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Abstract: Forests bear the historical legacies of human activities over thousands of years, including agriculture, trade, disease and resource extraction. Many of these activities may represent indices of the proposed geological epoch of the Anthropocene. Modifications to soil, topography and vegetation evidence anthropogenic influences. Yet studies of vegetation change throughout the humid tropics tend to occlude these by focussing on forest dynamics, timber, and biodiversity through permanent sample plots or forestry inventory plots. We highlight how history and social science can be combined with ecology to help better understand human signatures in forest dynamics. We (1) critically review ecological methods in the light of the environmental and social history of the Afrotropics; (2) map current plot networks for West and Central Africa in relation to the Human Footprint Index; (3) using two case-studies, demonstrate how history and social science bring new insights and inferences to plot-based studies; all leading to (4) novel forms of interdisciplinary collaboration for sustainable forest conservation, management and restoration.

Cover Letter

Dear Dr. Chin,

We are delighted to submit a revised version of our paper, entitled, "Deciphering African tropical forest dynamics in the Anthropocene: how social and historical sciences can elucidate forest cover change and inform forest management".

Through careful editing, we have reduced the number of words to under 4,000, as noted in your email. We have also addressed all the comments of the reviewer, as noted in the table.

We look forward to finalising this manuscript for publication.

Best wishes,

Gretchen Walters

*Detailed Response to Reviewers

Response to reviewers

Reviewer comment	Authors response
Editor's comments	
Therefore, we would like to invite you to address these minor issues while also conducting a required thorough round of copy-editing. In this regard, attached in EES, please see detailed copy edits of your manuscript through the Introduction as an illustration of what is required. You will see substantial changes in the Abstract. You will also see that the changes economize the word count substantially, as well as turn most sentences in passive form into active tenses. We ask that you continue this type of detailed line-by-line copy-editing, or alternatively seek the assistance of an experienced or professional copy-editor.	This has been done. Please see the tracked changed version.
We would like to see a revised and copy-edited version under 4000 words (text plus abstract).	The article (text including abstract) now stands at 3,995 words.
Editing of Word version of document by editorial team	
Please remove reference to "Capitalocene" Not only does this paper not need it, it is not equipped to address this complex issue.	We removed reference to the "Capitalocene", but maintained the reference to Moore 2015. Line 46, "all markup view". We hope we interpreted this comment correctly.
Associate Editor	
Many thanks for this interesting paper. A relevant paper that is not cited is Aleman, J. C., Jarzyna, M. A., & Staver, A. C. (2018). Forest extent and deforestation in tropical Africa since 1900. Nature ecology & evolution, 2(1), 26.	This reference has been added, lines 154, 184, 434-435, in the "all markup view".
Reviewer #1	
List of keywords: Do you think there is any validity in including the word 'deforestation' in your list of keywords?	The paper does not focus enough on deforestation to merit a key word. It does not appear once in the text (and only once in the references).
Line 35 Remove one of the 'argues for' in the sentence.	This has been changed in Line 45, "all markup view"
Line 66 Perhaps you wish to consider adding the word 'to' in the sentence so as to read: "...to understand and quantify human influence on the environment in the recent past and to inform forest management."	This has been changed in line 80, "all markup view".

Line 73 I suspect you meant to write "accessible" and not "assessable". Perhaps I am wrong but you might want to think about this suggestion anyway.	This has been changed line 88, “all markup view”.
Line 82 It is not altogether clear that the word 'methods' in this sentence is referring to 'historical methods'. Perhaps you would want to consider writing: "...it increasingly benefits from historical data, historical methods (e.g. Hunter and Sluyter 2015) and ecological collaboration..." Alternatively you could write: "..historical data and methods..."	This has been changed in line 98, “all markup view”.
Line 111 Change 'HPF' to 'HFP" to read: "The HFP measures the cumulative impact..."	This has been changed in Line 131, “all markup view”.
Finally, you might want to go over the references again just to make sure that you are using the correct journal abbreviations and that the appropriate bits of the reference are italicised as requited by the Journal.	The references have been re checked for consistency, according to the journal’s guidelines. In papers which have over 10 co-authors, we used “et al.”

***Title Page (including author details)**

Deciphering African tropical forest dynamics in the Anthropocene: how social and historical sciences can elucidate forest research and management

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Deciphering ~~Anthropocene~~ African tropical forest dynamics in the Anthropocene: how social and historical sciences can elucidate forest reserach~~cover change~~ and ~~inform forest~~ management

Abstract

Forests ~~have been greatly impacted by anthropogenic activities for thousands of years and~~ bear the historical legacies of human activities over thousands of years, including agriculture, trade, disease and resource extraction~~, amongst others~~. Many of these activities may represent indices of the proposed geological epoch of the Anthropocene. ~~Depending on where one places the start of the current geological epoch, where people are the primary driver of global environmental change, many of these activities can be understood as indices of the Anthropocene. These influences can be discerned through m~~Modifications to soil, topography and vegetation evidence~~record~~ anthropogenic ~~their~~ influences. -Yet ~~,~~studies of vegetation change throughout the humid tropics~~, when vegetation change, especially in forests, has been studied~~ ~~have~~tend to occlude these by focussing~~ed~~ on forest dynamics, timber, and biodiversity through permanent sample plots or forestry inventory plots.~~, the focus has been on forest dynamics, timber, and biodiversity, which misses these wider historical legacies. We focus~~ We ~~This paper~~ ~~on the~~ highlights how ~~contribution that the~~ history~~ical~~ and social science~~s~~ can be combined with ecology to ~~can contribute to make to reading the Anthropocene more fully~~help better understanding ~~the~~ human signatures in ~~through ecological studies of~~ forest dynamics.

We ~~The novel contribution of this paper is that it associates different disciplines and proposes how their methods and reflections can be coordinated to address common questions of forest legacies in the Anthropocene. In this viewpoint article, we The paper~~ (1) critically review~~s~~ ecological methods in the light of the ~~sub-Saharan, tropical African~~ environmental and social history of the Afrotropics;~~,~~ (2) map~~s~~ current plot networks for West and Central Africa in ~~light of~~relation to the ~~Index of the~~ Human Footprint Index;~~,~~ (3) ~~provide~~ using two case-~~-~~studies, ~~(Liberia and Gabon) to~~ demonstrate~~s~~ how history and ~~anthropology~~ social science bring new ~~can enrich the~~ insights and inferences to~~from~~ plot-based studies~~,~~; ~~and~~ all leading to (4)

~~suggests~~ novel forms of ~~specific ways that~~ interdisciplinary collaboration for ~~can contribute to ecological studies and~~ sustainable forest conservation, management and restoration.

Keywords

Forest ecology, Africa, historical sciences, social sciences, forest management, interdisciplinarity

1. Progress in linking past anthropogenic activity to present-day forest structure

The ways ~~that we~~that tropical forests are studied and conceptualized ~~of conceiveing and studingstudyingy tropical forests~~ haves changed greatly in recent decades. ~~, in part thanks to~~ The ~~pioneering~~ works of geographers and anthropologists in the Amazon (e.g. Balée and Erickson 2006) and in Africa (e.g. Fairhead and Leach 1996) have ~~partly spearheaded~~helped bring about these changes, ~~which~~ challenginged researchers to consider the influences of humans on forest structure and biodiversity. In the early 2000s, ~~although~~ ecologists believed that ~~the~~ peopleast (Foster *et al.* 2003) hadve not affected current ecosystem dynamics to a large extent ~~were largely unaffected by the past (Foster *et al.* 2003);~~, however, ~~it is scholars now increasingly recognised~~ it is now widely accepted that past human impacts have not only- shaped ecosystems, but also have become a geological force – captured in the concept of the "Anthropocene" (e.g., Ellis *et al.* 2013). While ~~those who proposed the term~~ some argue for a 1950s start to the proposed geologic epoach (e.g. Zalasiewicz et al. 2010), others ~~argues for~~ (Lewis and Maslin 2015) argue for an earlier ca 1500 start, which coincides with the beginning of global capitalism (Moore 2015)-. ~~, chiming with Moore's (2015) idea of the Capitalocene.~~ In Africa, these 'Anthropocene' impacts include the slave trade, colonisation, Atlantic trade, disease epidemics and lifestyles of prehistoric societies (Maddox 2006; Kay and Kaplan 2015), often leaving their mark on forest structure and biodiversity hundreds of years later.

Comment [A1]: Please remove reference to "Capitalocene" Not only does this paper not need it, it is not equipped to address this complex issue.

Ecologist P.W. Richards (1952) warned that no ecologists working in the African rain forest should not ignore the possibility that their study area might have been significantly modification of their study areas ed by recent human activity in the recent past (1952). Foresters were aware of the relationship between cultivation and pioneer forest species (Letouzey 1957); others noted the importance of understanding forest change in relation to the life span of trees (White and Oates 1999). For example, tThe forests of Oban, Nigeria, for example, now construed as 'Old Growth', were previously inhabited (Rosevear 1979: 78) based on the evidence of trees that were left by farmers when the land was depopulated hundreds of years earlier. This example suggests that the lifespan of a tree, and what occurred during that period, could be important for understanding forest dynamics (Bourland *et al.* 2015). In some cases, current forest cover, with species of economic importance to the timber trade, have their origins in the past African societies (Aubréville 1948).

