Ecological Indicators 48 (2014) 440–447

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Development of a Flooded Forest Anthropization Index (FFAI) applied to Amazonian areas under pressure from different human activities

José Leonardo Lima Magalhães [a,*], Maria Aparecida Lopes [b], Helder Lima de Queiroz [a]

[a] Instituto de Desenvolvimento Sustentável Mamirauá, Estrada do Bexiga, n° 2.584, Bairro: Fonte Boa, Tefé, 69550-000 AM, Brazil
[b] Universidade Federal do Pará, Instituto de Ciências Biológicas, Rua Augusto Corrêa, n° 01, Bairro: Guamá, Belém, 66075-110 PA, Brazil

ARTICLE INFO

Article history:
Received 21 January 2014
Received in revised form 2 July 2014
Accepted 1 September 2014

Keywords:
Environment monitoring
Disturbance indicators
Biodiversity loss
Land use
Human disturbance

ABSTRACT

The floodplain forests in the Amazon basin suffer from the continued exploitation of natural resources and, after being disturbed, show slow and sometimes irreversible recovery. Our goal was to create an index that could be used to assess the relative level of human disturbance in floodplain forests and determine the relative importance of different types of disturbance on a given site and between sites. The index proposed here (Flooded Forest Anthropization Index – FFAI) assesses human disturbance on a local scale and is composed by 15 indicators divided into three groups that represent different levels of impact: (1) simplification of ecosystems and reduction of local diversity; (2) ecosystem replacement/destruction; (3) disturbances with the potential to impact the ecosystem in both ways. The FFAI proved to be robust and revealed a wide range of values in the evaluated landscapes. The sites classified *a priori* as more anthropogenic showed significantly higher FFAI values than the less anthropogenic ones (0.14 ± 0.05 and 0.08 ± 0.02, respectively, $F = 18.9$, $df = 19$, $p < 0.0001$). The FFAI enabled a comprehensive assessment of human disturbance on a local scale in Amazonian floodplain forests and can be a useful tool for decision makers in choosing priority areas for interventions and for targeting the type of intervention that must be carried out. Although specific to floodplains, the index can be adjusted to be used in other ecosystems.
© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Historically, forests in Amazonia have suffered disorderly occupation and, although once abundant, the natural resources are currently vulnerable to continued exploitation in areas close to large urban centers and to its expansion into previously undisturbed areas (Barreto et al., 2006; Laurance et al., 2012). In Brazilian Amazonia, floodplain forests, which are very dynamic ecosystems, are particularly vulnerable to anthropogenic environmental impact, as only 1% of their area is under direct protection (MMA, 2007). Furthermore, human actions affect the balance of these ecosystems which, having once been exploited, show slow and sometimes irreversible recovery (Fortini et al., 2006; Schöngart, 2008). Therefore, identifying and quantifying human disturbance (anthropization) is critical for the development of better strategies for the conservation of floodplain forests.

The Amazon basin is the largest river basin in the world and about 800,000 km^2 of its area is occupied by floodplains, two thirds of which are in Brazil (Hess et al., 2003; Melack and Hess, 2010). The two main types of floodplains are (1) *várzeas*, covering about 400,000 km^2, of relatively recent origin (Holocene), flooded by white water rivers originating in the Andes and rich in sediments (Ferreira and Stohlgren, 1999; Junk et al., 2011), and (2) *igapós*, covering about 100,000 km^2, flooded by black water rivers and associated to the Tertiary and Precambrian periods (Montero et al., 2012).

These ecosystems have been influenced by human actions since the arrival of man in the region over 10–12 thousand years ago, through activities such as hunting and plant gathering (Lu et al., 2010; Nilsson and Fearnside, 2011; Paula et al., 2005; Peres, 2000). However, human impact intensified with European colonization, due to the rubber and jute culture cycles and, more recently, livestock expansion (Albernaz et al., 2012; Fortini and Zarin, 2011; Merry et al., 2004; Zarin et al., 2001). The ease of access and proximity to the river itself lead to many direct and indirect impacts through deforestation, pollution of rivers, mining and the construction of hydroelectric dams (Barreto et al., 2006; Ferreira et al., 2013; Moran and Building, 1993; Scabin et al., 2012). These

* Corresponding author. +55 91 9265 9003.
E-mail addresses: jleobio@gmail.com (J.L.L. Magalhães), maria@ufpa.br (M.A. Lopes), helder@mamiraua.org.br (H.L.d. Queiroz).

http://dx.doi.org/10.1016/j.ecolind.2014.09.002
1470-160X/© 2014 Elsevier Ltd. All rights reserved.

