

# PERU: DEFORESTATION IN TIMES OF CLIMATE CHANGE

ALBERTO CHIRIF  
editor



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# PERU: DEFORESTATION IN TIMES OF CLIMATE CHANGE

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# CONTENTS

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Deforestation in times of Climate Change <b>ALBERTO CHIRIF</b>	13
Coca, Forests and Indigenous Amazonian Peoples <b>HUGO CABIESES CUBAS</b>	25
The growth of oil palm in the Peruvian Amazon: deforestation and land trafficking <b>JUAN LUIS DAMMERT</b>	53
Fighting Illegal Logging in Peru: The government's steps forward and the industry pushback <b>JULIA M. URRUNAGA</b>	71
Forests and Indigenous Peoples Facing Climate Change and Globalisation <b>JOSÉ ÁLVAREZ ALONSO</b>	91
Autonomous Territorial Government of The Wampis Nation. Recovering Socio-Historical Autonomy, Building a Common Future <b>SHAPIOM NONINGO</b>	113
Deforestation in titled native communities 2000-2015: the cases of the indigenous Awajún peoples of Alto Mayo and the Kakataibo peoples of the Central Forest <b>SANDRA RÍOS CÁCERES, ERMETO TUESTA AND RICHARD CHASE SMITH</b>	125
The Defaunation of the Tropical Forests and its Environmental Implications <b>CLAUDIA MARÍA GÁLVEZ DURAND BESNARD</b>	135
The Impact of Deforestation on the Water and Fish Populations of The Peruvian Amazon <b>CARLOS CAÑAS</b>	145
The challenges for achieving conservation and sustainable development within the wetlands of the Pastaza-Marañón basin, Peru <b>TIMOTHY R. BAKER, DENNIS DEL CASTILLO TORRES, EURÍDICE HONORIO CORONADO, IAN LAWSON, MANUEL M. BRAÑAS, MARIANA MONTOYA AND KATHERINE ROUCOUX</b>	155
The impact of roads on indigenous territories <b>ERMETO TUESTA</b>	175

# THE CHALLENGES FOR ACHIEVING CONSERVATION AND SUSTAINABLE DEVELOPMENT WITHIN THE WETLANDS OF THE PASTAZA-MARAÑÓN BASIN, PERU

Timothy R. Baker, Dennis del Castillo Torres,  
Eurídice N. Honorio Coronado, Ian Lawson, Manuel Martín Brañas,  
Mariana Montoya, Katherine Roucoux

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The wetlands of the Pastaza-Marañón basin in northern Peruvian Amazonia are record-breaking: situated in the centre of one of the largest remaining areas of intact forest on the planet, they contain the largest known peatland complex in Amazonia. Thick layers of organic matter accumulate where the soil remains constantly wet and the large quantities of below-ground carbon make these the most carbon-dense of all Amazonian forests. These wetlands also have a multi-millennial history of occupation by indigenous people who hold a rich knowledge of the forests and their uses. Today, extensive natural stands of a renewable, bountiful and valued resource - the *Mauritia flexuosa* palm - help to sustain local communities along the myriad rivers which cross the landscape. However, this region also faces threats from the chronic damage caused by oil pollution and the uncertain implications of planned infrastructure developments. These forests therefore also pose one of the key questions for conservation today: how can substantial areas of intact tropical forest be sustained over the coming decades, whilst also supporting and improving the livelihoods of the people who live there?

The purpose of this article is to address this question by firstly documenting the history of the scientific exploration of these ecosystems, which helps to place these wetland forests in their regional and global context. Secondly, we explore our emerging knowledge of the relationships these forests have with people. In particular, we discuss the threats faced by these communities and their forests and the actions that are required to ensure that these ecosystems are sustainably managed and persist into the future.

## **The history of the biological description of the wetlands**

From the 1970s onwards, the forests of the northern Peruvian Amazon attracted interest from ecologists in search of the most diverse tropical forests because of their very high species richness (Gentry, 1988; Vásquez Martínez, 1997). Ecologists marvelled at the high alpha (ie local) diversity of the plots they studied in upland, non-flooded, *terra firme* forests of the region, where tree species richness of



forests on the most fertile soils can exceed 300 species per hectare (Gentry, 1988). Subsequently, the description of the unique biodiversity of the forests that grow on patches of upland, white sand soils led to the recognition that this region contains not only some of the most diverse forests in the world at the scale of individual plots but also extremely high diversity at the scale of landscapes – in other words, high beta diversity (Tuomisto *et al.*, 1995; Fine *et al.*, 2005). A paradigm of high diversity, at both point and landscape scales, was therefore established for these western Amazon forests.

