vegetation in an Andean peatland system. *Mires and Peat*, 15, 14, 21 pp.

Polk, M.H., Young, K.R., Cano, A., León, B. (2019) Vegetation of Andean wetlands (bofedales) in Huascarán National Park, Peru. *Mires and Peat*, 24, 01, 26 pp.

Rodriguez Achung, F. (1995) *El resurso del suelo en la Amazonia Peruana, diagnostico para su investigación* (*Soil Resources in the Peruvian Amazon, a Diagnosis for Research*). Technical Document No. 14, Instituto de investigaciones de la amazonía peruana (IIAP), Iquitos, 58 pp. (in Spanish).

Román-Cuesta, R.M., Salinas, N., Asbjornsen, H., Oliveras, I., Huaman, V., Gutiérrez, Y., Puelles, L., Kala, J., Yabar, D., Rojas, M., Astete, R., Jordán, D.Y., Silman, M., Mosandl, R., Weber, M., Stimm, B., Günter, S., Knoke, T., Malhi, Y. (2011) Implications of fires on carbon budgets in Andean cloud montane forest: The importance of peat soils and tree resprouting. *Forest Ecology and Management*, 261, 1987–1997.

Roucoux, K., Baker, T.R., Gosling, W., Honorio, E., Jones, T.D., Lähteenoja, O., Lawson, I. (2012) Abrupt vegetation transitions characterise long-term Amazonian peatland development. *EGU General Assembly Abstracts*, Jan 2012, Vienna.

Roucoux, K.H., Lawson, I.T., Jones, T.D., Baker, T.R., Coronado, E.H., Gosling, W.D., Lähteenoja, O. (2013) Vegetation development in an

Amazonian peatland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 374, 242–255.

Roucoux, K.H., Lawson, I.T., Baker, T.R., Del Castillo Torres, D., Draper, F.C., Lähteenoja, O., Gilmore, M.P., Honorio Coronado, E.N., Kelly, T.J., Mitchard, E.T.A., Vriesendorp, C.F. (2017) Threats to intact tropical peatlands and opportunities for their conservation. *Conservation Biology*, 31, 1283–1292.

Salvador, F., Monerris, J., Rochefort, L. (2014) Peatlands of the Peruvian Puna ecoregion: types, characteristics and disturbance. *Mires and Peat*, 15, 03, 17 pp.

Schulz, C., Martín Brañas, M., Núñez Pérez, C., Del Aguila Villacorta, M., Laurie, N., Lawson, I.T., Roucoux, K.H. (2019) Peatland and wetland ecosystems in Peruvian Amazonia: indigenous classifications and perspectives. *Ecology and Society*, 24, 1–16.

Soosaar, K., Schindler, T., Machacova, K., Pärn, J., Fachín-Malaverri, L.M., Rengifo-Marin, J.E., Alegría-Muñoz, W., Jibaja-Aspajo, J.L., Negron-Juarez, R., Zárate-Gómez, R., Garay-Dinis, D.J., Arista-Oversluijs, A.G., Tello-Espinoza, R., Pacheco-Gómez, T., Mander, Ü. (2022) High methane emission from palm stems and nitrous oxide emission from the soil in a Peruvian Amazon peat swamp forest. *Frontiers in Forests and Global Change*, 5, 849186, 10 pp.

Swindles, G.T., Kelly, T.J., Roucoux, K.H., Lawson, I.T. (2018) Response of testate amoebae to a late Holocene ecosystem shift in an Amazonian peatland. *European Journal of Protistology*, 64, 13–19.

Teh, Y.A., Murphy, W.A., Berrio, J.-C., Boom, A., Page, S.E. (2017) Seasonal variability in methane and nitrous oxide fluxes from tropical peatlands in the western Amazon basin. *Biogeosciences*, 14, 3669–3683.

van Lent, J., Hergoualc'h, K., Verchot, L., Oenema, O., van Groenigen, J.W. (2019) Greenhouse gas emissions along a peat swamp forest degradation gradient in the Peruvian Amazon: soil moisture and palm roots effects. *Mitigation and Adaptation Strategies for Global Change*, 24, 625–643.

Vásquez Arévalo, F.A., Zárate Gómez, R., Socolar, J.B., Díaz Alván, J., Perez Peña, P.E. (2020) First record of the gray-legged tinamou, *Crypturellus duidae*, and other poor-soil specialist birds from peatlands in the Putumayo River basin, Loreto, Peru. *Acta Amazonica*, 50, 155–158.

