

2. IMPACT OF CLIMATE CHANGE ON BIODIVERSITY, SOCIAL-ECOLOGICAL-SYSTEMS AND ITS MEASUREMENTS

A MONITORING NETWORK TO DETECT THE IMPACT OF CLIMATE CHANGE ON TREE BIODIVERSITY AND CARBON IN AMAZONIAN FLOODPLAIN FORESTS

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INTRODUCTION

Peruvian floodplain forests are one of the largest freshwater ecosystems in Amazonia covering 13.5 million hectares or 18% of Peru (MINAM, 2011). These ecosystems are economically important to local communities as many of their valuable natural resources and agricultural products form the basis of important economic supply chains to urban areas. However, climate change may cause important changes in seasonal fluctuations in river levels in these ecosystems (Gloor *et al.*, 2013). For example, a recent study showed that populations of wild animals in the Pacaya Samiria Natural Reserve generally decreased due to severe flooding in 2010 (Bodmer *et al.*, 2014); terrestrial mammals were the most affected because of their dependence on dry areas during the flood to hunt. As the frequency of such flooding events may increase in the future (Espinoza *et al.*, 2013; Gloor *et al.*, 2013), there is a need to understand the resilience of these forests to current and future climatic and human impacts.

To understand the ecology of floodplain forests, we need to understand the role of the flooding and nutrient supply gradients for determining how these ecosystems function. The flood pulse of the rivers and their nutrient supply are important features of the floodplain. White-water rivers carry nutrients from the Andes, whereas black-water rivers form inside the floodplains and have low nutrient content. Forests that are flooded by white-water rivers will also have high nutrient content in the soils, while forests influenced by black-water rivers have low soil nutrient contents (e.g. palm swamp). Seasonally flooded forests develop in areas of influence of major rivers and are flooded each year for one to six months. Palm swamps are located in depressions, which receive less influence of major rivers, and maintain permanent surface water from precipitation (Junk *et al.*, 2011). Despite their low floristic diversity compared to the surrounding upland forests, floodplain forests have high regional diversity (beta diversity), with potentially even higher values than terra firme forest (Pitman *et al.*, 2014).

Natural dynamics of rivers cause erosion and deposition of sediments generating a natural succession in vegetation (Salo *et al.*, 1986). This complex landscape influences the patterns of carbon stocks in these ecosystems. Estimates of above-ground carbon using remote sensing in Peru predict a national store of 6.9 Pg C, with highly variable carbon densities in the largest Peruvian floodplain, Pacaya-Samiria National Reserve of $72.9 \pm 29.2 \text{ Mg C ha}^{-1}$ (Asner *et al.*, 2014). Extensive below-ground carbon deposits stored as peat (organic matter) have also been recently confirmed in the region of Loreto (Lähteenoja *et al.*, 2012). Palm swamps (748 Mg C ha^{-1}), pole forests ($1340 \text{ Mg C ha}^{-1}$) and open peatlands (663 Mg C ha^{-1}) are the most representative vegetation types accumulating peat (Draper *et al.*, 2014). These areas that represent only 3% of the whole of the Peruvian forests have added 40% of the carbon stocks of Peru.

Direct human impacts due to resource harvesting lead to degradation across the seasonally flooded forests and palm swamps which are the two most extensive floodplain forest types in Peru. High value timber species such as mahogany and cedar were once common in seasonally flooded forests but have been heavily logged and their populations are in some cases close to local extinction (Kvist *et al.*, 2001). Decades of fruit harvesting by cutting female individuals has heavily degraded *Mauritia* palm swamps that are close to local communities.

Monitoring changes over time requires long-term networks based on permanent forest plots (Honorio Coronado *et al.*, 2015). The Instituto de Investigaciones de la Amazonía Peruana (IIAP) in collaboration with the Universities of Leeds and Saint Andrews in the UK are leading efforts to monitor the long-term dynamics of the floodplain forests by using ecological and palaeoecological data. By monitoring the past and present of these ecosystems we aim to predict the future and their potential sensitivity to changes in climate.

We focus on using permanent plots as a tool to detect changes in composition. For example, in the case of Andean woody species, similar techniques have been used to demonstrate species migration to higher altitudes due to temperature increases (Feeley *et al.*, 2011). Another study conducted in Ghana, Africa showed that the reduction in rainfall observed over the last 20 years in the area altered the floristic composition of the forest, favouring species adapted to drought (Fauset *et al.*, 2012). However, very little is known about the vulnerability of lowland Amazonian forests and there is no previous study of the effect of droughts and severe flooding on floodplain forests (Gloor *et al.*, 2013).

Changes in species composition of certain types of floodplain forests would affect the environmental services they provide. For example, palm swamps and pole forests are important carbon reservoirs (Draper *et al.*, 2014). The accumulation of organic material as peat below ground depends on high, permanent water saturation in the soil. Severe and frequent droughts could lead to the loss of carbon due to the decomposition of peat. Therefore, the aims of our monitoring network are to answer three questions: (1) How do tree diversity and floristic composition vary in the floodplain forests?, (2) How much carbon is stored in the floodplain forests?, (3) Which factors determine spatial variation in diversity, composition and carbon stocks?, (4) Which environmental changes and human activities have determined the present and will influence the future floristic composition and carbon stocks of these forests?

