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Forest structure of artificial islands in the Tucuruí dam reservoir in northern Brazil: a test core-area model

Leandro V. FERREIRA[1], Selvino NECKEL-OLIVEIRA[2], Ulisses GALATTI[3], Sarita B. FÁVERI[4], Pia PAROLIN[5]

ABSTRACT

Construction of hydroelectric dams in tropical regions has been contributing significantly to forest fragmentation. Alterations at edges of forest fragments impact plant communities that suffer increases in tree damage and dead, and decreases in seedling recruitment. This study aimed to test the core-area model in a fragmented landscape caused by construction of a hydroelectric power plant in the Brazilian Amazon. We studied variations in forest structure between the margin and interiors of 17 islands of 8-100 hectares in the Tucuruí dam reservoir, in two plots (30 and >100m from the margin) per island. Mean tree density, basal area, seedling density and forest cover did not significantly differ between marginal and interior island plots. Also, no significant differences were found in liana density, dead tree or damage for margin and interior plots. The peculiar topographic conditions associated with the matrix habitat and shapes of the island seem to extend edge effects to the islands' centers independently of the island size, giving the interior similar physical microclimatic conditions as at the edges. We propose a protocol for assessing the ecological impacts of edge effects in fragments of natural habitat surrounded by induced (artificial) edges. The protocol involves three steps: (1) identification of focal taxa of particular conservation or management interest, (2) measurement of an "edge function" that describes the response of these taxa to induced edges, and (3) use of a "Core-Area Model" to extrapolate edge function parameters to existing or novel situations.

KEYWORDS: core-area model, forest edges, fragmentation, hydroelectric dams

Estrutura da floresta em ilhas artificiais no reservatório da Usina Hidrelétrica de Tucuruí, Brasil: Um teste do modelo de área nuclear

RESUMO

A construção de usinas hidrelétricas em regiões tropicais tem contribuído significativamente para a fragmentação da floresta. As alterações nas bordas de fragmentos florestais causam profundos impactos na comunidade de plantas, tais como, o aumento em de árvores mortas ou danificadas e a diminuição do recrutamento de plântulas. Este estudo tem como objetivo testar o modelo de área nuclear (core-area model) em uma paisagem de floresta fragmentada resultante da formação do lago da Usina Hidrelétrica de Tucucui na Amazônia. Foram medidas as variações na estrutura em 17 ilhas, com tamanhos variando de 8 a 100 hectares. Em cada ilha foram colocadas duas parcelas, a 1ª parcela a 30 metros da margem e a 2ª parcela a mais de 100 metros da margem da ilha. A densidade e a área basal de árvores, a densidade da regeneração natural e a cobertura do dossel da floresta não foram significativamente diferentes entre as parcelas da borda e do interior das ilhas. Também não foram encontradas diferenças significativas na densidade de lianas, no número de troncos mortos ou árvores danificadas entre as parcelas da borda e do interior das ilhas. A grande declividade do terreno das ilhas, a matriz circundante (água) e a forma irregular da ilhas podem ser os fatores responsáveis me provocar a extensão do efeito de borda em todas as ilhas analisadas, independente do tamanho e grau de isolamento. Nós propomos um novo protocolo para avaliar os impactos ecológicos dos efeitos de borda em fragmentos de habitat criados artificialmente. Este protocolo envolve três etapas: (1) identificação dos táxons biológicos de particular interesse de conservação ou de gestão (2) medição das das variáveis responsaveis pela resposta dos táxons induzidas pelo efeito de borda e (3) Usar o modelo de área nuclear (core area model) na extrapolação das variáveis medidas em situacões novas ou existentes.

PALAVRAS CHAVES: modelo de área nuclear, efeito de borda, fragmentação, usinas hidrelétricas.