Wang, B., Hapsari, K.A., Horna, V., Zimmermann, R., Behling, H. (2022) Late Holocene peatland palm swamp (aguajal) development, carbon deposition and environment changes in the Madre de Dios region, southeastern Peru. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 594, 110955, 11 pp.

Wang, S., Zhuang, Q., Lähteenoja, O., Draper, F.C., Cadillo-Quiroz, H. (2018) Potential shift from a carbon sink to a source in Amazonian peatlands under a changing climate. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 115, 12407–12412.

Winton, R.S., Flanagan, N., Richardson, C.J. (2017) Neotropical peatland methane emissions along a vegetation and biogeochemical gradient. *PloS ONE*, 12, 1–12.

Suriname

Augustinus, P., Slager, S. (1971) Soil formation in swamp soils of the coastal fringe of Surinam. *Geoderma*, 6, 203–211.

Bosma, W., Kroonenberg, S.B., van Lissa, R.V., Mass, K., de Roever, E. (1984) An explanation to the geology of Suriname. In: de Vletter, R. (ed.) *Contributions to the Geology of Suriname 8*, Ministry of Natural Resources and Energy and Surinam Government Geological and Mining Service, Mededeling, 31–82.

Brinkman, R., Pons, L.J. (1968) *A Pedo-Geomorphological Classification and Map of the Holocene Sediments in the Coastal Plain of the Three Guianas*. Soil Survey Papers 4, Soil Survey Institute of the Netherlands (Stichtung voor Bodemkartering), Wageningen, 40 pp.

CELOS (2017) Surinam soil, SWIRIS, Paramaribo. Online at: https://www.swris.sr/wp-content/uploads/2017/09/soils.jpg

GONINI (2022) Geological map of Surinam. Online at: https://www.gonini.org/

Lindeman, J.C. (1953) *The Vegetation of the Coastal Region of Suriname: Results of the Scientific Expedition to Suriname 1948–49. Botanical Series No. 1*. Drukkerij en Uitg.-Mij. v/h Kemink, Utrecht, 151 pp.

Rine, J.M., Ginsburg, R.N. (1985) Depositional facies of a mud shoreface in Suriname, South America – a mud analogue to sandy, shallow-marine deposits. *Journal of Sedimentary Research*, 55, 633–652.

Schulz, J. (1960) Ecological studies on rain forest in Northern Suriname. *Mededelingen van het Botanisch Museum en Herbarium van de Rijksuniversiteit te Utrecht*, 163, 1–267.

Sevenhuijsen, R.J. (1977) *Irrigatie uit een moeras: een hydrologische studie van de Nannizwamp in Suriname* (*Irrigation from a Swamp: A*

Hydrological Study of the Nannizwamp in Suriname). Verslagen van landbouwkundige onderzoekingen 869 (Agricultural Research Report 869), Centre for Agricultural Publishing and Documentation, Wageningen, 143 pp. (in Dutch).

Teunissen, P.A. (1976) Notes on the vegetation of Suriname I - Vegetation changes in a dammed up fresh water swamp in NW Suriname. *Acta Amazonica*, 6, 117–150.

van der Eyk, J.J. (1957) *Reconnaissance Soil Survey in Northern Surinam*. Wageningen University, Wageningen, 112 pp.

van der Voorde, P. (1957) *De bodemgesteldheid van het ritsenlandschap en van de oude kustvlakte in Suriname* (*Soil Conditions of the Ridge Landscape and Ancient Coastal Plain in Suriname*). Dissertation, Wageningen University, Wageningen, 212 pp. (in Dutch).

Versteeg, A.H. (1992) Environment and man in the young coastal plain of West Suriname. In: Prost, M.T. (ed.) *Évolution des Littoraux de Guyane et de la Zone Caribe Méridionale Pendant le Quaternarie*, Symposium PICG 274-ORSTOM, Cayene (Guyane), Editions de I'ORSTOM (Colloques et Séminaires), Paris, 531–530.

Wong, T. (1984) Stratigraphy and sedimentary history of the Guiana Basin. In: de Vletter, R. (ed.) *Contributions to the Geology of Suriname 8*, Ministry of Natural Resources and Energy and Surinam Government Geological and Mining Service, Mededeling, 83–90.

Wong, T.E. (1992) Quaternary stratigraphy of Suriname. In: Prost, M.T. (ed.) *Évolution des Littoraux de Guyane et de la Zone Caribe Méridionale Pendant le Quaternarie*, Symposium PICG 274-ORSTOM, Cayene (Guyane), Editions de I'ORSTOM (Colloques et Séminaires), Paris, 559–578.