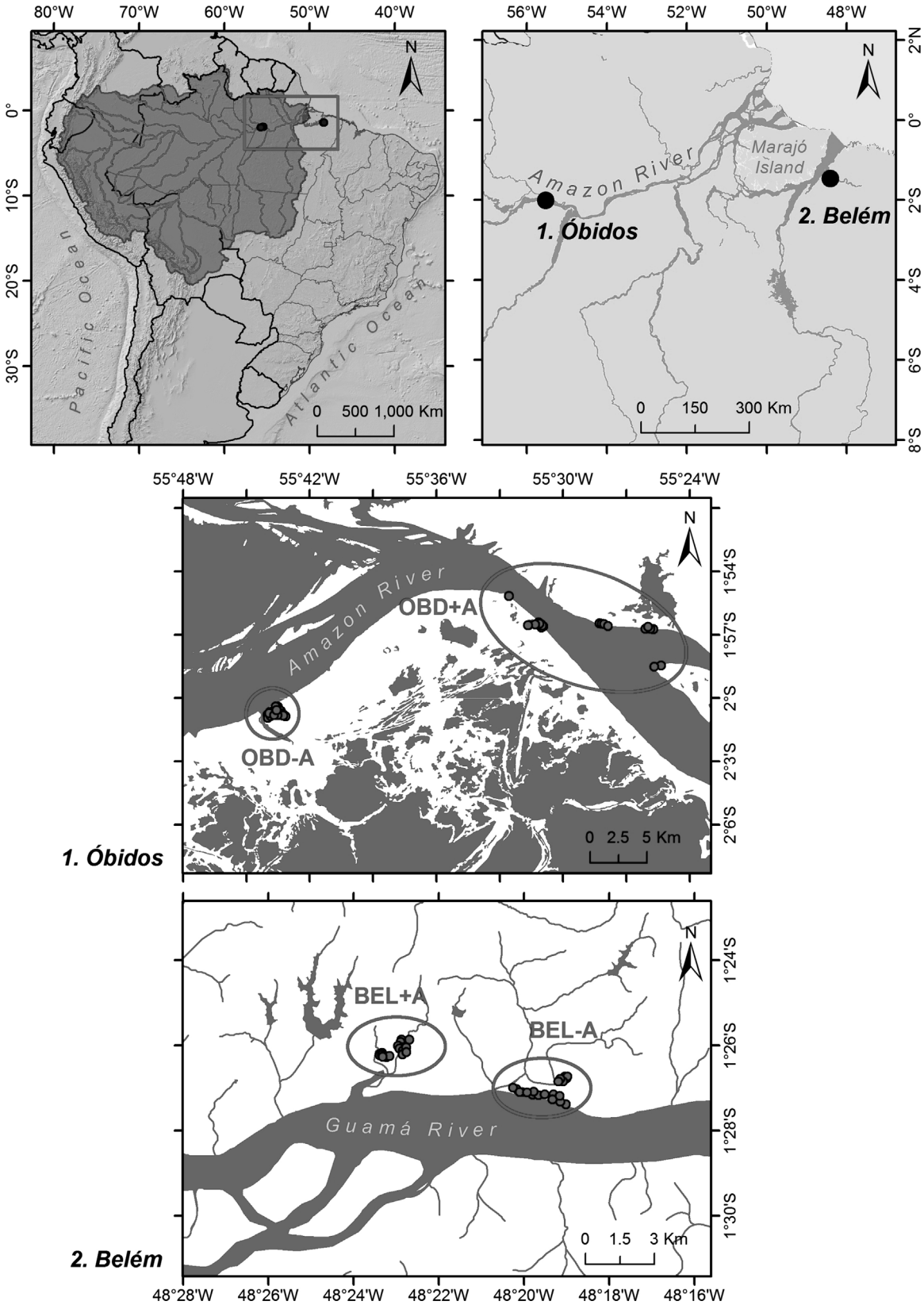

Fig. 1. Map showing the location of the plots where the Flooded Forest Anthropization Index (FFAI) was applied to the landscapes in two localities: (1) Óbidos (OBD) and (2) Belém (BEL), in more anthropic (+A) and less anthropic (−A) sites.

activities, in addition to their destructive and irreversible influence in the short term, have increased with human population growth, causing further pressure, since many settlements live in floodplain forests or in adjacent *terra firme* areas (Almeida et al., 2004; Coomes et al., 2009; Zarin et al., 2001).

It is important to understand the current state of floodplain ecosystems and monitor their change over time in order to define strategies for conservation and sustainable management (Barlow et al., 2012; Laurance et al., 2012; Vatn and Vedeld, 2012). A common protocol for assessing the level of impact would help to determine the areas under more or less impact, which may assist in identifying priority areas for public and/or private intervention. However, the challenges are great: the Amazon biome has continental dimensions, the extent of its floodplain forests is huge, and the flood regime limits studies *in loco* for most of the year (Melack and Hess, 2010). It is also very difficult to choose indicators that appropriately reflect the level of impact of human actions on the environment and on the natural community, as well as to integrate them with the different occupancy histories, types and intensity of different uses. In addition, the indicators should have relatively easy access in order to be measured and evaluated in a shortage of time and resources, as always occurs in environmental impact assessment initiatives, and should be easy to understand and to be applied by laymen, i.e., the direct participation of scientists or highly qualified experts should not be necessary.

The index (Flooded Forest Anthropization Index – FFAI) proposed herein assesses the level and types of human disturbance on a local scale. Our goal was to create an index that could be used to: (1) assess the relative level of human disturbance in floodplain forests by comparing the index applied to different sites; and (2) determine the relative importance of different types of disturbance at a given site and between sites. For this, we tried to choose indicators that could represent all types of human activities in Amazonia that might impact the natural communities of flooded forests. Moreover, to determine which human actions were the most influential at each location is also essential to address mitigation and/or compensatory impact measures. Areas identified as priorities for public intervention could then be evaluated in more detail and monitored with the same field protocol, and the evolution of both the impact and the consequences of any interventions examined with the FFAI.

2. Material and methods

2.1. Study Areas

The landscapes chosen to test the new index, herein named Óbidos (OBD) and Belém (BEL) (Fig. 1), are *várzea* forests and have different flood regimes. The floodplains of the lower Amazon, where BEL is located, are influenced by oceanic flow that gradually decreases as one moves away from the river mouth, and are called tidal *várzeas* (Almeida et al., 2004; Lima and Tourinho, 1996; Zarin et al., 2001). At these sites, the flooding, which is amplified during the rainy season, occurs daily during high tides. At the equinox (March and September) adjacent forests at higher topographic levels are also flooded. In the middle Amazon River, where OBD is located, and in the upper Amazon, there is no influence of the tide, and the flood regime is linked mainly to river flooding. These are called seasonal *várzeas* and floods reach their maximum level in the rainiest months (Ayres, 1995; Wittmann et al., 2004, 2002).

Human occupation in these landscapes began with the presence of large indigenous populations near the studied areas (Nilsson and Fearnside, 2011; Schaan, 2010). Archaeological records indicate that these populations had already transformed the landscape over at least five thousand years; management of fish and other water resources, and clearings for housing and agriculture, mainly of cassava at a small scale, are inherited habits and have been kept by their descendants to this day in almost all regions along the Amazonian rivers (Lu et al., 2010; Schaan, 2010). In central Amazonia, near Óbidos, jute culture (*Corchorus capsularis*) followed by cattle and water buffalo ranching were the main economic activities in the late 19th century and early 20th century (Sheikh et al., 2006; Winklerprins, 2006). In the lower Amazon, the European colonization process was older, and close to

Table 1
The first applied field protocol to test the FFAI contained 53 indicators measured within the plots and in their neighborhood.