In contrast to their diversity, the upland forests of this region are not particularly remarkable in terms of above-ground carbon stocks. These forests contain approximately 135 Mg C ha<sup>-1</sup> (Baker *et al.*, 2004a) – a high value compared to drier tropical ecosystems or many temperate forests, but markedly lower than the highest aboveground biomass forests of Amazonia which occur on the Guiana Shield (with typically >200 Mg C per ha; Johnson *et al.*, 2016), and lower than typical values for African and Asian moist tropical forests (Sullivan *et al.*, 2017b). Even the grandest upland forests of the western Amazon contain trees that are not particularly tall, or of particularly large diameter, or of species with particularly dense wood, compared to many other moist tropical forests. The wetland forests of the Pastaza-Marañón basin are usually even shorter in stature, thinner, and more open than the upland forests, so it is no surprise that biomass maps based on remote sensing data show the Pastaza-Marañón basin as a ‘black hole’ with low values of above-ground carbon (Asner *et al.*, 2014).

These perspectives on the forests in this region were, however, overturned by the scientific exploration of the peatlands of the Pastaza-Marañón basin. The story of the on-going biological description of these wetlands illustrates the formative role that unanticipated observations play in scientific discovery and the value of bringing perspectives from other regions and fields of investigation to understand what lies in front of us. It also reminds us of how our research builds on the work of others and how insights that are each based on innovative and pioneering measurements and observations accumulate over time to transform our knowledge.

The possible presence of extensive peatland areas in the wetlands of western Amazonia was first noted in the scientific literature by Kalle Ruoklainen, Leif Schulman, and Hanna Tuomisto (Schulman *et al.*, 1999; Ruokolainen *et al.*, 2001). These publications were based on a series of conversations and field observations during the 1990s: Juan Ruiz Celidonio had mentioned to them of an open swamp with *Sphagnum* moss and peat near the Rio Ucayali, and they themselves had also found at least two metres of peat in a palm swamp in Yasuní, Ecuador in 1997, which demonstrated the potential of these ecosystems to accumulate large amounts of organic matter. In addition, with other colleagues from Finland, they had participated in the first broad description of the wetlands of the Peruvian Amazon based on overflying the region and speculated on the possible presence of peat (Kalliola *et al.*, 1991). These biologists had a background of studying the

northern boreal biome, where peatlands are generally expected to form under specific waterlogged conditions. For them, the scattered observations of peat in Amazonia were a strong indication that the decomposition of organic matter is impeded by the same factors in the tropics as in the boreal zone, despite the common wisdom of the time, which held that decomposition in the tropics is so efficient that peat cannot form.

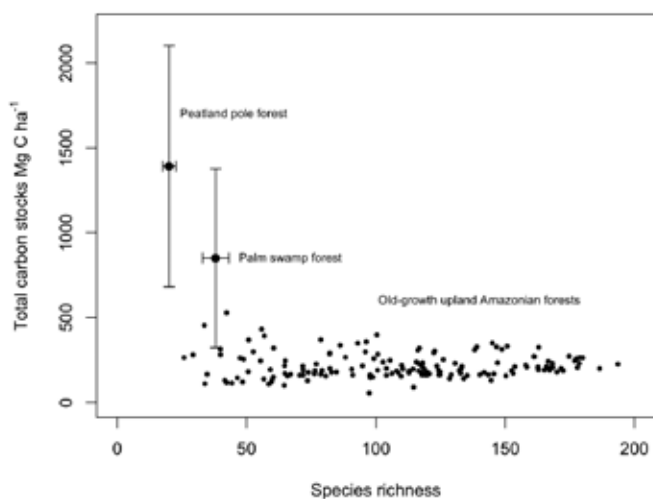
Independently, Dennis del Castillo, who had begun to work at the Instituto de Investigaciones de la Amazonia Peruana (IIAP) in the 2000s, realised the capacity of the almost monodominant stands of *Mauritia flexuosa* to accumulate organic matter, based on his observations of organic matter accumulation beneath oil palm plantations in Nigeria. At IIAP, Guzmán (2004) carried out a preliminary economic valuation of the environmental benefits of sustainable wetland management including some field data collection, and subsequently Dennis del Castillo and colleagues made the study of the carbon stocks of the palm swamps a research priority. This step led to the first project, funded by INCAGRO, to measure the below-ground carbon stocks of these ecosystems, led by Luis Freitas. The results were a revelation: these observations suggested that these forests could harbour remarkable quantities – more than  $600 \text{ Mg C ha}^{-1}$  – of carbon below the ground stored as peat (Freitas *et al.*, 2006), far in excess of estimates of the aboveground biomass of nearby upland forests.

The work led by IIAP (Freitas *et al.*, 2006) and the observations and estimates of Schulman *et al.* (1999) and Ruokolainen *et al.* (2001) were largely independent lines of enquiry, but were both linked as responses to the emerging recognition of the importance of terrestrial carbon stocks as a key regulator of the global carbon cycle during the 1990s: Schulman *et al.* (1999) was a direct response to the need to model the different terrestrial carbon pools in the tropics with greater precision (Tian *et al.*, 1998), and Freitas *et al.* (2006) was framed in terms of the possibility of accessing payments for carbon storage as an ecosystem service. Whilst Dennis del Castillo's observation focussed on the high productivity of these ecosystems, Ruokolainen *et al.* (2001) focussed on how the waterlogged would slow down the rate of decomposition. Together, these two observations demonstrated the key condition that is required for the presence of peat: that, on average, the rate of organic matter production must exceed the rate of decomposition.