Wong, T.E., Kramer, R., de Boer, P.L., Langereis, C., Sew-A-Tjon, J. (2009) The influence of sea-level changes on tropical coastal lowlands; the Pleistocene Coropina Formation, Suriname. *Sedimentary Geology*, 216, 125–137.

Venezuela

Ballesteros, T. (2015) Paleoecological study of vegetation dynamics in the Neotropical Gran Sabana since last glacial. Dissertation. Universidad de Barcelona, Barcelona, 229 pp.

Crum, H. (2002) Miscellaneous notes on *Sphagnum*: 12. *Novon*, 12, 441–445.

Dubroeucq, D., Volkoff, B. (1988) Évolution des couvertures pédologiques sableuses à podzols géants d’Amazonie (Evolution of sandy soil mantles to the giant podzols of Amazonia). *Cahiers de l’ORSTOM série Pédologie*, 24, 191–214 (in French).

Dubroeucq, D., Volkoff, B. (1998) From Oxisols to Spodosols and Histosols: evolution of the soil mantles in the Rio Negro basin (Amazonia). *CATENA*, 32, 245–280.

Flantua, S.G.A., Hooghiemstra, H., Vuille, M., Behling, H., Carson, J.F., Gosling, W.D., Hoyos, I., Ledru, M.P., Montoya, E., Mayle, F., Maldonado, A., Rull, V., Tonello, M.S., Whitney, B.S., González-Arango, C. (2016) Climate variability and human impact in South America during the last 2000 years: synthesis and perspectives from pollen records. *Climate of the Past*, 12, 483–523.

Gavaud, M., Blancaneaux, P., Dubroeucq, D., Pouyllau, M. (1986) Les paysages pédologiques de l'Amazonie vénézuélienne (Soil landscapes in the Venezuelan Amazon). *Cahiers de l’ORSTOM série Pédologie*, 22, 265–284 (in French).

Lasso, C.A., Rial, A., Colonnello, G., Machado-Allison, A., Trujillo, F. (eds.) (2014) *Humedales de la Orinoquia (Colombia-Venezuela)* (*Wetlands of the Orinoquia (Colombia-Venezuela)*). Hydrobiological and Continental Fisheries Resources of Colombia XI, Alexander von Humboldt Biological Resources Research Institute (IAvH), Bogotá, 301 pp. (in Spanish)

Leal, A. (2010) *Historia holocena de la vegetación y el fuego en bordes sabana/bosque y turberas de la Gran Sabana, Guayana Venezolana* (*Holocene History of Vegetation and Fire on Savanna/Forest Edges and Peatlands of the Gran Sabana, Venezuelan Guyana*). Dissertation, Universidad Simón Bolívar, Baruta, 309 pp. (in Spanish).

Leal, A., Bilbao, B., Berrio, J.C., Behling, H., Montoya, J.V., Méndez, C. (2016) Late-Holocene gallery forest retrogression in the Venezuelan Guayana new data and implications for the conservation of a cultural landscape. *The Holocene*, 26, 1049–1063.

Malpica Piñeros, C. (2019) *Mapping of Venezuelan Peatlands*. Master’s thesis, University of Greifswald, 69 pp.

Montoya, E., Rull, V., Nogué, S., Díaz, W.A. (2009) Paleoecología del Holoceno en la Gran Sabana, SE Venezuela: análisis preliminar de polen y microcarbones en la Laguna Encantada (Holocene palaeoecology of the Gran Sabana, SE Venezuela: Preliminary analysis of pollen and microcarbons from Laguna Encantada). *Collectanea Botanica*, 28, 65–79 (in Spanish).

Montoya, E., Rull, V., Nogué, S. (2011a) Early human occupation and land use changes near the boundary of the Orinoco and the Amazon basins SE Venezuela: palynological evidence from El Paují record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 310, 413–426.

Montoya, E., Rull, V., Stansell, N.D., Abbott, M.B., Nogué, S., Bird, B.W., Díaz, W.A. (2011b) Forest–savanna–morichal dynamics in relation to fire and human occupation in the southern Gran Sabana (SE Venezuela) during the last millennia. *Quaternary Research*, 76, 335–344.

Montoya, E., Rull, V., Stansell, N.D., Bird, B.W., Nogué, S., Vegas-Vilarrúbia, T., Abbott, M.B., Díaz, W.A. (2011c) Vegetation changes in the Neotropical Gran Sabana (Venezuela) around the Younger Dryas chron. *Journal of Quaternary Science*, 26, 207–218.