Throughout the humid tropics, ecologists have studied forest ecosystems have been studied by ecologists through permanent sample plots (PSPs) (Lopez-Gonzalez *et al.* 2011)., (sometimes often brought together inthrough networked)s, that usinge common research questions, methodology or databases (Anderson-Teixeira *et al.* 2015). A few decades ago, PSP research was principally comprisedncerned with community ecology, species diversity, and management (Condit 1995). Increasingly, researchers use these plots are used to understand changes in carbon and forest response to climate change (Talbot *et al.* 2014), indicating alternative uses of that these datasets are useful for other purposes. However, these are not the only tropical forests plot networks across tropical forests: extensive networks of forest inventory plots (FIPs) also existoccur. In coastal central Africa, they cover more than 11 million ha (de Wasseige *et al.* 2009). While foresters FIPs are used by foresters to assess the timber stock with FIPs, ecologists also use PSPs are used by

~~ecologists~~ to study forest ecology and biodiversity. ~~However, t~~These plots ~~have the~~ potentially can ~~to~~ answer questions beyond their ecological or forestry remit, ~~however,~~ and so can~~they~~ address the historical and political contexts in which the forests have grown (Robbins 2012). Both types of plots can ~~be used for~~ facilitate “Anthropocene” studies to understand and quantify human influence on the environment in the recent past and to inform forest management.

Forest ecologists increasingly collaborate with paleo-biologists (Lovejoy and Heinz 2007) to explore the legacy of anthropogenic activities on forests from past millennia (Willis *et al.* 2004; Hayashida 2005). Collaborative research~~Increased collaborations~~ with archaeologists (Iles 2016) suggest methodological flaws when ~~that inferences of forest history drawn from~~ plots ~~that~~ do not consider the legacies of human history ~~are methodologically flawed~~. Furthermore, PSPs were largely established in ~~types of~~ forests ~~that were~~ considered ‘intact’, ‘pristine’, and ‘old growth’, or in accessible locations~~, clumped around assessableaccessible areas~~ (e.g. ~~such as~~ research stations) (Pitman *et al.* 2011). This first bias ~~enticed~~ led ~~forest~~ ecologists to examine such plots as if they were ‘undisturbed’~~-~~, ~~to the~~ neglecting ~~of~~ anthropogenic legacies. ~~, and t~~The second bias ~~calls into questions~~led them to ~~attempts to~~ generalis~~ations~~e from plot-based results to the wider landscape (Hecht and Saatchi 2007).

Given the transformation of the African environment ~~by events~~ in the last 500 years, such as by the Atlantic trade, new collaborations with the social-historical sciences~~archaeology~~ can ~~be combined with support other methods to understand~~ elucidate how human activities transformed the forest~~, eliciting new collaborations~~. ~~Taking the case from~~L~~l~~and-use research, -for example, although ~~it was~~ originally dominated by remote sensing, ~~it~~ increasingly benefits from historical data, historical methods (e.g. ~~-~~Hunter and Sluyter 2015) and ecological collaboration (Watson *et al.* 2014) to reconstruct land-use, forest change and carbon cycling. Such methods ~~are~~ also apply ~~icable~~ to ~~the study of~~ research on forest dynamics, forest management and plots, but require new collaborations with social scientists and historians to discern legacies that archaeology is less able to detect, such as ~~the~~ political drivers shaping ~~how~~ landscapes ~~were used~~. Although some research drawing on plots, paleobiological methods and aerial photography does discern the legacy of recent disturbances in the present-day forest structure (e.g Delègue *et al.* 2001; van Gemerden *et al.* 2003), this often remains ~~minimised or~~ unexplained.

~~In this viewpoint article, we argue~~ This article highlights how~~that~~ elucidating forest legacies across plot networks requires new interdisciplinary collaborations amongst ecologists, foresters, anthropologists and historians, ~~are required to study forest legacies across plot networks and~~while discerning lessons for sustainable management and forest recovery. The ~~novel contribution of this~~ paper ~~is that it associates different disciplines and proposes~~ shows how different disciplines ~~studies~~ can coordinatee ~~their~~ methods and reflections ~~of different disciplines can be coordinated~~ to address common questions of forest legacies in the 'Anthropocene'. Below, ~~W~~we (1) ~~consider~~assess the coverage and methods of PSPs and FIPs in tropical Africa in ~~the~~ light of sub-Saharan, tropical African forest history; ~~,~~(2) ~~provide~~ using two case studies, ~~to~~ demonstrate how history and anthropology can enrich plot-based studies and inform sustainable forest management; ~~,~~ and ~~then~~ (2) suggest how future research can facilitate this type of interdisciplinary collaboration ~~can occur~~.

2. Current ecological and forest inventory plot methods

Ecological studies of~~on~~ forest dynamics in tropical Africa mostly rely on PSPs, by monitoringg ~~where~~ individual trees ~~are monitored~~ over time (Picard *et al.* 2010). The size of PSPs varies from 100 m^2 to 500 ha (~~, with~~ one ha is~~being~~ the most common size). These plots have some methodological and interpretation limitations (Sheil 1995). They were established as part of disconnected studies, so their spatial distribution is uneven and does~~they do~~ not follow a sampling design that ~~can~~ enables statistically significant inferences to be drawn regionally (Picard *et al.* 2010). The balance between known 'disturbed' and presumed 'intact' forests remains uncontrolled, and given that the ecological questions that drove their establishment led to more plots being established in presumed 'intact' locations, there is a 'majestic forest' bias in the data set (Phillips *et al.* 2002). ~~To demonstrate this point,~~ Figure 1 details the current distribution of PSPs in western and central Africa rainforests ~~of western and central Africa~~ overlaid with the Human Footprint (HFP) index. The HFP~~F~~ measures the cumulative impact of direct pressures on nature from human activities based on eight spatial variables: extent of built environments, cropland, pastureland, human population density, night-time lights, railways, roads, and navigable waterways.[1]

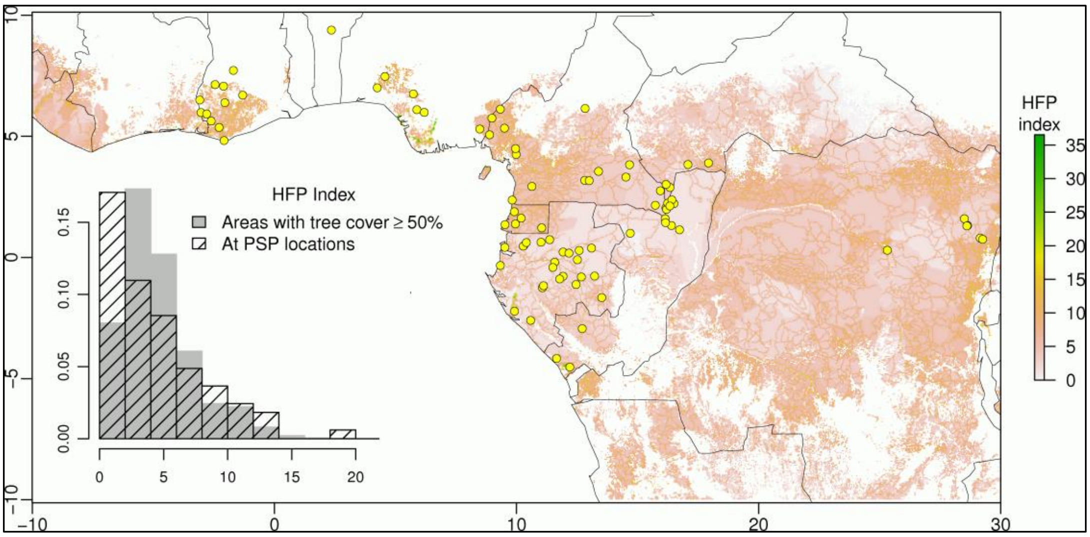

Fig. 1. Locations of Permanent Sample Plots (PSP) with the Human Footprint (HFP) index in the background. Dots = PSPs. ~~and t~~The HFP~~uman Footprint~~ in the background is based on the NASA index. White indicates areas with tree cover < 50%. X-axis of the inset plot = ~~reflects the~~ HFP while y-axis = ~~reflects its~~ density of distribution.

[1] This index was developed by WCS, CIESIN and Columbia University, with a publicly-~~-~~accessible data set (http://dx.doi.org/10.7927/H4M61H5F).

In Figure 1, the HFP index of PSPs is significantly smaller than the average HFP at the regional level, suggesting that PSPs are not representative of forests at that level, due to their placement in forests with less human impact, and therefore, should not be used alone to draw conclusions about forest history. However, forest researcher ~~if FIPs are~~ additionally use~~d~~ FIPs~~ in forest studies~~, ~~this bias may be reduced due to~~ their more extensive cover may reduce this bias.

FIPs, although more extensive, have other problems. ~~These are u~~Used to estimate~~ the~~ timber resources at the scale of a forest concession (~~ranging~~ 50,000-500,000 ha), they~~ and~~ follow sampling designs. Although some ~~these~~ plots ~~have long been considered to~~may lack rigour, others~~some~~ can be ~~validly~~ studied~~-~~ using statistics (Réjou-Méchain *et al.* 2011) and could~~may~~ be used to infer forest dynamics at larger scales. For example, they can ~~be used to~~ probe globally important questions concerning forest dynamics in the context of historical social change and land-use,~~ with a view~~ to learn about ~~social history,~~ ecosystem recovery and historic global carbon cycle fluctuations~~ in global carbon cycles~~. Such questions become increasingly important to understand~~ing~~ and quantify~~ing~~ human influence on the environment in the recent past and to inform~~ing~~ sustainable forest use (Aleman et al. 2018).