LONG-TERM MONITORING IN FLOODPLAIN FORESTS

Our floodplain forest network comprises 38 floristic inventories in the Marañón, Ucayali and Amazon rivers in Loreto, and one inventory in Ucayali (Figure 1). These inventories were carried out using the Amazon Forest Inventory Network (RAINFOR) protocol for forest plot establishment and remeasurement (Phillips *et al.*, 2009) in three main forest types: seasonally flooded forest (11 plots), palm swamp (16 plots), and pole forest (12 plots). Each plot covers 0.5 hectares of forest (SUC-03 plot is 1 ha), and the diameter of all individuals equal or greater than 10 cm were measured at breast height (DBH, 1.3 m). Sixteen of these plots were established for permanent monitoring and all individuals were marked at the point of diameter measurement and tagged. Ca. 90% of individuals are identified to species level. In total, we have studied 21 hectares of forest and registered 13,334 individual trees corresponding to 391 species, 208 genera and 56 families. In 2017, we will lead the third re-measurement of these forest plots, considering a census interval of 3-5 years.

Floristic composition and diversity

This dataset shows that floristic composition is highly distinctive among floodplain forest types (Honorio *et al.*, 2015; Draper, 2015). Palm swamps and pole forests are dominated by one or few taxa. For example, *Mauritia flexuosa* (Arecaceae) is highly abundant in palm swamp plots representing 37% of total individuals, followed by *Mauritiella armata* (Arecaceae), *Tabebuia insignis* (Bignoniaceae) and *Virola pavonis* (Myristicaceae) that represent another 15% of individuals. In a similar way, *Pachira brevipes* (Malvaceae) is highly abundant in pole forest plots representing 40% of total individuals, followed by *Mauritia flexuosa* (6%) and *Mauritiella armata* (5%). None of the species is highly abundant or represents more than 4% of total individuals in seasonally flooded forest plots. More than 50% of the total individuals of these forests are represented by 43 species including *Inga stenoptera* (Fabaceae), *Eschweilera alboflora*, and *E. parvifolia* (Lecythidaceae).

As previous studies have shown, seasonally flooded forests are less diverse than surrounding terra firme forests (Nebel *et al.*, 2001; Wittmann *et al.*, 2002; Wittmann *et al.*, 2004). However, forests on low nutrient-soil condition in unflooded forests (white-sand forest) and the floodplain (palm swamp and pole forest) contain the lowest alpha diversity (Table 1).