These early publications and observations inspired efforts to measure the carbon stocks of these largely permanently flooded forests in more detail and across more sites. Kalle Ruokolainen and Hanna Tuomisto suggested that Amazonian peatlands would be an ideal research topic for Outi Lähteenoja who sought a challenging research question related to Amazonian ecology. The result was a landmark study that quantified through a pioneering series of transects across these ecosystems the substantial and extensive carbon deposits that lie beneath them (Lähteenoja *et al.*, 2009b). Subsequently, interest in these ecosystems began to broaden, and IIAP continued to play a central role within this research. Eu-

ridice Honorio, at IIAP, established permanent forest inventory plots in the palm swamps around Jenaro Herrera, which had previously been ignored by ecologists simply because of the difficulty of working in these areas, in order to study their structure and dynamics (Honorio-Coronado *et al.*, 2015). Katy Roucoux, Ian Lawson and Tim Baker viewed the deposits of organic matter as an opportunity to apply palaeoecological methods, particularly analysis of the pollen preserved in the peat, to understand the role that past disturbance by humans played in causing nearby upland forests to accumulate carbon (Baker *et al.*, 2004b, Roucoux *et al.*, 2013; Kelly *et al.*, 2018). Freddie Draper added his interest in forest ecosystems and remote sensing to the expanding knowledge of variation in floristic composition and peat thickness in the region, and mapped the distribution of different vegetation classes for the first time and their associated carbon stocks (Draper *et al.*, 2014). Remarkably, when the below-ground carbon stocks are considered, one of these vegetation types – a small stature forest growing on the thickest peat deposits – contains the highest concentration of carbon of any vegetation in Amazonia ( $1391 \pm 710 \text{ Mg C ha}^{-1}$ ; Fig. 1; Draper *et al.*, 2014). Overall the peatland complex contains over 3 billion tonnes of carbon below the ground, which is equivalent to 62 years of annual greenhouse gas emissions from human activities in Peru (MINAM, 2016).

Figure 1



**Figure 1.** Estimates of total carbon stocks and species richness for peatland pole forest and palm swamps from the Pastaza Marañón basin (Draper *et al.*, 2014; Draper *et al.*, 2018) and for 157, one hectare upland forest plots from across Amazonia and the Guiana Shield (Sullivan *et al.*, 2017a; Sullivan *et al.*, 2017b). Aboveground carbon stocks in these studies are for all trees  $\geq 10$  cm diameter and



exclude coarse woody debris, leaf litter and trees <10 cm diameter. Aboveground biomass values as dry weight from Sullivan *et al.* (2017b) were converted to carbon using an average carbon content across angiosperm species of 47% (Sullivan *et al.*, 2017b). Belowground stocks to 2 m depth for the sites in Sullivan *et al.* (2017b) were estimated as 54% of the aboveground values, based on the average below: aboveground ratio of carbon stocks of the same pools for three Amazonian sites (Malhi *et al.*, 2009; Quesada *et al.*, 2011). Values of total carbon stocks for the wetland forests include the surface peat deposits with an average depth of 3.15 m in peatland pole forest and 1.73 m in palm swamps (Draper *et al.*, 2014). Species richness values are standardised as the number of species per 300 stems for the upland sites (Sullivan *et al.*, 2017b) and as the number of species per 500 stems for the peatland pole forest and palm swamp (Draper *et al.*, 2018); species richness values are therefore slightly overestimated in the wetland compared to the upland sites. Estimates for the wetland forests are mean values  $\pm$  1 SE.

The biodiversity of the forests of the Pastaza-Marañón basin also attracted attention as it was clear that these systems were not only carbon-dense, but that they also contained some unusual and poorly known vegetation types (Lähteenoja *et al.*, 2009a). In particular, the most carbon dense, ombrotrophic peatlands share species of trees (Draper *et al.*, 2018), ferns (e.g. *Lindsaea divaricata*; Lehtonen & Tuomisto, 2007) and, based on the fieldwork of Jose Alvarez, birds (Lähteenoja *et al.*, 2009a) with forests growing on upland, white sand soils in the region. This peatland forest type, now known in the literature as ‘varillal hidromorfo’ or ‘peatland pole forest’, was first informally recognised and named by Filomeno Encarnación, also at IIAP, who produced the first key to the different forest types of the Peruvian Amazon (Encarnación, 1985). Although not described in the published key, he had recognised that the forests on the western bank of the Amazon near Tamshiyacu, south of Iquitos, were unusual; they shared the structural characteristics of the similarly resource-poor white sand forests in containing many small diameter trees, but the soils were waterlogged and rich in organic matter, rather than consisting of sand. In addition, the alpha diversity of these permanently waterlogged forests was also notably low in the context of surrounding upland forests: *Mauritia flexuosa* can form almost monodominant stands (Honorio-Coronado *et al.*, 2015), and the peatland pole forests is the most species-poor old-growth tropical forest known in Amazonia (Fig. 1; Draper *et al.*, 2018).