Comparing estimates of changes in aboveground biomass for forests based on PSPs and FIPs reveals ~~T~~the significance of these methodological flaws~~ is revealed when comparing estimates of changes in aboveground biomass for forests based on these PSPs and FIPs~~. Using 260 PSPs in African rainforests, the mean aboveground dry biomass was reported as 395.7 Mg ha^{-1} (95% CI: 14.3) (Lewis *et al.* 2013) whereas others using the same allometric equation ~~as Lewis et al.~~ but drawing on data from FIPs found much lower levels: ~~, ranging from~~ 324 Mg ha^{-1} (~~in~~ Gabon) (Maniatis *et al.* 2011) , ~~and~~ 241.7-303.7 Mg ha^{-1} (~~in southern~~ Central African Republic), and~~to~~ 225.3-235.3 Mg ha^{-1}

(~~in the~~ Republic of Congo) (Gourlet-Fleury *et al.* 2011). Lewis et al. (2013) cautiously specified that they reported biomass for intact closed-canopy forests, but the ~~scale of such~~ differences suggest~~s~~ the significance of non-intact (i.e. disturbed) forests at the landscape level and difficulties in interpreting ~~how~~ plot data ~~should be interpreted, especially when plots come~~ from different forest types and histories.

The forest signal of past anthropogenic activities lies in the size distribution of light-demanding (disturbance-prone) tree species. With the exception of monodominant forests, a one-hectare plot says little about the size distribution of any species. However, if these signals are analysed across a larger area, it becomes easier to understand their origin and extent. ~~However, using structural changes alone to infer forest changes may turn into a circular reasoning.~~ Historical knowledge is ~~also~~ needed to disentangle ~~whether~~ perturbations resultinge~~d~~ from human activities or other influences, such as elephants, which can also ~~have a large~~ impact ~~on~~ forest structure (Blake *et al.* 2009).

3. African forest history

African forest history comprises a complex interplay of climatic drivers and land-use changes at different timescales (McIntosh *et al.* 2015). Global models of~~n~~ historical land-use suggest that significant parts of Central and West Africa had increasingly reduced natural forest cover from 1,000 AD ~~onwards~~ with an associated carbon loss (Kaplan *et al.* 2011). ~~The periods of modelled~~ The 'first significant use' of landscapes in West and Central Africa drastically increased from the start of the first millennium (Ellis *et al.* 2013), but with significant differences in forest loss and gain from the 1900s to present (Aleman et al. 2018).~~.~~

Trade between Europe and the Afrotropicsica historically has long had an influenced-on forest dynamics. It bBeginningan in the fifteenth century, it gradually extendeding along the Atlantic coast and inland, where it encounteringed trade networks and that creatinged social upheavals in West and Central Africa, changes in governance, and the restructuring of polities and trade routes (e.g. Coquery-Vidrovitch 1985). -The introduction of new crops (e.g. manioc) droveresulted in economic transformations, while slavery, warfare, and disease epidemics resulted in the depopulated entireion of areas, -that some and cast aswhich Ford (1971: 489) understood as “biological warfare on a vast scale” (Ford 1971: 489).

In Atlantic Central Africa, peak human population density potentially occurred inaround the 16th century, after which the population decreased until around the 19th century (Oslisly et-al. 2013). During this period, the Atlantic trade alone potentially resulted in a loss of 11 million people from the continentAfrica (Maddox 2006). Furthermore, in Africa, the worldwide Spanish influenza epidemic likely lead to the death of at least 1.5 million people- in Africa, in 1918-1919 (Spinage 2012: 1201–2). This unevene demographic impact, though uneven, left vast tracts of land depopulated in humid West Africa (Fairhead and Leach 1998) and Central Africa, the latter of which was accentuated early in the 20th century -bywith forced, colonial resettlement along roads in the 20th century (Gray 2002, Fig. 2). There isA ample eEvidence from a variety of the observations of early foresters and other sources- indicates that mostthe majority, if not all, of the areas under studiedy by PSPs and FIPs in West and Central Africa may have beenwere shaped by these complex factors, as described by two . The cases below describe such historical landscapes.

4. Evidence from Western and Central Africa

4.1 Liberia

West Africa's The Upper Guinea Forest region of West Africa is a 'hotspot' of global biodiversity (Poorter *et al.* 2004), threatened by land-use change by logging, rubber and industrial agriculture (Fairhead and Leach 1998). Liberia comprises holds the greatest area of Upper Guineathis forest, with 41,238 km^2 or 37.7% of historic forest cover remaining (Poorter *et al.* 2004:6). However, historical observations and a recent researchsurvey reveal that much of this forest is can be described as 'anthropogenic' or 'domesticated' due to the effects of past and current settlement and agro-forestry dynamics which have shaped the current forest species compositions of forests (Fairhead and Leach 1998). This history ishas been occluded by ecological studies that assume forests are 'pristine' without evaluating theirplot history even when located in areas of known anthropogenic influence. Bongers et -al. (1999), for example, represented plot species composition as primarily an effect of climatic variation, even when these species distributions are known to beoften influenced by anthropogenic processes. (e.g. Cotton [*Ceiba pentandra*], Kola [*Cola nitida*], *Terminalia ivorensis, Terminalia superba*) are . Aall of these species); all of which are propagated and managed as useful species by local people in this region (Fairhead and Leach 1996; Bongers *et al.* 1999).

Muchany of Liberia's forests have beenare shaped by past, long-term swidden-fallow dynamics, viz., but are unmanaged and subject to felling. tThey are embedded with the overgrown, sites of old settlements, which are considered 'sacred' by local peoples due to the presence of certain tree species (e.g. Cotton, Kola), ancestors and spirits, and therefore often afforded protection from felling. These 'old town spots' also feature fertile 'African Dark Earths' and are frequently cultivated

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as cacao agro-forests (Fraser *et~~-~~al.* 2016) meriting the term~~calling them~~ ~~. Hence, the most accurate descriptor for these spaces~~ are~~is~~ 'sacred agroforest'.

A recent survey of 83 localities in ~~four counties (~~Gbarpolu, Bong, Lofa, Nimba counties~~)~~ near forestry concessions, where plots are likely used for management, found at least one sacred agroforest at 51 locations, 94 in total (Appendix 1, Fraser et~~-~~al. 2016). At the local scale~~resolution~~, mapping and transects within a 3km radius (ca. 2,827 ha) of a settlement found~~demonstrated~~ 18.6 ha of ~~showed that~~ sacred agroforests~~-cover 18.6 ha of the landscape~~, with the majority of adjacent areas~~most of the rest of the vicinity~~ covered in variously aged~~s greed of~~ fallow vegetation ~~of various ages~~ (Diabate pers. comm.). In comparing transects in sacred agroforests and secondary forest, ~~it found that~~ sacred agroforest increases biodiversity at the landscape level due to differing species composition~~, in particular~~ in both ~~mature~~ canopy species and seedlings. This study failed to find~~study tried and failed to find~~ old growth forest ~~areas within and beyond~~in this area (see Fraser et al 2016: "Baema", Figure 1, Appendix 2). This ~~Observations during fieldwork indicate this~~ pattern appears to be ~~is~~ typical of NW Liberia with ~~. M~~major historical disturbance ~~is~~ also ~~occured~~occurred ~~attested~~ in neighbouring settlements. ~~by t~~The diaries of two African American explorers, George L. Seymour and Benjamin J. K. Anderson, who ~~passed through~~traversed the ~~study~~ area in 1858, ~~. They~~ reported, '*it is common to see a hundred-acre farm in one cutting'* (Fairhead et al. 2003). A ~~a~~nd, ~~that~~ '*Standing upon an elevation, it seemed to me that the people had attempted to cover the whole country with their rice fields…Only here and there could be seen patches of large forest trees*.' (Fairhead et al. 2003:190-191).

Early foresters recognised t~~T~~he anthropogenic landscapes that emerged from ~~through~~ such processes over time ~~were recognized by early foresters~~. In the 1940's, forester Karl Meyer walked 2,300 km through Liberia's forests observing that '*abandoned villages are, in some sections, very*

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common,' ~~and characterised Liberia as an *'over-used worn out country of great antiquity',* wherein~~ and, areas '*with no signs of occupancy 'during recent centuries are few and scattered'*(Mayer 1951:25).~~-~~ Hence, today's~~- 'natural'~~ forest is composed of secondary forest, historically disturbed through shifting cultivation, ~~but~~ with largely unmanaged succession (Fairhead and Leach 1998), dotted with sacred agroforests (Fraser et al. 2016, Appendix 1).