Within the plots	In the neighborhood
1. Number of cut trees	27. Distance between the plot and the closest human settlement
2. Anthropic clearings: number and sizes	28. Number of households in the closest settlement
3. Presence of walking trails	29. Age of the closest settlement
4. Number of hunting gears including traditional gear and traps	30. Water bodies between the plot and the closest settlement: presence, number and size
5. Number of hearing gun-shots during sampling	31. Size of the water bodies between the plot and the closest settlement
6. Number of domestic dogs met during sampling	32. Distance between the plot and the second closest human settlement
7. Number of hunters met during sampling	33. Number of households in the second closest settlement
8. Exotic fruiting species: number of species and individuals	34. Age of the second closest settlement
9. Pioneer trees: number of species and individuals	35. Water bodies between the plot and the second closest settlement: presence, number and size
10. Poutry: species and number of individuals	36. Occurrence of timber exploitation
11. Suines: evidence, number of individuals	37. Urbanization (paved roads, constructions, sewage, etc.)
12. Goats: evidence, number of individuals	38. Abandoned mines
13. Cattle: evidence (footprints, faeces, etc.), number of individuals	39. Evidence of old forest fires
14. Buffalo: evidence (footprints, faeces, etc.), number of individuals	40. Evidence of recent forest fire
15. Horses: evidence (footprints, faeces, etc.), number of individuals	41. Active manual mines
16. Number of fires	42. Active industrial mines
17. Organic garbage/debris	43. Presence of mixed gardens (agroforestry systems and/or silviculture)
18. Inorganic garbage	44. Domestic or family gardens
19. No land tenure known	45. Abandoned gardens
20. Abandoned area	46. Monospecific plantations: occurrence, number and size
21. Federal protected area	47. Abandoned plantations: occurrence, number and size
22. State protected area	48. Pastures: occurrence, number and size
23. Other sort of protected area	49. Abandoned pastures: occurrence, number and size
24. Family tenure of the land	50. Occurrence of poltry breeders
25. Communal tenure of the land	51. Occurrence of suine breeders
26. Private area (company or single owner/developer)	52. Occurrence of goat breeders
	53. Presence of corrals and intensive cattle ranching

Table 2
Groups, indicators and grading used to calculate the Flooded Forest Anthropization Index (FFAI).

Indicators	Gradation
Group 1– simplification of ecosystems and reduction of natural diversity (weight 1)	
1. Exploitation of non-timber products	
No trace	0
Exudates extraction (oil, latex, etc.)	1
Extraction of vegetable fiber, straw or fruits	2
Extraction of heart of palm	3
Extraction of two non-timber items	4
Extraction of three non-timber items	5
Extraction of more than three non-timber items	6
2. Hunting (traps, hunting trails, shots during sampling, hunters in the plot, hunting devices and hunting trails)	
No trace	0
1–3 hunting traces	1
4–6 hunting traces	2
Group 2–indicators of disturbances that lead to replacement/destruction of the ecosystem (weight 1.5)	
3. Livestock (small and medium sized animals: poultry–chicken and ducks, pigs and goats/sheep) ranging free or in small breeders (one to a dozen)	
No trace	0
1 free animal or small breeder	1
2–4 free animals or small breeders	2
5–7 free animals or small breeders	3
9–11 free animals or small breeders	4
12 free animals or small breeders	5
4. Livestock (small and medium sized animals–poultry–chicken and ducks, pigs and goats/sheep) ranging free or living in medium and/or large breeders with more than a dozen animals	
No trace	0
13 free animals or small breeders	1
14–16 free animals or small breeders	2
17–19 free animals or small breeders	3
20–22 free animals or small breeders	4
23 or more free animals or small breeders	5
5. Forest logging – ratio of the number of cut trees to standing trees (DBH> 10 cm) x 100 (%)	
0	0
>0–1	1
>1–2	2
>2–4	3
>4–8	4
>8–16	5
>16–32	6
>32–64	7
>64	8
6. Agriculture (small plantations) – areas with less than or equal to 0.1 hectare	
No trace	0
Small gardens $\leq$ 0.001 ha	1
0.001 < Small gardens $\leq$ 0.01 ha	2
0.01 < Small gardens $\leq$ 0.03 ha	3
0.03 < Small gardens $\leq$ 0.05 ha	4
0.05 < Small gardens $\leq$ 0.08 ha	5
0.08 < small gardens $\leq$ 0.1 ha	6
7. Agriculture (large plantations) – areas larger than 0.1 ha	
No trace	0
0.1 < larger plantations $\leq$ 0.3 ha	1
0.3 < larger plantations $\leq$ 0.5 ha	2
0.5 < larger plantations $\leq$ 0.8 ha	3
0.8 < larger plantations $\leq$ 1 ha	4
Larger plantations > 1 ha	5
8. Livestock (large sized animals bigger than sheep or goat, such as horses, cattle and buffalo) ranging free in small herds (up to 20 animals)	
No trace	0
1–2 animals of any of the above species	1
2–3 horses or 3–4 cattle	2
5–8 cattle or 1–4 buffalo	3
9–16 animals of one species or two species present	4
More than 17 animals of one species, or more than two species present	5
9. Livestock (large sized animals bigger than sheep or goat, such as horses, cattle and buffalo) – corrals and pastures)	
No trace	0
Abandoned pastures or corrals (includes bare soil)	1
Abandoned pastures and corrals (includes bare soil)	2
Corrals or pastures in use (intensive or extensive farming)	3
Corrals or pastures in use (intensive or extensive farming) and abandoned pastures or corrals (includes bare soil)	4
Corrals or pastures in use (intensive or extensive farming) and abandoned pastures and corrals (includes bare soil)	5

Table 2 (*Continued*)