Overall, these findings turned the paradigm of high diversity and relatively low above-ground carbon stocks in northwestern Amazon forests on its head. In fact, these forests are now known to contain some of the least diverse tropical forests and, rather than being an area of low carbon stocks, the Pastaza-Marañón basin is the hotspot for carbon storage across the whole of Amazonia. The only element of the original paradigm that the description of these wetland forests has enhanced is that their existence further increases the already very high, landscape-scale, beta diversity of northern Peruvian Amazon forests (Draper *et al.*, 2018).

## The wetlands of the Pastaza-Marañón basin in a global and regional context

While their biodiversity and carbon storage are clearly exceptional, the wetland forests of the Pastaza-Marañón basin are also distinctive in terms of the processes that underlie their formation, compared to other wetlands in Amazonia and to tropical peatlands across the globe. The magnitude  $M_w$  8 earthquake in June 2019 centred at Lagunas on the southwestern edge of the peatland complex reminded us of the primary underlying reason for the existence of these ecosystems in this particular region of the Peruvian Amazon: they occur here because of the tectonic activity and on-going subsidence during the Quaternary that has led to the formation of the Ucayali-Marañón (or Ucayali) and Pastaza depressions (Dumont & Fournier, 1994; Dumont, 1996). These depressions are part of the Andean foreland basin which formed due to flexing of the continental lithosphere on the eastern edge of the Andes (Beaumont, 1981; Dumont, 1996). These ripples in the lithosphere are attributed to both the eastern movement of the Andes into the Brazilian Craton and as a reaction to the vertical, downward force of the uplifted Andes to the west of the Pastaza-Marañón basin (Beaumont, 1981; DeCelles & Giles, 1996; Dumont, 1996). The location of these depressions in the one of the highest and aseasonal rainfall areas of Amazonia and at a collecting point for water from Amazonian tributaries from a large part of western Amazonia, has created the permanent waterlogging required for peat formation. This a globally unique context for tropical peatlands: the peatlands of SE Asian forests occur in similarly high rainfall areas, but the largest peatlands are found in coastal areas and poor drainage there is linked to sea-level rise since the end of the last glacial period (Page *et al.*, 2006), whilst those of the Congo basin appear to have formed in a shallow but stable interfluvial basin (Dargie *et al.*, 2017).

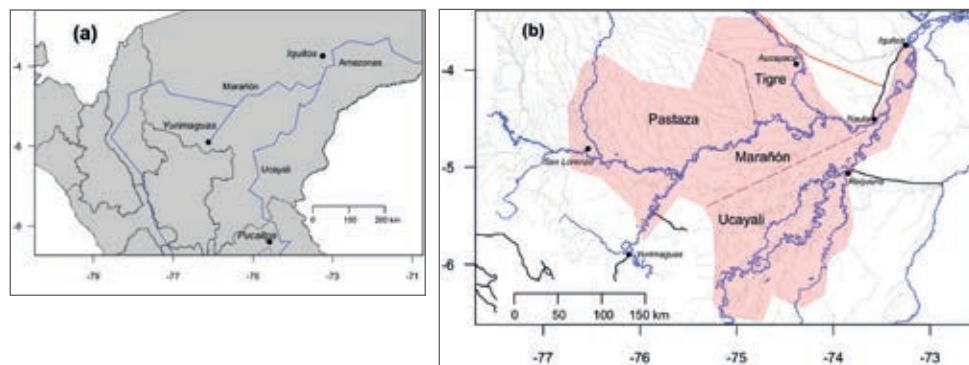
It is also important to note that the combination of ecosystems in the Pastaza-Marañón basin – a mosaic of permanently waterlogged and peat-forming palm swamps, peatland pole forests and open peatlands, as well as seasonally flooded forests which are typically not associated with peat formation – is very different from the two other major areas of wetland vegetation in the Amazon basin: the seasonally flooded forests that occur in central Amazonia, along the main stems of the Negro, Solimões and Amazon rivers, and the grassland-dominated Llanos de Moxos, in Beni, Bolivia (Hess *et al.*, 2015). In simple terms, the wetland forests of the Pastaza-Marañón basin are often permanently waterlogged, whereas the Brazilian flooded forests experience a very strong flood pulse and experience strong seasonal contrasts in water levels. The maximum seasonal fluctuation in river levels in the wetlands of the Pastaza-Marañón basin, in the higher reaches of Amazonia, is much lower than a floodpulse that can exceed 10m along some Brazilian rivers in central Amazonia (Junk *et al.*, 2011). Of course, there is substantial variation within both regions depending on the local context of the sites, but this difference means that although both areas of wetland contain forest, the adaptations that spe-

cies require, floristic composition, and tendency for the wetlands to be associated with peat formation, are very different. For example, whereas peat formation is common in the Pastaza-Marañón basin, it has been observed only rarely in central Amazonia (Lähteenoja *et al.*, 2013), despite model predictions of its existence (Gumbrecht *et al.*, 2017). In contrast, the Llanos de Moxos has the same geological origin as the Pastaza-Marañón basin as a foreland basin to the east of the Andes (Dumont, 1996). However, the climate in this region has a very strong dry season which, in conjunction with the much smaller watershed, means that peat does not form extensively, and indeed the relatively arid climate favours herbaceous, rather than forested, ecosystems (Hess *et al.*, 2015).