In 2006, Liberia revised its national forestry law, ~~to~~ promoting~~e~~ sustainable forest management. In 2009, the Community Rights Law was enacted, empowering ~~, seeking to "empower~~ communities to engage in sustainable forest management on their lands~~"~~. That ~~same~~ year, industrial logging companies were granted ~~,~~ 25% of Liberia's forests, yet ~~were granted to industrial logging companies, with although~~ the implementation of the forestry laws remain~~ing~~s difficult (Altman et al. 2012; O'Mahoney 2019). ~~Liberia's forests have a dynamic history, and settlement patterns have led to the formation of African Dark Earths, which are associated with different canopy tree species to background soils, aggregating agrobiodiversity at the landscape scale (Fraser et al. 2016).~~ ~~Based on this case, Tthe following~~We make the following management recommendations: ~~are made.~~ First, the government largely does not recognise the ~~environmental~~ history of Liberian forests ~~is largely unrecognised by the government~~. This encourages viewing~~s of the~~ forests as a resource stock ~~of resources~~ rather than a cultural artefact. ~~So i~~It is important that the linkages between extant forest peoples, such as the Loma and their ancestors who created these forests (Fraser et al 2015), are ~~grounded~~ recognised in representations of forests by ~~how the~~ government, media, and in school curricula ~~the representation of forests by the government, media, and curricula, and internationally~~. Second, if the two abovementioned~~new~~ laws are not ~~need to be~~ implemented, ~~. If not enforced, then the descendants of the~~ peoples ~~who created these forests~~ will lose ~~their~~ tenurial~~e~~ rights over the agrobiodiversity created by their ancestors. An awareness

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campaign should~~mustis necessary to~~ ensure that people know their tenure rights. Together these ~~two~~ interventions~~, the first~~ ~~- about~~ raising historical awareness and ~~, the second about raising~~ legal awareness~~,~~ - could~~could~~ empower citizens to conserve the landscapes that are also their cultural heritage.

4.2 Gabon

In Gabon, ~~like in the rest of the Congo Basin,~~ archaeology, palynology, diatoms, phytoliths, and tree population genetics have partially reconstructed~~trends in~~ ~~partial~~ forest history ~~have been reconstructed from archaeology, palynology, diatoms ,and phytoliths, and tree population genetics~~ (Brncic *et al.* 2007; Piñeiro et al. 2017). However, history and linguistics~~ical disciplines~~ also explain the interactions of ~~how~~ people and forests ~~have interacted~~ over time (Vansina 1990), including ~~how~~ societal change~~s in societies~~ impactings vegetation structure (Walters 2012). A~~One of the~~ dominant, sub-endemic timber species~~trees~~ to~~, and a sub-endemic species to~~ Gabon, Okoume (*Aucoumea klaineana*), colonizes slash-and-burn openings, ~~a phenomenon~~ which forester Aubréville described as "Okoume being the son of manioc" (Aubréville 1948). Once mature, large stands indicate the presence of past villages (Biraud 1959). However, disease, brought by trade and colonial rule severely ~~impacted~~affected village placement and human demography ~~was severely impacted by disease, brought by trade and colonial rule~~ (Headrick 1990, Chamberlin 1977, Gray 2002), resulting in changes to forest composition.

Oral histories ~~Work in~~ from the Parc National de Waka (PNW) area ~~in Ccentral Gabon~~ near PSPs (Balinga *et al.* 2006), ~~using oral histories from the Parc National de Waka (PNW) area~~ (Hymas 2016) found that ~~the~~ current stands of Okoume originated ~~are due to~~from colonial concession plantation agriculture ~~historic, concessionary agriculture plantations that supplied the workers of historic~~

~~concessions~~ during ~~from~~ the late-1800s to mid-1900s. These forests are ~~a result of complex events~~the outcome of complex historical trajectories. I~~-~~nter-ethnic conflict over natural resources ~~that led to the~~ depopulated~~ion of~~ the area in the early 1800s~~-~~; ~~due to inter-ethnic conflict over natural resources. This area was r~~it was repopulated in the late 1800s through~~due to~~ trade concessions, and ~~but was once again~~then again depopulated in the 1920s by~~due to~~ trade-induced disease, and further depopulated in 1960 by~~due to~~ the ~~the~~ government~~al~~ resettlement policy (Fig. 2). ~~in~~In the 1960s, logging companies were attracted to the ~~large~~ Okoume stands, which resulted in ~~This area was again~~a repopulation by workers~~ed as people migrated to work with logging companies who were attracted to the large Okoume stands in the 1960s~~. In 2003, ~~T~~the PNW was ~~later~~ created to protect elephant populations (WCS, 2007), ~~which are~~ attracted to abandoned village sites, ~~typically~~ rich in planted fruit trees (Barnes *et al.* 1991).

In another case, using the FIPs of a forestry concession in the Haut-Abanga, Engone Obiang et al. (2014) diagnosed 'old, naturally-declining' populations of Okoume through a tree diameter~~n~~ analysis~~ of tree diameters~~. The modal diameter of Okoume wais~~ofwas~~ 50-60 cm, ~~and~~ corresponding~~ed~~ to 60-~~70 year old~~70-year-old trees~~ aged 60-70 years~~. ~~This age The recent history of the Haut-Abanga coincideds with this structure.~~ The ~~In collaboration with an anthropologist researching and in consulting the~~ historical literature~~, it was found that found~~showeds that the ~~e~~ area ~~was found to be~~was a former ~~n old once a~~ communication ~~corridor~~corridor that~~. The corridor~~ lost its~~this~~ role with~~hen~~ the establishment of the modern road network~~ was established~~. The area,~~river banks~~ ~~was ere~~ populated until the 1940s~~, but by the 1950s,~~ became almost empty~~ due~~ in the 1950s due to the resettlement policy (Peyrot 2008), Fig. 2.

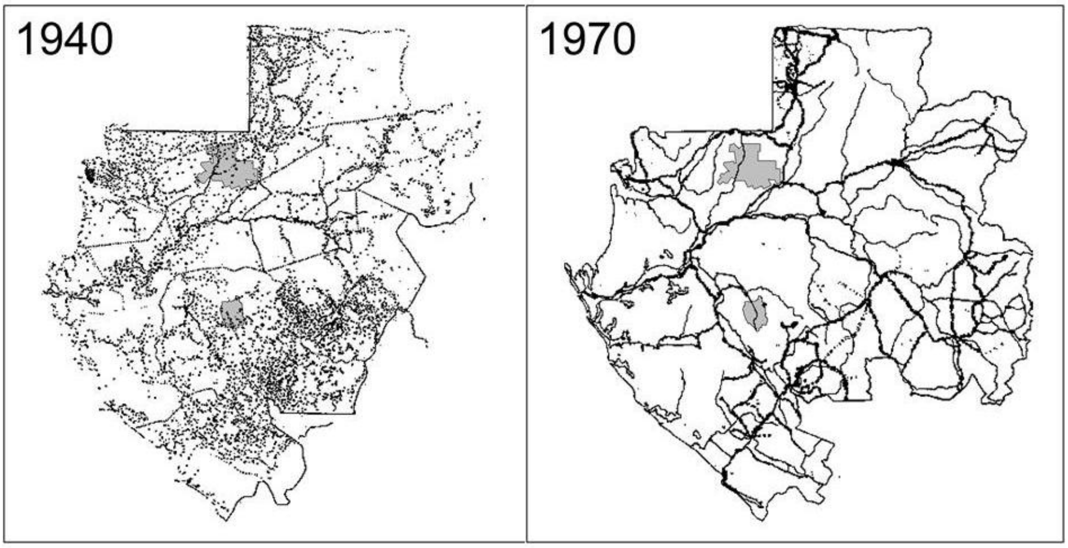

Figure 2. Population distribution of Gabon in 1940 prior to the resettlement policy and in 1970, afterwards (adapted from Sautter 1966), showing the Haut Abanga Concession in the north, and PNW in the center.

Okoume is Gabon's~~the~~ most important timber species~~ in Gabon~~ but other commercial species are fast-growing and light-demanding, ~~species~~ too. For such species, ~~the~~ current stocks are often ~~is~~ the legacy of past disturbances, such as slash-and-burn cultivation~~ around villages, that once created favourable conditions~~. Hence, forest history plays a role in determining their distribution. Nonetheless, ~~the~~ current ~~scheme for~~ sustainable forest management ~~implicitly~~ relies on the hypothesis of demography at equilibrium, where young trees continuously replace large ones. Sustainability is assessed through the recovery rate of the species at the end of the felling cycle. When the recovery rate becomes too low, forest managers ~~a common management action is to~~often increase the minimum size of felled trees. Although this measure may have short-term success in maintaining species stock, it does not acknowledge the role of history in ~~determining~~ shaping it. As a result, these stocks may decline, with~~having~~ ~~. This decline has~~ both environmental and economic consequences, bringing~~ and so, thus questioning~~ the concept of 'sustainable forest management' into question (Karsenty 2018a).

To address unsustainable forest management, in 2018, Gabon announced that all forest concessions must become certified by the Forest Stewardship Council (FSC) standard by 2022. ~~Requiring ~~T~~t~~he standard goes beyond the issue of sustainable stocks (Karsenty 2018b), but its implementation has often been problematic (Nepomuceno et al 2019). ~~However, ~~I~~i~~t is unlikely that "sustainable stocks" ~~that this latter issue will be solved~~ can be achieved without considering their historical origin ~~of the stocks~~. Forest management plans must factor in ~~This~~ historical dimensions ~~of stocks should be diagnosed in forest management plans, which is currently not the case,~~ and when natural recovery is no longer possible, silvicultural techniques, including planting, should be proposed ~~when natural recovery is no longer possible~~.

5. Interdisciplinary collaboration to understand tropical African tropical forests in the Anthropocene

Today's West and Central Africa forests ~~in West and Central Africa~~ provide an archive of the slave trade, ~~its~~ conflicts, diseases and depopulations that left farm and village lands abandoned. Attempts to read forest~~their~~ composition and dynamics only through the lens of 'natural history' and 'climate change' overlooks this history and the associated meaning for those who live there, and reduces the ability to manage these legacy forests.