Indicators	Gradation
Corrals and pastures in use (intensive or extensive farming) and abandoned pastures and corrals (includes bare soil)	6
10. Human settlement (tracks of human displacement, waste and exotic species)	
No trace	0
Traces of organic/inorganic waste	1
Displacement tracks	2
Traces of organic/inorganic waste and displacement tracks	3
Presence of exotic species (fruit, timber, ornamental etc.)	4
Traces of organic/inorganic waste or displacement tracks and the presence of exotic species	5
Traces of organic/inorganic waste and displacement and the presence of exotic species	6
11. Human settlement (dwellings- single houses, villages – and other human buildings – fences, backyard, hovel)	
No trace	0
Traces of human buildings	1
Traces of abandoned dwellings	2
Traces of simple dwellings	3
Traces of two types of dwellings and other human buildings	4
Traces of three types of dwellings and other human buildings	5
12. General – size of anthropic clearings	
No anthropic clearings	0
Clearings $\leq 100\,m^2$	1
$100 <$ Clearings $\leq 300\,m^2$	2
$300 <$ Clearings $\leq 600\,m^2$	3
$600 <$ Clearings $\leq 200\,m^2$	4
$1200 <$ Clearings $\leq 2400\,m^2$	5
Clearings $> 2400\,m^2$	6
13. General – number of anthropic clearings	
No anthropic clearings	0
1–2 clearings	1
3–4 clearings	2
5–8 clearings	3
9–16 clearings	4
>16 clearings	5
Group 3 – indicators of disturbances with the potential to impact the ecosystem in both ways (weight 2)	
14. General – Fire – small fires or controlled fire	
No trace	0
1–2 small fires or evidence of old controlled fire in less than 10% of the plot area	1
3–4 small fires or evidence of old controlled fire in 10–15% of the plot area	2
5–8 small fires or evidence of old controlled fire in 15–20% of the plot area	3
9–16 small fires or evidence of old controlled fire in 20–50% of the plot area	4
>16 small fires or evidence of old controlled fire in more than 50% of the plot area	5
Traces of fire (recent small fires, recent controlled fires), recent forest fires, burned brush, and exposed soil linked to recent fire activity	6
15. General – mining/panning/use of mineral resources	
No trace	0
Traces of past exploitation of disaggregated soil/sub-soil elements (includes bare soil)	1
Abandoned mines (presence of mixed soil, bodies of silted water)	2
Current extraction of disaggregated soil/sub-soil elements (sand, clay, pebbles, gravel, etc.)	3
Active mines (manual activity, use of pans etc.)	4
Industrial mining activity	5
Active mines (activity of dredgers and barges, high pressure water pumps, traces of mercury use, etc.)	6
Activity of hydrocarbon exploitation	7

Belém, capital of Pará state, the extraction of *açaí* (*Euterpe oleracea*) and selective logging are the main economic and transformational forest activities that still remain, but play a secondary role in the local economy (Almeida et al., 2004; MunizMiret et al., 1996; Schaan, 2010).

2.2. Development and testing of the Flooded Forest Anthropization Index (FFAI)

The FFAI was built from a field protocol initially containing 53 indicators of human disturbance, including 26 measured within sampling plots and 27 measured in their neighborhood (Table 1). The indicators were defined based on the field experience of the authors and through consultation of the scientific literature on the uses of floodplain forests in the Amazon biome (Asner et al., 2005; Cochrane and Schulze, 1999; Funi and Paese, 2012; Merry et al., 2004; Scabin et al., 2011; Sheikh et al., 2006; Winklerprins, 2006).

We tested the initial protocol in October 2010 in the region of the middle Amazon River (municipalities of Santarém and Alenquer). After examining the results, we excluded the indicators that generated poor evaluation *in loco* and were more suitable to be measured by remote sensing techniques. We merged similar indicators and finally included a new one related with the exploitation of non-timber forest products, that was missing in the first round of indicators proposed. At the end of this revision, there were 15 remaining indicators (Table 2).

Based on concepts of conservation ecology (Didham et al., 2007; O'Dwyer and Green, 2010; Russo, 2008; Willis et al., 2004), the 15 remained indicators were arranged into three groups representing different levels of impact that received different weights in

the FFAI (Table 2): Group (1) indicators of disturbances that imply the simplification of ecosystems and the decrease of local diversity, such as the extraction of non-timber products and hunting (weight 1, 2 indicators); Group (2) indicators of disturbances that lead to the replacement/destruction of the ecosystem, such as animal rearing, logging, plantations, and other elements of human settlements (weight 1.5, 11 indicators); and Group (3) indicators of disturbances with potential to impact the ecosystem in both ways, first promoting the loss of diversity and then the replacement of ecosystems in the long term. They include burning and mining activities (weight 2, 2 indicators).

To reach a partial score, each indicator received gradations with scores ranging from 0 (zero), for no observed impact, until a maximum impact for that indicator. Since the number of gradations and its possible maximum values can vary between indicators, the values were standardized by dividing the observed scaling value (g_o) by the maximum value of each indicator (g_m). The standardized value of each indicator was then multiplied by the weight corresponding to the group of indicators to which it belongs (p), resulting in the final value of each indicator. The FFAI is equal to the sum of indicators divided by the sum of the weights of all indicators which is 22.5 (P, Eq. (1)), so the FFAI ranges from 0 (zero) in areas without human impact to 1 for fully impacted areas.

$$\mathrm{FAAI} = \sum_{i}^{n} \left(\frac{g_o}{g_m}\right) \times \frac{p_i}{P} \quad (1)$$

where g_o is the observed gradation of the indicator i,g_m is the maximum gradation of the indicator I, p is the weight of indicator i and P is the sum of the weights of all indicators.

In the application of the index, it is important to bear in mind that different types of disturbance could overlap at a single plot, for instance, when a number of trees are cut and form a clearing that is set on fire afterwards. One should count the number of cut trees, measure the size of the clearing and record the use of controlled fire. All these indicators provide information on disturbances that are complementary, and non-exclusive.

2.3. Data collection

Data collection in Belém occurred between December 2010 and January 2011 and in Óbidos in October 2011. Based on information from local residents in each study area, we selected two sites of floodplain forest, one in a relatively preserved and apparently undisturbed area (less anthropic) and another in an area known to be exploited and clearly disturbed (more anthropic). For the application of the anthropization protocol at each site, we systematically established 20 sampling plots of 75 m × 75 m along the main river channel, at least a hundred meters apart from each other. Half the plots were established in places of less flooding (high *várzea* – HV) and the other half in places of more flooding (low *várzea* – LV), in order to represent the variation in the level of local flooding. Aside these systematic procedures the location of any particular plot was chosen at random, and plot size was kept in the minimum needed to reach reliable measures of all indicators included in the protocol. Two observers travelled each plot systematically, collecting protocol information only inside each plot. No local population reports were used.