### Processes and patterns of carbon storage

Fluvial dynamics are crucial for understanding the variation in peat accumulation and forest composition within the Pastaza-Marañón basin, as the history of river dynamics appears to define the broad distribution of forest types (Fig. 2b). For example, the Rio Ucayali has moved south, and the Rio Marañón to the north, within the Ucayama depression during the Quaternary (Fig. 2b, Dumont, 1996) and the areas that have been influenced by each of these rivers over time have rather different characters. The region of historical influence of the sediment-rich and meandering waters of the Rio Ucayali is dominated by seasonally flooded forests that are only occasionally associated with peat formation (termed ‘tahuampa’ or ‘restinga’ in Peru or varzea in the terminology from central Amazonia; Nebel *et al.*, 2001; Junk *et al.*, 2011). In contrast, the area of historical influence of the Rio Marañón is dominated by rivers with low sediment loads and peat-rich palm swamps (‘aguajales’; consistent with ‘igapo’ in the terminology from central Amazonia; Junk *et al.*, 2011). To the north of the Rio Marañón, the Rio Tigre has followed a relatively stable course over the last few thousand years due to a diversion about 8,000 years ago which isolated this basin from its original Andean headwaters and reduced its flow (Bernal *et al.*, 2011a). This stability has led to this basin being associated with the deepest peat deposits and ‘varillal hidromorfico’ vegetation; in contrast, the constantly shifting Rio Pastaza to the west has created one of the largest inland alluvial fans in the world, and is associated with abundant open peatlands (Draper *et al.*, 2014). Undoubtedly, any change in river dynamics, resulting from a greater frequency of high river discharge events related to climate change (Gloor *et al.*, 2015) or direct or indirect efforts by people to alter the course and flow of these rivers, may alter the distribution of vegetation types, the resources associated with them and the capacity of the peatlands to accumulate carbon.

Figure 2



**Figure 2.** (a) Schematic map of the location of the main rivers and cities to be connected via the hidrovia in northern Peruvian Amazonia; (b) the four principal rivers of the Pastaza-Marañón basin showing their estimated area of historical influence (see text for more detail). Route of proposed road alongside the Rio Tigre and location of the oldest continuous peat deposits discovered to date at Aucayacu also shown.

In terms of floristic composition, succession, dispersal and quite simply, time, are also important factors that underlie the patterns that we see today (Draper *et al.*, 2018). For example, the young age of many of the formations that we see today and the patchiness of tree species distributions suggests that dispersal limitation – the chance arrival of particular taxa as a new landscape develops – determines many of the compositional patterns that we see today (Draper *et al.*, 2018). These processes contrast strongly with typical explanations for species diversity in old growth tropical forests, that focus on, for example, identifying niche differences, in terms of soil preferences (Phillips *et al.*, 2003), light requirements (Whitmore, 1989), or susceptibility to pathogens (Bell *et al.*, 2006) that assume that ecosystems are at equilibrium. In general, successional patterns related to fluvial dynamics are a major driver of variation in vegetation types within the wetlands of the Pastaza-Marañón basin (Kalliola *et al.*, 1991). Although there is agreement that open peatlands represent an early successional stage, and ombrotrophic peatland pole forests are an end point (Kelly *et al.*, 2017), understanding the full range of successional processes within these landscapes remains an important challenge. Palaeoecological studies of the past two thousand years of vegetation change at the present-day palm swamp at Quistococha (Roucoux *et al.*, 2013) and at an ombrotrophic pole forest at San Jorge demonstrate very rapid changes in composition likely related to sites becoming isolated, or connected to, the main river channels (Roucoux *et al.*, 2013; Kelly *et al.*, 2017). In any given location, a palm swamp, for example, can develop – or disappear – in just a few decades as the flooding regime alters. The potential for very rapid change is relevant today for considering the potential impact of climate

change: the resources that people currently use could disappear or shift in space very quickly. For example, extreme drought and floods cause immediate reductions in the populations of animals that depend on the wetter, or drier, parts of the landscape respectively, with immediate impacts on livelihoods (Bodmer *et al.*, 2018).