PSPs and FIPs in the Afrotropics~~ica~~ ~~can~~ provide a research lens ~~not only~~ into both 'forest ecology' and ~~but also into how~~ past ~~the~~ environmental ~~has~~ ~~responded to past~~ change. This requires ~~that we~~ asking a wider range of questions of these plots, ~~; questions that must be~~ collaboratively researched using ecologically and socio-historically focused inquiry. To ask such questions, ~~these require~~ new forms~~ways~~ of research are required~~ing them~~, but ~~in association~~ combining~~with~~

different disciplines disciplines that usethat have differentdiverse lexicons, timeframes, epistemologies and methodologies is one of, some of the biggest challenges of achieving interdisciplinary research (Lele and Kurian 2011). In our case, I interdisciplinary research programs mustneed to be developed whereby an with an integrated methodology can bring togethercombining relevant data from archaeology and history ((working with artefacts and texts), anthropology and, political and historical ecology, withand ecology to understandinterpret forest diversity patterns. These interdisciplinary initiatives, require researchers to "share the conceptual world of their colleagues", and openly discussing how to approaching the research beyond disciplinary boundaries (Darbellay 2015:-167).

In achievingTo do this, it is imperative to a recognisetion that the ecology of the people have recently impactedshape forests hasve been recently impacted by people is necessary, as demonstrated in the Gabon case. Thinking in terms of social-ecological and biocultural systems Employing framings such as a systems approach (c.f. Fischer 2018), including social ecological and biocultural systems, will can demonstrate society--environment interconnections, between society and the environment. This then can leading to discussions on how to collaboratively study these impacts collaboratively can be collaboratively studied. As set out by pPolitical ecologist Paul Robbins (2012) proposes that, links between these socio-al and political forces and can be made to the following ecological characteristics can be made includeing: type and direction of environmental change, drivers of that change (including keystone processes, —colonisation patterns or cultural processes which have largescale changes on the landscape (Marcucci 2000))[2], the environment in which these changes occur, the impact of- how cultural practices impact on the

[2] Including keystone processes, colonisation patterns or cultural processes which have largescale changes (Marcucci 2000).

system~~[3]~~ (sensu Maraccuci 2000), and how it ~~the system~~ recovers. The final step can ~~include~~, as noted in the Liberia case, explicitly~~ly~~ link~~ing~~ historical forests to current forest usage and land claims ~~on these forests~~.

In the case of PSPs, synthesising ~~the~~ existing historical and archaeological research for each plot and linking to specific periods, can show ~~explore~~ how present-day forest structure and diversity ~~these~~ are linked to disturbances ~~may be linked to present-day forest structure and diversity~~ (Fairhead, unpublished data). ~~In the case of~~When studying ~~these~~ impacts through FIPs, documenting the species most susceptible to disturbance, as ~~done~~ in the Gabon case, is a first step. -The places where these signals are strongest (e.g. mono-dominant forests), can then be explored. By providing a view on how ecological patterns and processes have reacted in the past to environmental changes, historical ecology can inform how ~~ecosystem~~ forest structure and process may respond to future ~~global~~ change (Safford *et al.* 2012).

Such collaborations will also ~~help discern~~inform ~~the sustainability of current~~ forest management still rooted in equilibria paradigms despite historical ~~and forestry~~ evidence ~~that question this rationale~~ (Morin-Rivat *et al.* 2017). Some forest managers ~~today~~ are aware that the ~~current~~ management of some ~~commercial~~ species is not sustainable because the ~~current exploitable~~ stock is a legacy of past human perturbations ~~that have favouringed light-demanding species~~ (Morin-Rivat et al. 2016). However, ~~including~~ a historical perspective on the current structure of commercial species would offer a stronger basis for sustainable management. In both case-studies, ~~the~~ forest history and species ~~the~~ responses~~ of species~~ are different, and each country has different sustainable forest management strategies. However, neither country's policies acknowledge the

~~[3] Including keystone processes, colonisation patterns or cultural processes which have largescale changes (Marcucci 2000).~~

impact that history has on timber stocks, nor ~~and therefore does not~~ address if and how to maintain and manage these stocks. Furthermore, neither recognises forests as historical and cultural products of people living there today.

In this paper, we reviewed limitations of plot-based research in light of Afrotropical history, which heavily influenced the history of these forests, compared the usage of PSPs and FIPs, ~~reviewed the limitations of plot-based researchmethods and their limitations in the light of sub-Saharan, tropical African environmentalAfrotropical history,~~ and provided cases ~~to~~ demonstrating~~e~~ how interdisciplinary research collaborations ~~between the social and historical sciences~~ can enrich ~~the conclusions from~~ plot-based studies. We propose ~~that~~ future work focus on using ~~existing~~ plot networks to research new questions, in collaboration with historians and social scientists. The~~A~~ lack of ~~such a~~ historical perspectives on~~of~~ forests will limit ~~finding ways to~~ addressing sustainability (Roberts *et al.* 2018, this issue). However, new collaborations will not only help deepen conclusions from forest ecology~~studies of these forests~~, but also influence study design and management options~~, as demonstrated in the two cases~~.
~~We have shown that Without interdisciplinary collaborations, conclusions from studies may be limited (Cadotte et al. 2017). hHumans have heavily influencedd tThe history of these forests has been heavily influenced by humans (Lewis *et al.* 2015) and argued that i~~Interdisciplinary collaboration is one way to explore how the forests ~~has been impacted~~ have been shaped during the ~~'~~Anthropocene. This new view ~~of forests~~ suggests that ~~' We provided a novel definition of and to define sustainable management and conservation - strategies, whereby~~ some tree species ~~may~~ require new forms~~ways~~ of management and~~; and~~ some forests ~~may~~ deserve new recognition as cultural landscapes~~ worth conserving~~.

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Deciphering African tropical forest dynamics in the Anthropocene: how social and historical sciences can elucidate forest research management

Abstract

Forests bear the historical legacies of human activities over thousands of years, including agriculture, trade, disease and resource extraction. Many of these activities may represent indices of the proposed geological epoch of the Anthropocene. Modifications to soil, topography and vegetation evidence anthropogenic influences. Yet studies of vegetation change throughout the humid tropics tend to occlude these by focussing on forest dynamics, timber, and biodiversity through permanent sample plots or forestry inventory plots. We highlight how history and social science can be combined with ecology to help better understand human signatures in forest dynamics. We (1) critically review ecological methods in the light of the environmental and social history of the Afrotropics; (2) map current plot networks for West and Central Africa in relation to the Human Footprint Index; (3) using two case-studies, demonstrate how history and social science bring new insights and inferences to plot-based studies; all leading to (4) novel forms of interdisciplinary collaboration for sustainable forest conservation, management and restoration.

Keywords

Forest ecology, Africa, historical sciences, social sciences, forest management, interdisciplinarity

1. Progress in linking past anthropogenic activity to present-day forest structure

The ways that tropical forests are studied and conceptualized have changed greatly in recent decades. The work of geographers and anthropologists in the Amazon (e.g. Balée and Erickson 2006) and in Africa (e.g. Fairhead and Leach 1996) have helped bring about these changes, challenging researchers to consider the influences of humans on forest structure and biodiversity. In the early 2000s, ecologists believed that people (Foster *et al.* 2003) had not affected current ecosystem dynamics to a large extent; however, it is now widely accepted that past human impacts have not only shaped ecosystems, but also have become a geological force – captured in the concept of the "Anthropocene" (e.g., Ellis *et al.* 2013). While some argue for a 1950s start to the proposed geologic epoch (e.g. Zalasiewicz et al. 2010), others (Lewis and Maslin 2015) argue for an earlier ca 1500 start, which coincides with the beginning of global capitalism (Moore 2015). In Africa, these 'Anthropocene' impacts include the slave trade, colonisation, Atlantic trade, disease epidemics and lifestyles of prehistoric societies (Maddox 2006; Kay and Kaplan 2015), often leaving their mark on forest structure and biodiversity hundreds of years later.

Ecologist P.W. Richards (1952) warned that ecologists working in the African rain forest should not ignore significant modification of their study areas by recent human activity. Foresters were aware of the relationship between cultivation and pioneer forest species (Letouzey 1957); others noted the importance of understanding forest change in relation to the life span of trees (White and Oates 1999). The forests of Oban, Nigeria, for example, now construed as 'Old Growth', were previously inhabited (Rosevear 1979: 78) based on the evidence of trees left by farmers when the land was depopulated hundreds of years earlier. This example suggests that the lifespan of a tree, and what occurred during that period, could be important for understanding forest dynamics (Bourland *et al.* 2015). In some cases, current forest cover, with species of economic importance to the timber trade, have their origins in past African societies (Aubréville 1948).

Throughout the humid tropics, ecologists have studied forest ecosystems through permanent sample plots (PSPs) (Lopez-Gonzalez *et al.* 2011), (often networked), using common research questions, methodology or databases (Anderson-Teixeira *et al.* 2015). A few decades ago, PSP research principally comprised community ecology, species diversity, and management (Condit 1995). Increasingly, researchers use these plots to understand changes in carbon and forest response to climate change (Talbot *et al.* 2014), indicating alternative uses of these datasets.