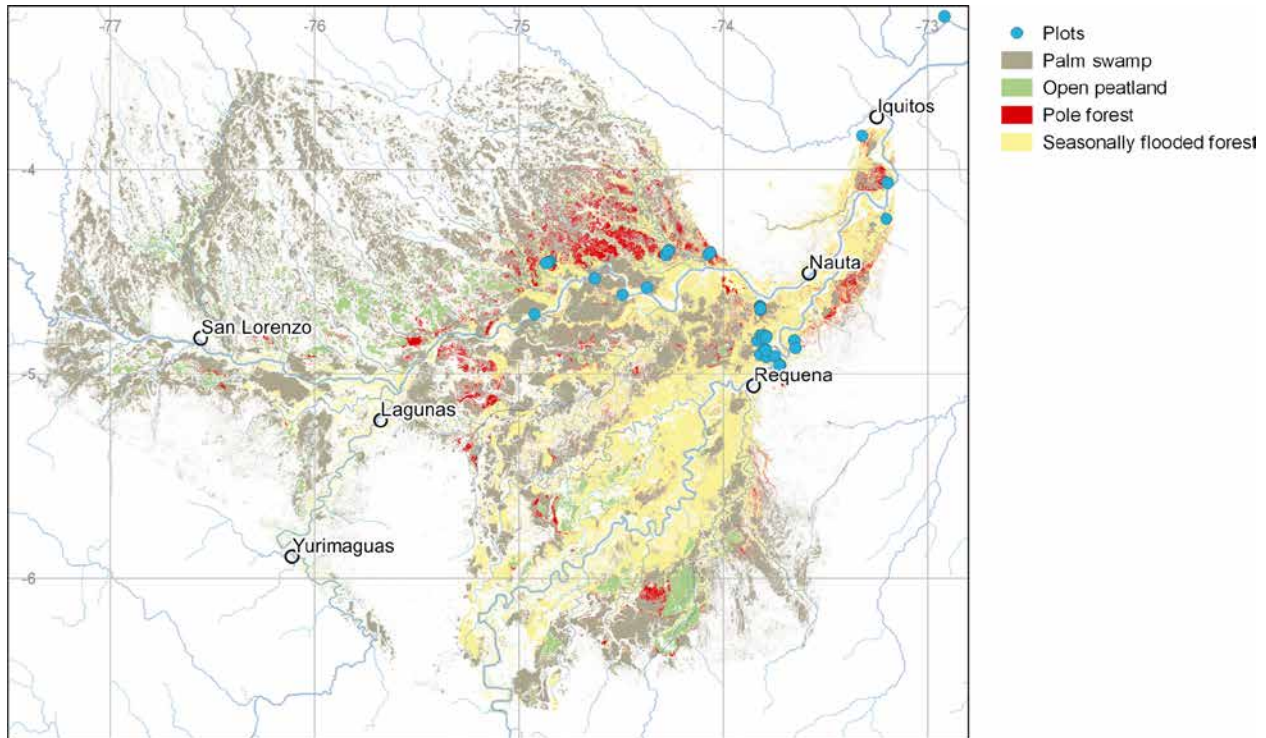


Figure 1: Location of 38 floristic inventories in the floodplain of Loreto. Vegetation map was modified from Draper *et al.* (2014) and shows the distribution of different floodplain forest types: open peatlands, pole forest, palm swamp and seasonally flooded forests.

Carbon stocks

Above-ground carbon in floodplain forests is generally lower than estimates of terra firme forests (Tabla 1). Nevertheless, carbon store belowground can reach 748 Mg C ha⁻¹ in palm swamps and 1340 Mg C ha⁻¹ in pole forests (Draper *et al.*, 2014). In total, Draper *et al.* (2014) showed that the Pastaza-Marañon-Ucayali foreland basin stores 3 million tonnes of carbon above- and below-ground with pole forests storing the greatest densities of carbon in Amazonia (1391 ± 710 Mg C ha⁻¹).

Table 1: Diversity and above-ground biomass of 39 forest inventories in the Peruvian floodplain. Thirteen additional RAINFOR forest plots established on white-sand and terra firme forests were included for comparison. Data provided by Forestplots.net (Lopez-Gonzalez *et al.*, 2011). Values represent mean ± standard error.

Forest type	Number of plots	Total area (ha)	Number of trees (ha ⁻¹)	Genus diversity (alfa fisher)	Wood density (g cm ⁻³)	Above-ground biomass (Mg ha ⁻¹)
Palm swamp	16	8	521 ± 30	10.1 ± 1.5	0.47 ± 0.02	195 ± 13
Seasonally flooded forest	11	6	536 ± 37	19.1 ± 1.8	0.61 ± 0.02	278 ± 24
Pole forest	12	6	989 ± 111	3.8 ± 0.6	0.54 ± 0.02	175 ± 31
White-sand forest	4	4	709 ± 171	13.9 ± 4.5	0.64 ± 0.01	217 ± 28
Terra firme	9	9	600 ± 6	54.6 ± 3.8	0.61 ± 0.01	316 ± 9

Forest dynamics

Our forest plots have also been important to understand the long-term dynamics of tropical forests. Abrupt changes in floristic composition as a result of succession and environmental change have been detected during the last 3,000 years at Quistococha, a palm swamp forest located near Iquitos (Roucoux *et al.*, 2013). The pollen record showed that *Mauritia* palm community was established 1,000 years ago, while other communities occupied this area in the past such as seasonally flooded forest, open swamp, and riverine plant communities.

Today, swamp forests remain very dynamic. We found unexpectedly high rates of tree mortality and recruitment in nutrient poor palm swamps (Figure 2). Mean annual rates of mortality and recruitment are above 3.5 %, and are higher than those observed for many terra firme forests in Amazonia (Phillips *et al.*, 2004).

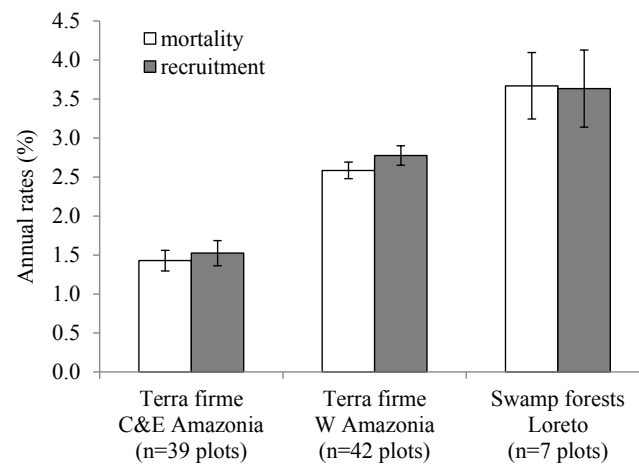


Figure 2: Comparison of annual rates of mortality and recruitment between Amazonian terra firme forests and swamp forests of Loreto (Mean \pm SE). Data for terra firme forests were taken from Phillips *et al.* (2004). Permanent forest plots in swamp forests are located in Jenaro Herrera and Veinte de Enero, Loreto.

CONCLUSIONS

Floodplain forests are an important component of the lowland forests of the Peruvian Amazonia. These forests are highly dynamic and may be sensitive to changes in climate. To ensure the different ecosystem services such as species diversity and carbon are maintained, the floodplain forests in Peru should be priority for conservation and forest management.

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