2.4. Data analysis

To assess the efficiency of the index in the separation of areas and sites with different degrees of human disturbance, we used an analysis of variance (ANOVA) with a factor of $p \leq 0.05$ and the Tukey test (Legendre and Legendre, 1998). We used a principal component analysis (PCA) to identify which types of human activities impact each area (locality) the most; in this last test, we used Euclidean distance as a measure of dissimilarity between sites (Krebs, 1999). The statistical programs PAST 1.4 (Hammer et al., 2001) and BioEstat 5.2 (Ayres et al., 2007) were used.

Additionally, we have developed an application with the FFAI so that interested parties, including researchers, students, decision makers from public agencies or private institutions, can use the index in an easy and interactive way. The FFAI is hosted on the site of the Institute of Development Mamirauá and can be downloaded for free (http://www.mamiraua.org.br/iafi).

3. Results

The FFAI had a wide range of observed values, from 0.02 to 0.27, with a mean of 0.11 ± 0.05. In general, the sites classified *a priori* as more anthropic showed significantly higher values than the less anthropic ones (0.14 ± 0.05 and 0.08 ± 0.02, respectively; $F = 18.9$, $df = 19$; $p < 0.0001$) (Fig. 2).

Although Belém and Óbidos have similar levels of human disturbance, according to the FFAI, the disturbances are associated with different types of human activities (Fig. 3). While in Belém disturbance is associated with agriculture on small farms, in Óbidos cattle rearing in small and large farms predominates. PCA axes clearly separated site locations in component 1 and more and less anthropic sites in component 2, and explained, respectively, 48.7% and 19.6% of the variance.

4. Discussion

Amazonia has been altered by human activities for a long time and pressures on the forest will probably increase in the future, considering the growing human population and the official plans to carry out infrastructure projects to develop the region. The extension of the Amazonian floodplain forests coupled with their highly dynamic nature leads to poorly documented variation in the natural communities (Parolin et al., 2004). Due to our lack of knowledge about assembling rules, and structure and composition patterns of those communities, it is difficult to separate the effects of natural factors, including geographical distance from that of human disturbances (Fortini et al., 2006; Wittmann et al., 2006)

In this context, the characterization of human pressures is fundamental to understanding how human activities affect the flooded forest structure and functioning and, therefore, it is a basic tool to conservation planning. With the FFAI, we can evaluate the

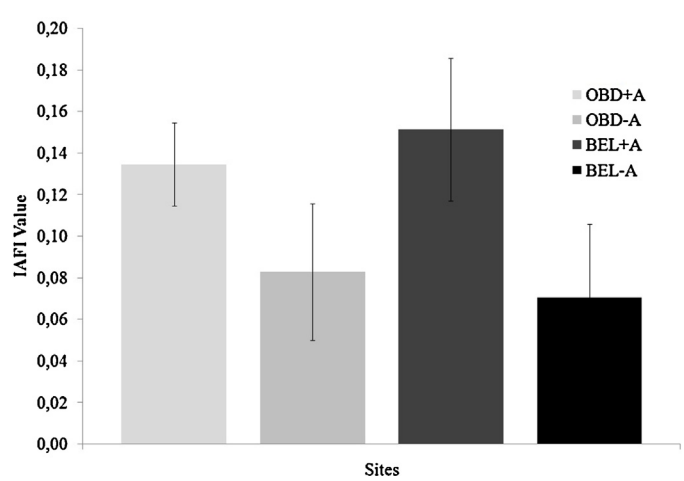

Fig. 2. Histogram showing the mean and confidence intervals of the index values of the Flooded Forest Anthropization Index (FFAI) for Belém (BEL) and Óbidos (OBD) with the more anthropic (A+) and less anthropic (A−) sites.

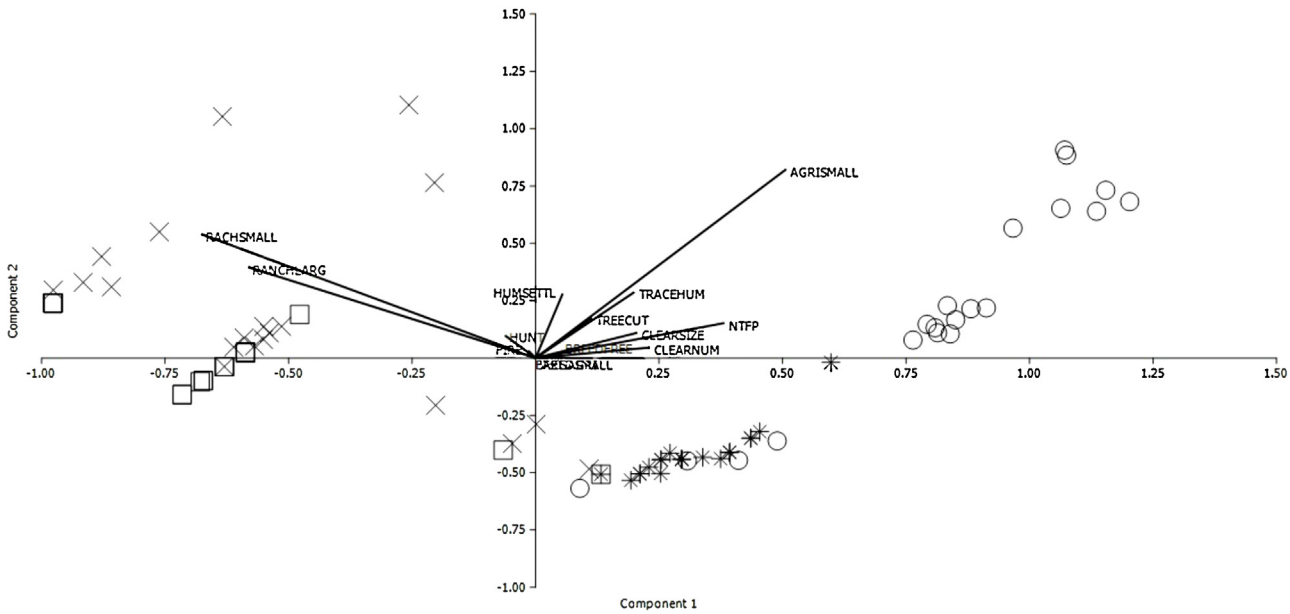

Fig. 3. Principal components analysis (bi-plot) of the scores produced by the indicators for each plot ($n = 80$). Symbols represents plots of each area: ○ = Belém, more antropic; * = Belém, less anthropic; × = Óbidos, more anthropic, □ = Óbidos, less anthropic; and lines represents FFAI indicators: NTFP = non-timber forest products; HUNT = hunting and gear; BREEDFREE = breeding small animals – free and small breeders; BREEDSMALL = breeding small animals – medium to large breeders; TREECUT = number of trees cut; AGRISMALL = small plantations; LARGAGRI = large plantations; RANCHSMALL = rearing of large animals – small properties; RANCHLARG = rearing of large animals – large properties; TRACEHUM = human settlements – tracks and waste; HUMSETTL = human settlements – dwellings and other buildings; CLEARSIZE = size of anthropic clearings; CLEARNUM = number of anthropic clearings; and FIRE = general – fire; MIN = general – mining.

effects of different intensities of human disturbance and identify the types of human activities that have the highest impact on each area. The index can be used as an additional variable to be considered in studies of floodplain forests.