However, these are not the only tropical forest plot networks: extensive networks of forest inventory plots (FIPs) also exist. In coastal central Africa, they cover more than 11 million ha (de Wasseige *et al.* 2009). While foresters assess timber stock with FIPs, ecologists also use PSPs to study forest ecology and biodiversity. These plots potentially can answer questions beyond their ecological or forestry remit, and so can address the historical and political contexts in which the forests have grown (Robbins 2012). Both types of plots can facilitate Anthropocene studies to understand and quantify human influence on the environment in the recent past and to inform forest management.

Forest ecologists increasingly collaborate with paleo-biologists (Lovejoy and Heinz 2007) to explore the legacy of anthropogenic activities on forests from past millennia (Willis *et al.* 2004; Hayashida 2005). Collaborative research with archaeologists (Iles 2016) suggest methodological flaws when plots do not consider the legacies of human history. Furthermore, PSPs were largely established in forests considered 'intact', 'pristine', and 'old growth', or in accessible locations (e.g. research stations) (Pitman *et al.* 2011). This first bias led ecologists to examine such plots as if they were 'undisturbed', neglecting anthropogenic legacies. The second bias led them to generalise from plot-based results to the wider landscape (Hecht and Saatchi 2007).

Given the transformation of the African environment in the last 500 years, such as by the Atlantic trade, new collaborations with the social-historical sciences can elucidate how human activities transformed the forest. Land-use research, for example, although originally dominated by remote sensing, increasingly benefits from historical data, historical methods (e.g. Hunter and Sluyter 2015) and ecological collaboration (Watson *et al.* 2014) to reconstruct land-use, forest change and carbon cycling. Such methods also apply to research on forest dynamics, forest management and plots, but require new collaborations with social scientists and historians to discern legacies that archaeology is less able to detect, such as political drivers shaping landscapes. Although some research drawing on plots, paleobiological methods and aerial photography does discern the legacy of recent disturbances in the present-day forest structure (e.g Delègue *et al.* 2001; van Gemerden *et al.* 2003), this often remains unexplained.

This article highlights how elucidating forest legacies across plot networks requires new interdisciplinary collaborations amongst ecologists, foresters, anthropologists and historians, while discerning lessons for sustainable management and forest recovery. The paper shows how different disciplines can coordinate methods and reflections to address common questions of forest legacies in the 'Anthropocene'. Below, we (1) assess the coverage and methods of PSPs and FIPs in tropical Africa in light of sub-Saharan, tropical African forest history; (2) using two case studies, demonstrate how history and anthropology can enrich plot-based studies and inform sustainable forest management; and (2) suggest how future research can facilitate this type of interdisciplinary collaboration.

2. Current ecological and forest inventory plot methods

Ecological studies of forest dynamics in tropical Africa mostly rely on PSPs, by monitoring individual trees over time (Picard *et al.* 2010). The size of PSPs varies from 100 m^2 to 500 ha (one ha is the most common size). These plots have some methodological and interpretation limitations (Sheil 1995). They were established as part of disconnected studies, so their spatial distribution is uneven and does not follow a sampling design that enables statistically significant inferences to be drawn regionally (Picard *et al.* 2010). The balance between known 'disturbed' and presumed 'intact' forests remains uncontrolled, and given that the ecological questions that drove their establishment led to more plots being established in presumed 'intact' locations, there is a ‘majestic forest' bias in the data set (Phillips *et al.* 2002). Figure 1 details the current distribution of PSPs in western and central Africa rainforests overlaid with the Human Footprint (HFP) index. The HFP measures the cumulative impact of direct pressures on nature from human activities based on eight spatial variables: extent of built environments, cropland, pastureland, human population density, night-time lights, railways, roads, and navigable waterways.[1]

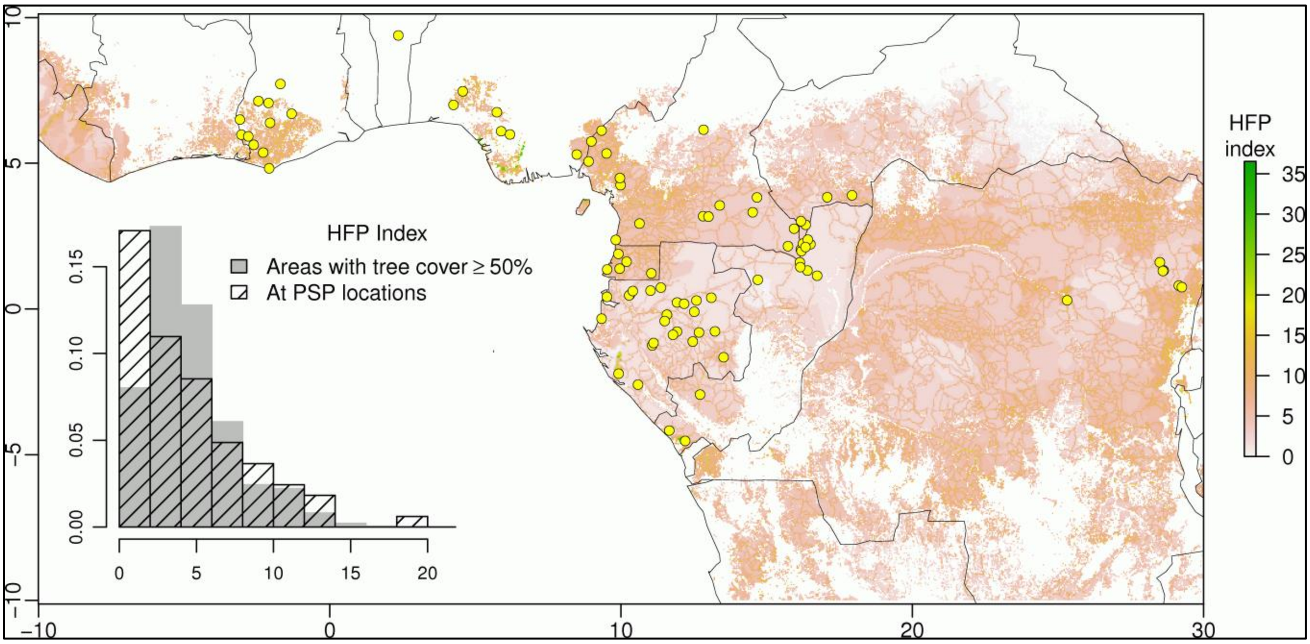

Fig. 1. Locations of Permanent Sample Plots (PSP) with the Human Footprint (HFP) index in the background. Dots = PSPs. The HFP in the background is based on the NASA index. White indicates areas with tree cover < 50%. X-axis of the inset plot = HFP while y-axis = density of distribution.

In Figure 1, the HFP index of PSPs is significantly smaller than the average HFP at the regional level, suggesting that PSPs are not representative of forests at that level, due to their placement in forests with less human impact, and therefore, should not be used alone to draw conclusions about forest history. However, forest researcher additionally use FIPs, their more extensive cover may reduce this bias.

FIPs, although more extensive, have other problems. Used to estimate timber resources at the scale

[1] This index was developed by WCS, CIESIN and Columbia University, with a publicly-accessible data set (http://dx.doi.org/10.7927/H4M61H5F).

of a forest concession (50,000-500,000 ha), they follow sampling designs. Although some plots may lack rigour, others can be studied using statistics (Réjou-Méchain *et al.* 2011) and could be used to infer forest dynamics at larger scales. For example, they can probe globally important questions concerning forest dynamics in the context of historical social change and land-use, to learn about ecosystem recovery and historic global carbon cycle fluctuations. Such questions become increasingly important to understand and quantify human influence on the environment in the recent past and to inform sustainable forest use (Aleman et al. 2018).

Comparing estimates of changes in aboveground biomass for forests based on PSPs and FIPs reveals the significance of these methodological flaws. Using 260 PSPs in African rainforests, the mean aboveground dry biomass was reported as 395.7 Mg ha^{-1} (95% CI: 14.3) (Lewis *et al.* 2013) whereas others using the same allometric equation but drawing on data from FIPs found much lower levels: 324 Mg ha^{-1} (Gabon) (Maniatis *et al.* 2011) , 241.7-303.7 Mg ha^{-1} (Central African Republic), and 225.3-235.3 Mg ha^{-1} (Republic of Congo) (Gourlet-Fleury *et al.* 2011). Lewis et al. (2013) cautiously specified that they reported biomass for intact closed-canopy forests, but the differences suggest the significance of non-intact (i.e. disturbed) forests at the landscape level and difficulties in interpreting plot data from different forest types and histories.

The forest signal of past anthropogenic activities lies in the size distribution of light-demanding (disturbance-prone) tree species. With the exception of monodominant forests, a one-hectare plot says little about the size distribution of any species. However, if these signals are analysed across a larger area, it becomes easier to understand their origin and extent. Historical knowledge is needed to disentangle perturbations resulting from human activities or other influences, such as elephants, which can also impact forest structure (Blake *et al.* 2009).

3. African forest history

African forest history comprises a complex interplay of climatic drivers and land-use changes at different timescales (McIntosh *et al.* 2015). Global models of historical land-use suggest that significant parts of Central and West Africa had increasingly reduced natural forest cover from 1,000 AD with an associated carbon loss (Kaplan *et al.* 2011). The 'first significant use' of landscapes in West and Central Africa drastically increased from the start of the first millennium (Ellis *et al.* 2013), but with significant differences in forest loss and gain from the 1900s to present (Aleman et al. 2018).