Nogué, S., Rull, V., Montoya, E., Huber, O., Vegas-Vilarrúbia, T. (2009) Paleoecology of the Guayana Highlands (northern South America) Holocene pollen record from the Eruoda-tepui, in the Chimantá massif. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 281, 165–173.

Pouyllau, M., Blancaneaux, P., Hidalgo, R., Araujo, J., Dubroeucq, D., Gavaud, M.E.A. (1988) *Atlas del inventario de tierras del Territorio Federal Amazonas* (*Land Inventory Atlas of the Federal Territory of Amazonas*). Ministerio del Ambiente y de los Recursos Naturales Renovables (MARNR) & Office de la Recherche Scientifique et Technique Outre Mer (France) (ORSTOM), Caracas, 223 pp. (in Spanish).

Rinaldi, M., Rull, V., Schubert, C. (1990) Analisis paleoecologico de una turbera en la Gran Sabana (Santa Cruz de Mapuri), Venezuela: Analisis preliminaries (Palaeoecological analysis of a peatland in the Gran Sabana (Santa Cruz de Mapuri), Venezuela: Preliminary analysis). *Acta Cientifica Venezolana*, 41, 66–68 (in Spanish).

Rodríguez, J.P., Rojas-Suárez, F., Hernández, D.G. (eds.) (2010) *Libro rojo de los ecosistemas terrestres de Venezuela* (*Red Book of Venezuela's Terrestrial Ecosystems*). Provita, Shell, Lenovo (Venezuela), Caracas, 324 pp. (in Spanish).

Rull, V. (1999) A palynological record of a secondary succession after fire in the Gran Sabana, Venezuela. *Journal of Quaternary Science*, 14, 137–152.

Rull, V. (2004) Is the Lost World really lost? Palaeoecological insights into the origin of the peculiar flora of the Guayana Highlands. *Naturwissenschaften*, 91, 139–142.

Rull, V. (2005) Vegetation and environmental constancy in the neotropical Guayana Highlands during the last 6000 years? *Review of Palaeobotany and Palynology*, 135, 205–222.

Rull, V., Montoya, E. (2014) *Mauritia flexuosa* palm swamp communities: natural or human-made? A palynological study of the Gran Sabana region (northern South America) within a neotropical context. *Quaternary Science Reviews*, 99, 17–33.

Rull, V., Vegas-Vilarrúbia, T. (2006) Unexpected biodiversity loss under global warming in the neotropical Guayana Highlands: a preliminary appraisal. *Global Change Biology*, 12, 1–9.

Rull, V., Abbott, M.B,, Vegas-Vilarrúbia, T., Bezada, M., Montoya, E., Nogué, S., Gonzalez, C. (2010) Paleoenvironmental trends in Venezuela during the last glacial cycle. In: Sánchez-Villagra, M.R., Aguilera, O.A., Carlini, A.A. (eds.) *Urumaco and Venezuelan Palaeontology: The Fossil Record of the Northern Neotropics*. Indiana University Press, Bloomington, 52–83.

Rull, V., Montoya, E., Nogué, S., Huber, O. (2011) Preliminary palynological analysis of a Holocene peat bog from Apakará-tepui (Chimantá Massif, Venezuelan Guayana). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 30, 79–88.

Rull, V., Montoya, E., Nogué, S., Vegas-Vilarrúbia, T., Safont, E. (2013) Ecological palaeoecology in the neotropical Gran Sabana region: Long-term records of vegetation dynamics as a basis for ecological hypothesis testing. *Perspectives in Plant Ecology, Evolution and Systematics*, 15, 338–359.

Rull, V., Montoya, E., Vegas-Vilarrúbia, T., Ballesteros, T. (2015) New insights on palaeofires and savannisation in northern South America. *Quaternary Science Reviews*, 122, 158–165.

Rull, V., Vegas-Vilarrúbia, T., Montoya, E. (2016) The neotropical Gran Sabana region: Palaeoecology and conservation. *The Holocene*, 26, 1162–1167.

Safont, E., Rull, V., Vegas-Vilarrúbia, T., Montoya, E., Huber, O., Holst, B.K. (2016) Late Holocene vegetation and fire dynamics on the summits of the Guayana Highlands: The Uei-tepui palynological record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 455, 33–43.

Schubert, C., Fritz, P. (1985) Radiocarbon ages of peat, Guayana Highlands (Venezuela): Some paleoclimatic implications. *Naturwissenschaften*, 72, 427–429.

Zinck, J.A., Huber, O. (eds.) (2011) *Peatlands of the Western Guayana Highlands, Venezuela: Properties and Paleogeographic Significance of Peats*. Ecological Studies 217, Springer, Berlin, 295 pp.