### **The human history of the wetlands**

Given the initial stimulus for studying the wetlands of the Pastaza-Marañón basin, most research to date in this region has focussed on their ecology. However, multi-disciplinary work is also now exploring the rich human history and understanding of these ecosystems by indigenous communities. In general terms, it is highly likely that people were living in, and using the resources from, the different Amazonian upland and wetland habitats of the Amazon, shortly after their arrival in South America about 11,200 years ago. One of the emblematic species of these peatlands - *Mauritia flexuosa* - has a pollen record that stretches back to the Miocene (Rull, 1998) and the use of fruits from a range of species of palm tree has been documented from the earliest sites of human occupation. For example, remains of *Attalea microcarpa*, *Astrocaryum vulgare* and *Attalea spectabilis* dating from 10,000 BP were found at the Pedra Pintada cave at Monte Alegre, Brazil (Roosevelt *et al.*, 1996), which suggests that the use of *Mauritia* was likely from a similarly early period. The relationships that have developed between people and these wetlands are therefore potentially strong and deep. For example, the Urarina have developed a specific terminology to describe the different peatland ecosystems which demonstrates detailed knowledge about their dynamics and biology and points to the cultural significance of the peatlands (Martín *et al.* 2019, Schulz *et al.*, 2019b); they also use the fibres from the young leaves of aguaje (*Mauritia flexuosa*) palms to make traditional textiles – a technique which has recently been declared as Patrimonio Cultural de la Nación (Resolución Viceministerial N° 115-2019-VMPCIC-MC; Martín *et al.* 2019).

There is also evidence that the occupation of these ecosystems over thousands of years was not associated with extensive ecological disruption. For example, abundant pottery, charcoal and even remains of maize (*Zea mays*) demonstrate that people inhabited the terraces above the lake and peatland of Quistococha from at least 2500 years ago (Rivas Panduro, 2006; Rivas *et al.*, 2006). However, the pollen from the nearby lake indicate that despite the presence of charcoal during the period of human occupation and therefore presumed use of fire by these people, there was no increase in pioneer tree species typical of disturbed habitats until the period of the expansion of the city of Iquitos over the last two hundred years (Kelly *et al.*, 2018). In part, this is likely due to the existence of a series of social and cultural controls, based on a shared values, beliefs and cultural practices, that today promotes sustainable use of these ecosystems (Martín *et al.*, 2019). In particular, the presence of spiritual beings - 'dwarfs' or 'madres' of the natural world - establishes a relationship of profound respect between people and their environment that goes much



further than just resource use. The existence of, for example, the *baainu*, the protector of the palm swamps, that lives in the wetlands of the territories of the Urarina community in the mid- and lower Rio Chambira, instils fear and respect, and without doubt, favours the conservation of these ecosystems (Schulz *et al.*, 2019b).

### **The conservation challenge today**

The low impact of indigenous groups on the wetlands of the Pastaza-Marañón basin, and more recently, the lack of any road connection between Iquitos and the national road network has led to this region containing one of the largest areas of remaining intact forest on the planet (Watson *et al.*, 2018). This status is however threatened and the future of these forests relies on us addressing how substantial areas of intact tropical forest can be sustained over coming decades, whilst also supporting the livelihoods of the people who live there. The challenge is perhaps three-fold: to work with communities across the basin to manage the long-standing damage caused by oil exploitation, to develop markets for sustainable resources based on biodiversity such as palm fruits, and to find ways to ensure any infrastructure development leads to minimal deforestation.

The extensive oil reserves in this region, which have been exploited since the 1970s in the northern part of the basin (Martínez *et al.*, 2007), present the greatest chronic threat to the health of the indigenous people, wildlife and water of the Pastaza-Marañón basin and beyond. Shocking levels of oil pollution occur both as the result of leaks in the North Peruvian oil pipeline, which stretches as narrow scar across the basin, and as a result of the release of water used in the production of oil. For example, a 2005 study by the Peruvian Ministry of Health, found that World Health Organisation limits for lead were exceeded in 66% of the blood samples from 74 indigenous children from six native Achuar communities; amongst adults, 99% of samples exceeded permissible limits for cadmium (Martínez *et al.*, 2007). In a meta-analysis of 194 analyses of the concentration of cadmium in river water samples from the Corrientes, Tigre, Pastaza and Marañón rivers, 19% exceeded Peruvian limits for drinking water (Yusta-García *et al.*, 2017). The presence of hydrocarbons derived from oil production has also been detected in soils in oil production areas, with likely but unknown impacts on the health of local fauna which consume the soil (Orta-Martínez *et al.*, 2018; Rosell-Melé *et al.*, 2018). The direct and indirect economic benefits to communities of petroleum extraction, through jobs, including payments for participating in clean-up operations and providing services including bushmeat to company workers, need to be viewed in the context of the health implications of long-term and repeated release of hydrocarbons into the environment, and the chronic disruption to these societies (Martínez *et al.*, 2007; Zárate, 2018). At the very least, the conservation challenge is to ensure that information about the health and environmental impacts is available to communities in a timely fashion, to support and strengthen the government bodies responsible for environmental monitoring

and to pressure both the companies and government bodies to ensure the oil extraction practices and pipeline infrastructure are adequate to eliminate pollution.