Trade between Europe and the Afrotropics historically influenced forest dynamics. Beginning in the fifteenth century, it extended along the Atlantic coast and inland, encountering trade networks and creating social upheavals in West and Central Africa, and restructuring polities and trade routes (e.g. Coquery-Vidrovitch 1985). The introduction of new crops (e.g. manioc) drove economic transformations, while slavery, warfare, and disease epidemics depopulated entire areas, which Ford (1971: 489) understood as "biological warfare on a vast scale"

In Atlantic Central Africa, peak human population density potentially occurred in the 16th century, after which the population decreased until the 19th century (Oslisly etal. 2013). During this period, the Atlantic trade alone potentially resulted in a loss of 11 million people from Africa (Maddox 2006). Furthermore, the worldwide Spanish influenza epidemic likely lead to the death of at least 1.5 million people in Africa, in 1918-1919 (Spinage 2012: 1201–2). This uneven demographic impact left land depopulated in humid West Africa (Fairhead and Leach 1998) and Central Africa, the latter of which was accentuated by forced, colonial resettlement along roads in the 20th century (Gray 2002, Fig. 2). Evidence from a variety of sources indicates that most of the areas studied by PSPs and FIPs in West and Central Africa were shaped by these complex factors, as described by two cases below.

4. Evidence from Western and Central Africa

4.1 Liberia

West Africa's Upper Guinea Forest region is a 'hotspot' of global biodiversity (Poorter *et al.* 2004), threatened by logging, rubber and industrial agriculture (Fairhead and Leach 1998). Liberia holds the greatest area of this forest, with 41,238 km^2 or 37.7% of historic forest cover remaining (Poorter *et al.* 2004:6). However, historical observations and recent research reveal that much of this forest is 'anthropogenic' or 'domesticated' due to settlement and agro-forestry dynamics which have shaped the current forest species composition (Fairhead and Leach 1998). This history is occluded by ecological studies that assume forests are 'pristine' without evaluating their history even in areas of known anthropogenic influence. Bongers et al. (1999), for example, represented plot species composition as primarily an effect of climatic variation, even when these species distributions are often influenced by anthropogenic processes. Cotton [*Ceiba pentandra*], Kola [*Cola nitida*], *Terminalia ivorensis, Terminalia superba)* are all species propagated and managed by people in this region (Fairhead and Leach 1996; Bongers *et al.* 1999).

Much of Liberia's forests are shaped by past, long-term swidden-fallow dynamics, viz., they are embedded with overgrown, old settlements, considered 'sacred' by local peoples due to the presence of certain tree species (e.g. Cotton, Kola), ancestors and spirits, and therefore often afforded protection from felling. These 'old town spots' also feature fertile 'African Dark Earths' and are frequently cultivated as cacao agro-forests (Fraser *etal.* 2016) meriting the term 'sacred agroforest'.

A recent survey of 83 localities in Gbarpolu, Bong, Lofa, Nimba counties near forestry concessions, where plots are likely used for management, found at least one sacred agroforest at 51 locations, 94 in total (Appendix 1, Fraser etal. 2016). At the local scale, mapping and transects within a 3km radius (ca. 2,827 ha) of a settlement found 18.6 ha of sacred agroforests, with the majority of adjacent areas covered in variously aged fallow vegetation (Diabate pers. comm.). In comparing transects in sacred agroforests and secondary forest, sacred agroforest increases biodiversity at the landscape level due to differing species composition in both canopy species and seedlings. This study failed to find old growth forest in this area (see Fraser et al 2016: "Baema", Figure 1, Appendix 2). This pattern appears to be typical of NW Liberia with major historical disturbance also occurred in neighbouring settlements. The diaries of two African American explorers, George L. Seymour and Benjamin J. K. Anderson, who traversed the area in 1858, reported, '*it is common to see a hundred-acre farm in one cutting'* (Fairhead et al. 2003). And, '*Standing upon an elevation, it seemed to me that the people had attempted to cover the whole country with their rice fields…Only here and there could be seen patches of large forest trees*.' (Fairhead et al. 2003:190-191).

Early foresters recognised the anthropogenic landscapes that emerged from such processes over time. In the 1940's, forester Karl Meyer walked 2,300 km through Liberia's forests observing that '*abandoned villages are, in some sections, very common*,' and areas '*with no signs of occupancy 'during recent centuries are few and scattered*'(Mayer 1951:25). Hence, today's forest is composed of secondary forest, historically disturbed through shifting cultivation, with largely unmanaged succession (Fairhead and Leach 1998), dotted with sacred agroforests (Fraser et al. 2016, Appendix 1).

In 2006, Liberia revised its national forestry law, promoting sustainable forest management. In 2009, the Community Rights Law was enacted, empowering communities to engage in sustainable forest management on their lands. That year, industrial logging companies were granted 25% of Liberia's forests, yet the implementation of the forestry laws remains difficult (Altman et al. 2012; O'Mahoney 2019).

We make the following management recommendations: First, the government largely does not recognise the history of Liberian forests. This encourages viewing forests as a resource stock rather than a cultural artefact. It is important that the linkages between extant forest peoples, such as the Loma and their ancestors who created these forests (Fraser et al 2015), are recognised in representations of forests by government, media, and in school curricula. Second, if the two abovementioned laws are not implemented, people will lose tenurial rights over the agrobiodiversity created by their ancestors. An awareness campaign should ensure that people know their tenure rights. Together these interventions - raising historical awareness and legal awareness - could empower citizens to conserve the landscapes that are also their cultural heritage.

4.2 Gabon

In Gabon, archaeology, palynology, diatoms, phytoliths, and tree population genetics have partially reconstructed forest history (Brncic *et al.* 2007; Piñeiro et al. 2017). However, history and linguistics also explain the interactions of people and forests over time (Vansina 1990), including societal change impacting vegetation structure (Walters 2012). A dominant, sub-endemic timber species to Gabon, Okoume (*Aucoumea klaineana*), colonizes slash-and-burn openings, which forester Aubréville described as "Okoume being the son of manioc" (Aubréville 1948). Once mature, large stands indicate the presence of past villages (Biraud 1959). However, disease, brought by trade and colonial rule severely affected village placement and human demography (Headrick 1990, Chamberlin 1977, Gray 2002), resulting in changes to forest composition.

Oral histories from the Parc National de Waka (PNW) area near PSPs (Balinga *et al.* 2006), (Hymas 2016) found that current stands of Okoume originated from colonial concession plantation agriculture during the late-1800s to mid-1900s. These forests are the outcome of complex historical trajectories. Inter-ethnic conflict over natural resources depopulated the area in the early 1800s; it was repopulated in the late 1800s through trade concessions, and then again depopulated in the 1920s by trade-induced disease, and further depopulated in 1960 by the government resettlement policy (Fig. 2). In the 1960s, logging companies were attracted to the Okoume stands, which resulted in a repopulation by workers. In 2003, the PNW was created to protect elephant populations (WCS, 2007), attracted to abandoned village sites, rich in planted fruit trees (Barnes *et al.* 1991).

In another case, using the FIPs of a forestry concession in the Haut-Abanga, Engone Obiang et al. (2014) diagnosed 'old, naturally-declining' populations of Okoume through a tree diameter analysis. The modal diameter of Okoume was 50-60 cm, corresponding to 60-70-year-old trees. The historical literature showed that the area was a former communication corridor that lost its role with the establishment of the modern road network. The area, populated until the 1940s, became almost empty in the 1950s due to the resettlement policy (Peyrot 2008), Fig. 2.

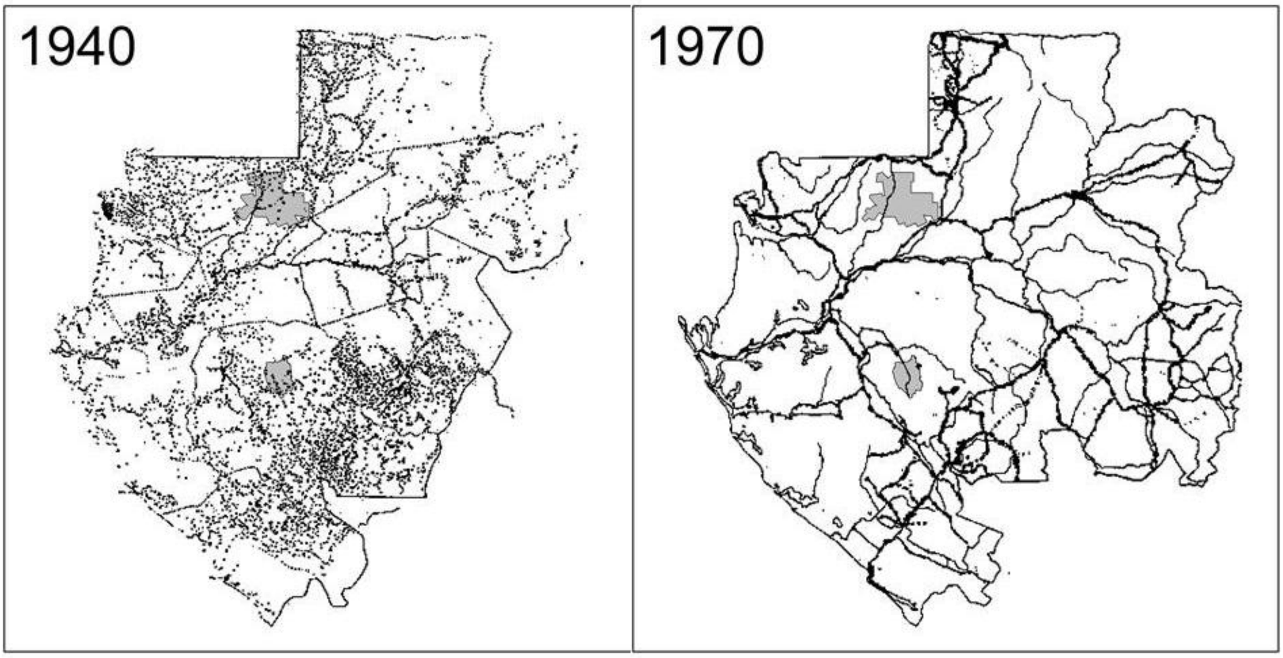

Figure 2. Population distribution of Gabon in 1940 prior to the resettlement policy and in 1970, afterwards (adapted from Sautter 1966), showing the Haut Abanga Concession in the north, and PNW in the center.