The FFAI proved to be efficient to measure the intensity of disturbance in floodplain forests. In this sense, the FFAI is a valuable tool since it enables the comparison between areas, discriminating sites as more or less disturbed in relation to each other. It also lists the types of anthropogenic disturbances that impacts at each site and, moreover, points out the relative importance of each type of disturbance in that particular area. In doing so, it also allows qualitative comparison between sites, or between different moments along the history of a particular site.

Each locality in the Amazonia has its own occupation history associated to different types and intensities of human disturbances that lead to diverging landscapes. This has been shown by the way in which the indicators separated Óbidos and Belém in the PCA (Fig. 3), even the less disturbed sites. While disturbances in Óbidos are more related to cattle farming, in Belém, human actions are more related to the use of the forest for subsistence of riverine populations, mainly through the use of non-timber forest products and timber extraction on a small scale.

Quantitative and qualitative assessment of human disturbance in each area can be a useful tool for decision makers who can choose priority areas for intervention, and the best type of intervention to be carried out. By identifying the causes of greatest impact in the area or region and by facilitating the identification by decision makers of the causes of environmental impact, the FFAI can be considered a robust index (Falcone et al., 2010).

In addition to its power to reveal the anthropization status of each site and to establish a comparison of this status among sites, the FFAI can be used as an environmental metric – an anthropic metric as opposed to natural explanatory variables. To evaluate the relative effect of human disturbances on ecosystems variability vs. natural factors, attributes of these systems need to be measured at the same scale as the FFAI. Thus, used in conjunction to ecosystem and/or community metrics it becomes a monitoring tool.

The FFAI was created to be applied to floodplain forests, since the chosen indicators were compiled using the authors experience in studying these ecosystems, and the literature consulted was also specific. In general, the FFAI can be applied quickly to diagnose the condition of human pressure to which a particular patch of floodplain forest is subjected, and the indicators should distinguish the specific causes of disruption in those areas. Although it is specific to floodplains, the application of FFAI can be expanded to other types of forested Amazonian ecosystems. However, its use in ecosystems other than that of floodplain forests demands a judicious assessment and, eventually, modifications and/or adaptations to specific conditions of the environment under review, even if there is a high probability that the human impacts caused are coincidental.

In short, the FFAI enables an assessment of human disturbance at a local scale in Amazonian flooded forests and can be a useful tool for decision makers in choosing priority areas for interventions and for targeting the type of intervention that must be carried out. At a local level, the FFAI is sensitive to different types of disturbance, including a broad spectrum of indicators. It gives different weights to human activities that only decrease the diversity, actions that replace ecosystems, and actions that have both of these effects. Moreover, it assesses the local strength of each type of human disturbance. The FFAI showed the expected performance when separating sites appointed *a priori* as less and more anthropic. Although specific to floodplains, the index can be adjusted to be used in other ecosystems. We hope to have a return from the scientific community so that we can further improve the version of the index presented here. Later, we intend to integrate the indicators of human disturbance at a local scale to indicators on a landscape scale. These indicators should enable the measurement of human actions on a landscape scale that may affect local natural communities where they cannot be detected by means of a local assessment.

Acknowledgements

This research was supported by CNPq/RedeGeoma (Process 550373/2010-1) and Mamirauá Institute (IDSM/MCTI). JLLM

receives a research grant from the DTI, GEOMA/MCTI of CNPq (Process 301992/2013-4). We thank the ICT staff of Mamirauá Institute for support in creating the application and the location maps. We also thank the helpful comments and suggestions provided by two anonymous reviewers.

References

Albernaz, A.L., Pressey, R.L., Costa, L.R.F., Moreira, M.P., Ramos, J.F., Franciscon, C.H., Assuncao, P.A., 2012. Tree species compositional change and conservation implications in the white-water flooded forests of the Brazilian Amazon. J. Biogeogr. 39, 869–883.

Almeida, S.S., Amaral, D.D., Silva, A.S.L., 2004. Análise florística e estrutura de florestas de Várzea no estuário amazônico. Acta Amaz. 34, 513–524.

Asner, G.P., Knapp, D.E., Broadbent, E.N., Oliveira, P.J.C., Keller, M., Silva, J.N., 2005. Selective logging in the Brazilian Amazon. Science 310 (80), 480–482.

J.M. Ayres, 1995. As matas de várzea do Mamirauá. Vol. 1 ed. CNPq, Sociedade Civil Mamirauá, Estudos de Mamirauá, Brasília.

Ayres, M., Ayres, Jr, M., Ayres, D.L., Santos, A., de A.S., dos, 2007. BioEstat. 5.0: aplicações estatísticas nas áreas das ciências biológicas e médicas, Sociedade Civil Mamirauá, Belém.

Barlow, J., Parry, L., Gardner, T.A., Ferreira, J., Aragão, L.E.O.C., Carmenta, R., Berenguer, E., Vieira, I.C.G., Souza, C., Cochrane, M.A., 2012. The critical importance of considering fire in REDD+ programs. Biol. Conserv. 154, 1–8.

Barreto, P., Souza Jr., C., Noguerón, R., Anderson, A., Salomão, R., Wiles, J., 2006. Human Pressure on the Brazilian Amazon Forests. World Resources Institute, Belém, Pará, Brasil.

Cochrane, M.A., Schulze, M.D., 1999. Fire as a recurrent event in Tropical forests of the Eastern Amazon: effects on forest structure, biomass, and species composition. Biotropica 31, 2–16.