In terms of infrastructure development, the fundamental significance of the wetlands of the Pastaza-Marañón basin for conservation and development is that this region lies directly between the city of Iquitos, with a population approaching half a million people (INEI 2018), and the rest of Peru. Any infrastructure connection, whether by road or river, between the city and the rest of the country depends on traversing the wetlands: current plans including linking Iquitos to transport networks by river (via the Rio Marañón and Rio Ucayali to Yurimaguas and Pucallpa respectively; Fig. 2a) and road (alongside the Rio Tigre; Fig. 2a y b). The proposed Hidrovía Amazónica aims to allow shorter journey times and increase river transport among regional hubs along the main tributaries of the Rio Amazonas - the Marañón, Ucayali and Huallaga rivers - by regular dredging of the shallowest reaches (Fig. 2a y b). Such dredging activities are employed across the world (e.g. on the Parana river in Argentina; Paarlberg *et al.*, 2015) as one of a suite of methods to maintain a minimum depth along navigable waterways, even though the high cost and large, negative environmental impact on the biology of the rivers, including fish populations and riverine vegetation is well established (Darby & Thorne, 1995). Indeed, even disregarding the environmental costs, simply the high economic cost of dredging provides a strong incentive to evaluate carefully how to perform any operation, in terms of, for example, where to place dredged sediments, in order to minimise the requirement for repeated dredging over time and to ensure that the proposed benefits for transport will be realised (Paarlberg *et al.*, 2015; van Vuren *et al.*, 2015). For the adjacent wetlands in the Pastaza Marañón basin, the key question for the proposed dredging is whether it would deepen the channels sufficiently to increase drainage and reduce flooding of the surrounding wetland landscape, as the maintenance of permanent waterlogging is crucial for peat formation. Both of these kinds of hydrological change - lower water table depths and a reduced depth and duration of flooding on adjacent land have been documented in stretches of rivers where sediment mining has taken place (Rinaldi *et al.*, 2005), but it is unclear whether the scale of dredging proposed for the hidrovía would be sufficient to have similar impacts on the wetlands of the Pastaza-Marañón basin. Clearly, a careful evaluation of the environmental impacts of this scheme on the adjacent wetlands is required.

The planned Iquitos – Saramiriza road presents different challenges. The proposed route would connect Iquitos to the national road network via a new road along the east bank of the Rio Tigre which would connect with existing access roads used by oil companies close to the Peru-Ecuador border. Although the route itself is beyond the border of the Ramsar-designated protected area of the Pastaza-Marañón basin, the main problem for the wetlands is that it passes close to the deepest and most ancient peat deposits known in the entire basin (Fig. 2, Roucoux *et al.*, 2017). Here, at site known as Aucayacu, there are seven metres of peat,

which date back over 8,000 years (Lähteenoja *et al.*, 2012). Road building can have negative local effects on wetland hydrology, but the bigger risk is that improved access could very easily open up the region to colonization and more intensive economic exploitation (e.g. collection of *Mauritia* fruits, which often entails felling entire trees). Numerous examples exist of new roads leading to increased rates of deforestation and environmental degradation in intact tropical forest settings (Laurance *et al.*, 2009), including following the paving of the InterOceanica highway in southern Peru (Asner *et al.*, 2010). In the case of the peatlands around the Rio Tigre, any disruption is likely to jeopardize their record-breaking below-ground carbon stocks and potentially generate nationally significant carbon emissions. Again, careful evaluation of the potential environmental impacts is required and plans need to be developed to mitigate these threats.

Despite these threats, the wetlands of the Pastaza-Marañón basin have two strong advantages for conservation: their high carbon stocks and the economic importance of non-timber products (Roucoux *et al.*, 2017). The conservation challenge here is to ensure that these opportunities are fully realised to the benefit of local communities. Although the value of the high carbon stocks of peatlands is not consistently recognised in national environmental policies in Peru (Lilleskov *et al.*, 2019), emphasising the carbon stocks of these areas is emerging as an important way to justify and achieve investment in conservation and sustainable management. For example, the Peruvian Fund for Nature Conservation (PROFON-ANPE) successfully obtained \$6 million for sustainable management of the palm swamps of Datem de Marañón province from the Green Climate Fund based on the protection of the belowground carbon stocks demonstrated by Draper *et al.* (2014). Similarly, the justification for the creation of the Yaguas National Park, which attracted a \$1 million investment by the Andes Amazon Fund, was partly based on the carbon stocks in the wetlands in this area. Developing carbon-based conservation is therefore a proven route to achieving conservation goals in this region and could be expanded (Roucoux *et al.*, 2017).