Okoume is Gabon's most important timber species but other commercial species are fast-growing and light-demanding, too. For such species, current stocks are often the legacy of past disturbances, such as slash-and-burn cultivation. Hence, forest history plays a role in determining their distribution. Nonetheless, current sustainable forest management relies on the hypothesis of demography at equilibrium, where young trees continuously replace large ones. Sustainability is assessed through the recovery rate of the species at the end of the felling cycle. When the recovery rate becomes too low, forest managers often increase the minimum size of felled trees. Although this measure may have short-term success in maintaining species stock, it does not acknowledge the role of history in shaping it. As a result, these stocks may decline, with both environmental and economic consequences, bringing the concept of 'sustainable forest management' into question (Karsenty 2018a).

To address unsustainable forest management, in 2018, Gabon announced that all forest concessions must become certified by the Forest Stewardship Council (FSC) standard by 2022. The standard goes beyond the issue of sustainable stocks (Karsenty 2018b), but its implementation has often been problematic (Nepomuceno et al 2019). It is unlikely that “sustainable stocks” can be achieved without considering their historical origin. Forest management plans must factor in historical dimensions and when natural recovery is no longer possible, silvicultural techniques, including planting, should be proposed.

5. Interdisciplinary collaboration to understand tropical African tropical forests in the Anthropocene

Today’s West and Central Africa forests provide an archive of the slave trade, conflicts, diseases and depopulations that left farm and village lands abandoned. Attempts to read forest composition and dynamics only through the lens of ‘natural history’ and ‘climate change’ overlooks this history and the associated meaning for those who live there, and reduces the ability to manage these legacy forests.

PSPs and FIPs in the Afrotropics provide a research lens into both ‘forest ecology’ and past environmental change. This requires asking a wider range of questions of these plots, collaboratively researched using ecologically and socio-historically focused inquiry. To ask such questions, new forms of research are required, but combining different disciplines that use diverse lexicons, timeframes, epistemologies and methodologies is one of the biggest challenges of achieving interdisciplinary research (Lele and Kurian 2011). Interdisciplinary research programs must be developed with an integrated methodology combining data from archaeology and history (artefacts and texts), anthropology and political and historical ecology, with ecology to understand forest patterns. These initiatives require researchers to "share the conceptual world of their colleagues", beyond disciplinary boundaries (Darbellay 2015:167).

In achieving this, it is imperative to recognise that people shape forests. Thinking in terms of social-ecological and biocultural systems (c.f. Fischer 2018), can demonstrate society-environment interconnections, leading to discussions on how to study these impacts collaboratively. Robbins (2012) proposes that links between socio-political forces and ecological characteristics include type and direction of environmental change, drivers of change, the environment in which changes occur, the impact of cultural practices on the system (sensu Maraccuci 2000), and how it recovers. The final step can, as noted in the Liberia case, explicitly link historical forests to current forest usage and land claims.

In the case of PSPs, synthesising existing historical and archaeological research for each plot and linking to specific periods, can show how present-day forest structure and diversity are linked to disturbances (Fairhead, unpublished data). When studying impacts through FIPs, documenting the species most susceptible to disturbance, as in the Gabon case, is a first step. The places where these signals are strongest (e.g. mono-dominant forests), can then be explored. By providing a view on how ecological patterns and processes have reacted in the past to environmental changes, historical ecology can inform how forest structure and process may respond to future change (Safford *et al.* 2012).

Such collaborations will also inform forest management still rooted in equilibria paradigms despite historical evidence (Morin-Rivat *et al.* 2017). Some forest managers are aware that the management of some species is not sustainable because the stock is a legacy of past human perturbations (Morin-Rivat et al. 2016). However, a historical perspective on the current structure of commercial species would offer a stronger basis for sustainable management. In both case-studies, forest history and species responses are different, and each country has different sustainable forest management strategies. However, neither country's policies acknowledge the impact that history has on timber stocks, nor address if and how to maintain and manage these stocks. Furthermore, neither recognises forests as historical and cultural products of people living there today.

In this paper, we reviewed limitations of plot-based research in light of Afrotropical history, which heavily influenced the history of these forests, compared the usage of PSPs and FIPs, and provided cases demonstrating how interdisciplinary research collaborations can enrich plot-based studies. We propose future work focus on using plot networks to research new questions, in collaboration with historians and social scientists. The lack of historical perspectives on forests will limit addressing sustainability (Roberts *et al.* 2018, this issue). However, new collaborations will not only help deepen conclusions from forest ecology, but also influence study design and management options.

Interdisciplinary collaboration is one way to explore how the forests have been shaped during the Anthropocene. This new view suggests that some tree species require new forms of management and some forests deserve new recognition as cultural landscapes.

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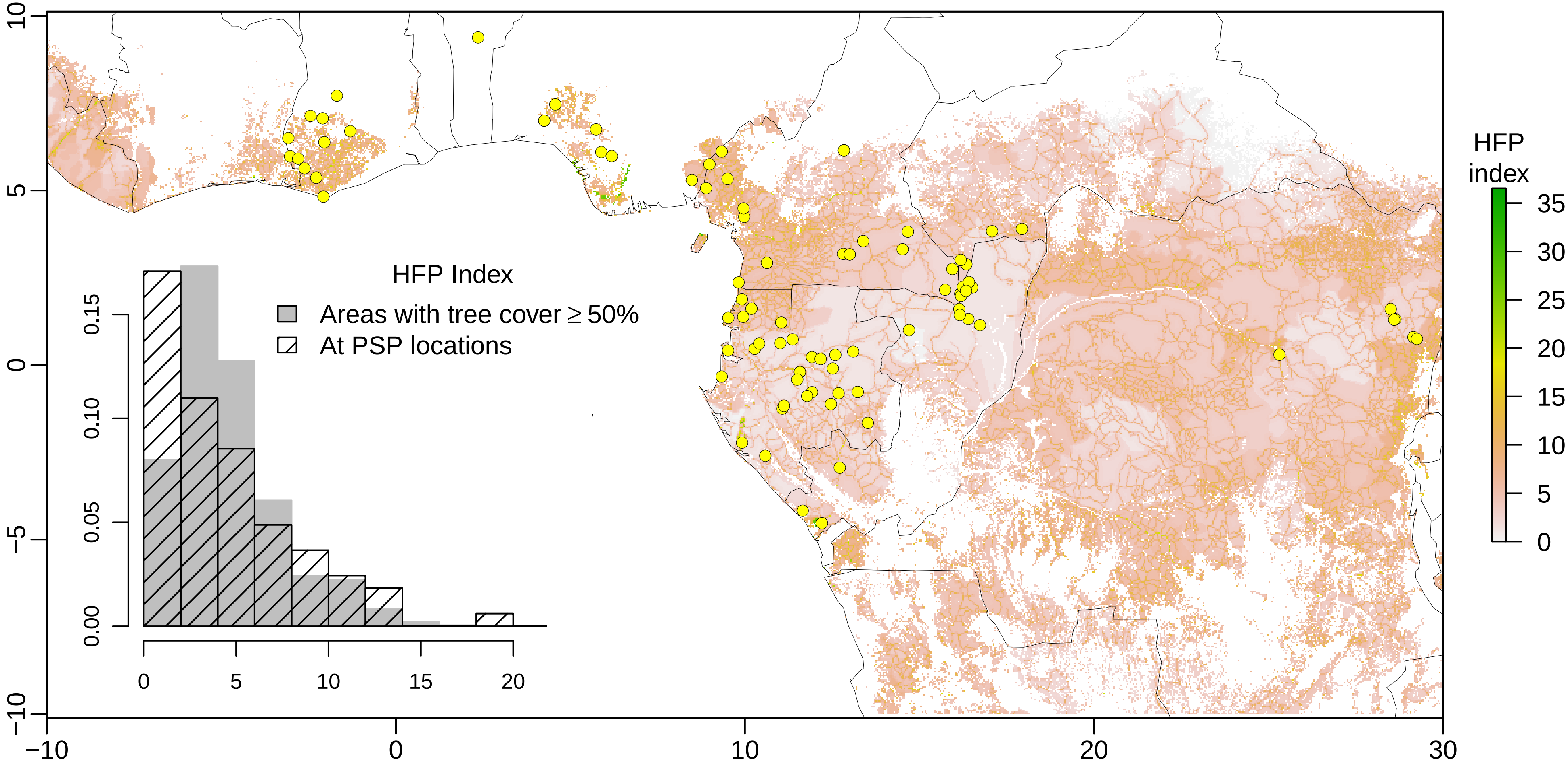
Figure 1



HFP index
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HFP Index
Areas with tree cover ≥ 50%
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Figure 2
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