Coomes, O.T., Abizaid, C., Lapointe, M., 2009. Human modification of a large meandering Amazonian river: genesis, ecological and economic consequences of the Masisea cutoff on the Central Ucayali, Peru. Ambio 38, 130–134.

Didham, R.K., Tylianakis, J.M., Gemmell, N.J., Rand, T.A., Ewers, R.M., 2007. Interactive effects of habitat modification and species invasion on native species decline. Trends Ecol. Evol. 22, 489–496.

Falcone, J.A., Carlisle, D.M., Weber, L.C., 2010. Quantifying human disturbance in watersheds: variable selection and performance of a GIS-based disturbance index for predicting the biological condition of perennial streams. Ecol. Indic. 10, 264–273.

Ferreira, L.V., Cunha, D.A., Chaves, P.P., Matos, D.C.L., Parolin, P., 2013. Impacts of hydroelectric dams on alluvial riparian plant communities in eastern Brazilian Amazonian. An. Acad. Bras. Cienc. 85, 241–251.

Ferreira, L.V., Stohlgren, T.J., 1999. Effects of river level fluctuation on plant species richness, diversity, and distribution in a floodplain forest in Central Amazonia. Oecologia 120, 582–587.

Fortini, L.B., Rabelo, F.G., Zarin, D.J., 2006. Mixed potential for sustainable forest use in the tidal floodplain of the Amazon River. For. Ecol. Manage. 231, 78–85.

Fortini, L.B.B., Zarin, D.J., 2011. Population dynamics and management of Amazon tidal floodplain forests: links to the past, present and future. For. Ecol. Manage. 261, 551–561.

Funi, C., Paese, A., 2012. Spatial and temporal patterns of deforestation in Rio Cajarí Extrative Reserve, Amapá, Brazil. PLoS One 7, 1–10.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol. Electron. 4, 1–9.

Hess, L.L., Melack, J.M., Novo, E.M.L.M., Barbosa, C.C.F., Gastil, M., 2003. Dual-season mapping of wetland inundation and vegetation for the central Amazon basin. Remote Sens. Environ. 87, 404–428.

Junk, W.J., Teresa, M., Piedade, F., Schöngart, J., Cohn-haft, M., Adeney, J.M., Wittmann, F., Piedade, M.T.F., 2011. A classification of major naturally-occurring Amazonian lowland wetlands. Wetlands 31, 623–640.

Krebs, C.J., 1999. Ecological Methodology, The Benjamin/Cummings Series in the Life Sciences. Benjamin/Cummings.

Laurance, W.F., Useche, D.C., Rendeiro, J., Kalka, M., Bradshaw, C.J., a Sloan, S.P., Laurance, S.G., Campbell, M., Abernethy, K., Alvarez, P., Arroyo-Rodriguez, V., Ashton, P., Benítez-Malvido, J., Blom, A., Bobo, K.S., Cannon, C.H., Cao, M., Carroll, R., Chapman, C., Coates, R., Cords, M., Danielsen, F., De Dijn, B., Dinerstein, E., Donnelly, M., a Edwards, D., Edwards, F., Farwig, N., Fashing, P., Forget, P.-M., Foster, M., Gale, G., Harris, D., Harrison, R., Hart, J., Karpanty, S., Kress, W.J., Krishnaswamy, J., Logsdon, W., Lovett, J., Magnusson, W., Maisels, F., Marshall, A. R., McClearn, D., Mudappa, D., Nielsen, M.R., Pearson, R., Pitman, N., van der Ploeg, J., Plumptre, A., Poulsen, J., Quesada, M., Rainey, H., Robinson, D., Roetgers, C., Rovero, F., Scatena, F., Schulze, C., Sheil, D., Struhsaker, T., Terborgh, J., Thomas, D., Timm, R., Urbina-Cardona, J.N., Vasudevan, K., Wright, S.J., Arias, G., Arroyo, J.C., Ashton, L., Auzel, M., Babaasa, P., Babweteera, D., Baker, F., Banki, P., Bass, O., Bila-Isia, M., Blake, I., Brockelman, S., Brokaw, W., Brühl, N., a, C., Bunyavejchewin, S., Chao, J.-T., Chave, J., Chellam, R., Clark, C.J., Clavijo, J., Congdon, R., Corlett, R., Dattaraja, H.S., Dave, C., Davies, G., Beisiegel, B.D.M., da Silva, R.D.N.P., Di Fiore, A., Diesmos, A., Dirzo, R., Doran-Sheehy, D., Eaton, M., Emmons, L., Estrada, A., Ewango, C., Fedigan, L., Feer, F., Fruth, B., Willis, J.G., Goodale, U., Goodman, S., Guix, J.C., Guthiga, P., Haber, W., Hamer, K., Herbinger, I., Hill, J., Huang, Z., Sun, I.F., Ickes, K., Itoh, A., Ivanauskas, N., Jackes, B., Janovec, J., Janzen, D., Jiangming, M., Jin, C., Jones, T., Justiniano, H., Kalko, E., Kasangaki, A., Killeen, T., King, H., Klop, E., Knott, C., Koné, I., Kudavidanage, E., Ribeiro, J.L.D. S., Lattke, J., Laval, R., Lawton, R., Leal, M., Leighton, M., Lentino, M., Leonel, C., Lindsell, J., Ling-Ling, L., Linsenmair, K.E., Losos, E., Lugo, A., Lwanga, J., Mack, A. L., Martins, M., McGraw, W.S., McNab, R., Montag, L., Thompson, J.M., Nabe-Nielsen, J., Nakagawa, M., Nepal, S., Norconk, M., Novotny, V., O'Donnell, S., Opiang, M., Ouboter, P., Parker, K., Parthasarathy, N., Pisciotta, K., Prawiradilaga, D., Pringle, C., Rajathurai, S., Reichard, U., Reinartz, G., Renton, K., Reynolds, G., Reynolds, V., Riley, E., Rödel, M.-O., Rothman, J., Round, P., Sakai, S., Sanaiotti, T., Savini, T., Schaab, G., Seidensticker, J., Siaka, A., Silman, M.R., Smith, T.B., de Almeida, S.S., Sodhi, N., Stanford, C., Stewart, K., Stokes, E., Stoner, K.E., Sukumar, R., Surbeck, M., Tobler, M., Tscharntke, T., Turkalo, A., Umapathy, G., van Weerd, M., Rivera, J.V., Venkataraman, M., Venn, L., Verea, C., de Castilho, C.V., Waltert, M., Wang, B., Watts, D., Weber, W., West, P., Whitacre, D., Whitney, K., Wilkie, D., Williams, S., Wright, D.D., Wright, P., Xiankai, L., Yonzon, P., Zamzani, F., 2012. Averting biodiversity collapse in tropical forest protected areas. Nature 489, 290–294.