The high importance of the wetlands for supplying non-timber forest products to communities is another opportunity for conservation. These ecosystems supply construction materials, timber, wood for charcoal, textiles, as well as meat in the form of caiman, peccaries and fish (Bodmer *et al.*, 2018; Schulz *et al.*, 2019a). However, in terms of potentially sustainable resources, their most important asset is palm fruits, notably from aguaje palms, which are harvested on a large scale and sold to local and regional markets (Horn *et al.*, 2018; Schulz *et al.*, 2019a). The presence of such an economically important species is unique among tropical peatlands globally. The opportunity for conservation is therefore clear: frankly, if it is not possible to conserve, derive economic benefits from and sustainably manage natural near-monodominant stands of such a productive and valued tropical tree species as the *Mauritia* palm, then there is truly little hope for conserving intact tropical forest. The conservation of these wetlands therefore represents an emblem-

atic example of the wider project in conservation to find ways to leverage the value of biodiversity to support sustainable development (Nobre *et al.*, 2016).

Developing a positive vision of what conservation success would look like for the Pastaza Marañón basin based on palm fruit harvesting, might most usefully draw on the development of the market for açai fruit from the palm *Euterpe precatoria* in Brazil. Similar to *Mauritia*, *E. precatoria* can grow in largely monodominant stands, particularly in the forests surrounding the estuary of the Amazon in eastern Pará state, Brazil (Brondízio *et al.*, 2002). Over recent years, açai fruit production has underpinned the development of businesses worth millions of dollars (Nobre *et al.*, 2016) and can provide a substantial income to communities: it contributes around 60% of household income from agricultural products in eastern Pará (Brondízio *et al.*, 2002), and, even where less abundant in an upland forest setting, an average of 17% of household incomes in communities in extractive reserves in Acre (Lopes *et al.*, 2019).

The management of açai presents perhaps three lessons for developing fruit harvesting of *Mauritia flexuosa*. Firstly, an increasing national and international market for the fruit, driven by an increasing market in expanding Brazilian cities as well as its emergence as an international ‘fashion food’ from the 1990s on the basis of its properties as an antioxidant, has driven the increase in demand for this product (Brondízio *et al.*, 2002). In comparison, *Mauritia* fruit remains an important regional product within Amazonian Peru, but both national and international markets need to be developed further if the economic potential of this fruit is to be realised. The interest of the Peruvian drinks company AJE, in using aguaje fruit in its Bio range of drinks could be a significant development. Secondly, açai production demonstrates that the use sustainable harvesting techniques is crucial. Açai harvesting is simpler than fruit harvesting for *Mauritia flexuosa*, because of the lower fruit height, thinner stems and presence of the fruit below the leaf bases of the palm. In contrast, *Mauritia flexuosa* fruits are typically harvested by cutting down the female trees which produce fruit, which has led to substantial degradation of the resource base (Baker *et al.*, 2010; van Lent *et al.* 2018). Projects that promote tree climbing to harvest aguaje fruits are clearly crucial, and the workshops organised by the fruit processing company Recursos Amazónicos Forestales SAC (RAF-SAC), IIAP, the Peruvian Protected Areas Authority (SERNANP), and the Peruvian Forest Service (SERFOR) are clearly an important step forward, but must be implemented as long-term, sustained support and need to be expanded to more communities. Finally, the large market for açai in Brazil, has led to the widespread implementation of agroforestry techniques to promote production. For example, weeding natural stands can lead to increase in density of açai from <20% to 90% of stems in eastern Para (Brondízio *et al.*, 2002). In terms of management, increasing the density of *Mauritia* is not such an important issue, as this species reaches very high densities under natural conditions (Honorio-Coronado *et al.*, 2015). However, such techniques may be valuable to restore degraded stands where the female trees have

been removed; in stands of *M. flexuosa* in eastern Brazil, careful management has produced stands that have seven female trees for each male individual, greatly increasing production compared to natural stands with equal numbers of male and female trees (Bernal *et al.*, 2011b).

The açai market also illustrates some of the issues which will likely emerge as the market expands, including the importance of maximising community benefit by their involvement in the transformation process of the fruit subsequent to harvesting and maintaining an appropriate balance of costs between the communities and companies who transport the fruit to market (Brondízio *et al.*, 2002). The proposal and maintenance of long-term, constant contracted prices with communities by RAFSAC and SERNANP to ensure a consistent income and commitment to sustainable harvesting is an important step to address these issues. Ensuring market expansion is associated with the development of efficient and effective monitoring techniques and understanding of the social and ecological implications will also be important.

In conclusion, despite the challenges, the optimistic message from the wetlands of the Pastaza Marañón basin, is that there is a realistic opportunity for fostering sustainable management that benefits local and indigenous communities, the regional and national economy, and also protects intact forests. The recent recognition of the carbon stocks of this region allied with the unique economic importance of the biodiversity of this region, is a powerful impetus to support and fund sustainable management. Moreover, the location of the aguajales in the centre of one of the world's last remaining areas of intact tropical forest, means that implementing these solutions has wide conservation relevance. The prize – preserving one of the most diverse, carbon-rich tropical forest landscapes on the planet over the coming decades – should inspire us to address the different facets of this challenge.

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