Legendre, P., Legendre, L.F.J., 1998. Numerical Ecology, Developments in Environmental Modelling. Elsevier Science.

Lima, R.R., Tourinho, M.M., 1996. Várzeas do rio Pará: principais características e possibilidades agropecuárias. FCAP, Serviço de Documentação e Informação, Belém 124.

Lu, F., Gray, C., Bilsborrow, R.E., Mena, C.F., Erlien, C.M., Bremner, J., Barbieri, A., Walsh, S.J., 2010. Contrasting colonist and indigenous impacts on amazonian forests. Conserv. Biol. 24, 881–885.

Melack, J.M., Hess, L.L., 2010. Remote sensing of the distribution and extent of wetlands in the Amazon basin. In: Junk, W.J., Piedade, M.T.F., Wittmann, F., Schongart, J., Parolin, P. (Eds.), Amazonian Floodplain Forests: Ecophysiology, Biodiversity and Sustainable Management. Springer, Netherlands, pp. 43–59.

Merry, F.D., Sheikh, P.A., McGrath, D.G., 2004. The role of informal contracts in the growth of small cattle herds on the floodplains of the Lower Amazon. Agric. Human Values 21, 377–386.

MMA, 2007. Áreas prioritárias para conservação, uso sustentável e repartição de benefícios da biodiversidade brasileira: atualização. Secretaria de Biodiversidade e Florestas, Ministério do Meio Ambiente (MMA), Brasilia, Brazil.

Montero, J.C., Piedade, M.T.F., Wittmann, F., 2012. Floristic variation across 600 km of inundation forests (Igapó) along the Negro River, Central Amazonia. Hydrobiologia .

Moran, E., Building, S., 1993. Deforestation and land use in the Brazilian Amazon. Hum. Ecol. 21.

MunizMiret, N., Vamos, R., Hiraoka, M., Montagnini, F., Mendelsohn, R.O., 1996. The economic value of managing the acai palm (*Euterpe oleracea* Mart) in the floodplains of the Amazon estuary, Para, Brazil. For. Ecol. Manage. 87.

Nilsson, M.S.T., Fearnside, P.M., 2011. Yanomami mobility and its effects on the forest landscape. Hum. Ecol. 39, 235–256.

O'Dwyer, J.P., Green, J.L., 2010. Field theory for biogeography: a spatially explicit model for predicting patterns of biodiversity. Ecol. Lett. 13, 87–95.

Parolin, P., Ferreira, L.V., Albernaz, A.L.K.M., Almeida, S.S., 2004. Tree species distribution in Várzea forests of Brazilian Amazonia. Folia Geobot. 39, 371–383.

Paula, M., Vargas, B., Andel, T., Van Vargas, M.P.B., Van Andel, T., 2005. The use of hemiepiphytes as craft fibres by indigenous communities in the Colombian Amazon. Ethnobot. Res. Appl. 3, 243–260.

Peres, C.A., 2000. Effects of subsistence hunting on vertebrate community structure in Amazonian forests. Conserv. Biol. 14, 240–253.

Russo, R.E., 2008. Wetlands: Ecology, Conservation and Restoration. Nova Science Publishers, Inc-New York.

Scabin, A.B., Costa, F.R.C., Schöngart, J., 2011. The spatial distribution of illegal logging in the Anavilhanas archipelago (Central Amazonia) and logging impacts on species. Environ. Conserv. 39, 111–121.

Scabin, A.B., Costa, F.R.C., Schöngart, J., 2012. The spatial distribution of illegal logging in the Anavilhanas archipelago (Central Amazonia) and logging impacts on species. Environ. Conserv. 39, 111–121.

Schaan, D., 2010. Long-term human induced impacts on Marajó Island Landscapes, Amazon Estuary. Diversity 2, 182–206.

Schöngart, J., 2008. Growth-oriented logging (GOL): a new concept towards sustainable forest management in Central Amazonian Várzea floodplains. For. Ecol. Manage. 256, 46–58.

Sheikh, P.A., Merry, F.D., McGrath, D.G., 2006. Water buffalo and cattle ranching in the Lower Amazon Basin: comparisons and conflicts. Agric. Syst. 87, 313–330.

Vatn, A., Vedeld, P.O., 2012. National governance structures for REDD+. Glob. Environ. Change 23, 422–432.

Willis, K.J., Gillson, L., Brncic, T.M., 2004. Ecology. How virgin is virgin rainforest? Science 304 (80), 402–403.

Winklerprins, A.M.G.A., 2006. Jute cultivation in the Lower Amazon, 1940–1990: an ethnographic account from Santarém, Pará, Brazil. J. Hist. Geogr. 32, 818–838.

Wittmann, F., Anhuf, D., Junk, W.J., 2002. Tree species distribution and community structure of central Amazonian Várzea forests by remote-sensing techniques. J. Tropic. Ecol. 18, 805–820.

Wittmann, F., Junk, W.J., Piedade, M.T.F., 2004. The várzea forests in Amazonia: flooding and the highly dynamic geomorphology interact with natural forest succession. For. Ecol. Manage 196, 199–212.

Wittmann, F., Schongart, J., Montero, J.C., Motzer, T., Junk, W.J., Piedade, M.T.F., Queiroz, H.L., Worbes, M., 2006. Tree species composition and diversity gradients in white-water forests across the Amazon Basin. J. Biogeogr. 33, 1334–1347.

Zarin, D.J., Pereira, V.F.G., Raffles, H., Rabelo, F.G., Pinedo-Vasquez, M., Congalton, R. G., 2001. Landscape change in tidal floodplains near the mouth of the Amazon River. For. Ecol. Manage. 154, 383–393.