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[1] Museu Paraense Emílio Goeldi, email:lvferreira@museu-goeldi.br

[2] Universidade Federal de Santa Catarina, email: neckel@ccb.ufsc.br

[3] Museu Paraense Emílio Goeldi email:ulisses@museu-goeldi.br

[4] Universidade Federal de Santa Catarina, email: sarita@ccb.ufsc.br

[5] Institut National de la Recherche Agronomique (INRA), email:pia.parolin@sophia.inra.fr

INTRODUCTION

Forest fragmentation in tropical regions shows great variation in physical and biological aspects (Lovejoy *et al.* 1983; Kapos 1989; Williams-Linera 1990; Benítez-Malvido 1998; Laurance *et al.* 2002), mainly due to the creation of edges and decreases in forest cover and matrix quality. Physical effects include radiation flux, air and soil humidity and temperature, wind speed, and water flux in soil and air (Kapos 1989; Williams-Linera 1990; Camargo and Kapos 1995). Biological effects include alterations at the edges of forest fragments that impact plant communities, leading to increases in dead tree and damage and decreases in seedling recruitment (Ferreira and Laurance 1997; Viana *et al.* 1997; Laurance *et al.* 1998).

Edge effects are one of the most important factors, and change environmental conditions at different distances inside forest fragments, depending on their size and shape, the age of the edge, type of secondary forest around the fragment, and regional land use (Kapos 1989; Williams-Linera 1990; Miller *et al.* 1991). In a Panamanian forest, changes in forest structure and dead tree were higher on the first 15 m from the border than on the fragment interior (Williams-Linera 1990). In Central Amazonian forest fragments Ferreira and Laurance (1997) observed high dead tree and damage up to 100 m from an edge. In the same study area, Kapos (1989) reported changes in microclimatic conditions extending up to 60 to 100 m into the interior of recently isolated forest fragments.

The core-area model was proposed by Laurance and Yensen (1991) to predict the impacts of edge effects on vegetation structure in fragments of varying sizes and shapes. The model suggests that edge effects will increase in forest remnants with irregular shapes. However, this model may not be representative of most forest fragments, as it has only been tested on a single landscape in the Amazon, where the fragments are square and the shape index is close to 1 (Ferreira and Laurance 1997). Ferreira and Laurance (1997) suggest that edge effects are more apparent when realistic fragment shapes are used in the model, rather than when an untypical landscape is used like the one in their study site.

Much of the southeast of the Brazilian state of Pará State is highly fragmented due to anthropogenic activities such as mining, farming, agriculture and hydroelectric dams. The construction of hydroelectric dams sometimes takes place in large hilly valleys, resulting in numerous isolated forest patches on islands that form from the higher points of the local topography. Although a large number of hydroelectric dams are projected to be built in the tropics (Wu *et al.* 2004), few biological studies have been carried out in the isolated forest fragments on islands in the reservoirs of dams (Terborgh *et al.* 2006; Lopez and Terborgh 2007; Brandão and Araujo 2008) and no study has been made on the edge effects in the forest structure of the isolated forest fragments in this system type.

To test the core-area model proposed by Laurance and Yensen (1991), we designed a study to determine variations in forest structure between the margin and interiors of islands of different sizes and shapes in the Tucuruí dam reservoir in the Para state in northern Brazil. Specifically, variations in tree density, basal area, seedling density, forest cover, liana density, dead tree and damage in paired marginal and interior island plots were used to characterize the edge effects on forested islands. These variables were compared between margin (<100m) and interior (>100m) plots from forest edges created in 1984 and 1985. The classification of plots into margin and interior was based on previous studies of forest dynamics indicating that most edge effects penetrate up to 100m from the edge (Ferreira and Laurance 1997; Laurance *et al.* 1998; Vasconcelos and Luizão 2004).

MATERIALS AND METHODS

Study site

This study was conducted in forest remnants on islands in the Tucuruí Dam reservoir in Para State, northern Brazil (3°43' to 5°15'S; 49°12' to 50°00'W). This artificial lake was formed in 1984 and 1985, and it flooded an area of upland forest of approximately 2.918 km^2 (Eletronorte 2000). This resulted in the creation of more than 2.200 islands of different sizes, shapes and degrees of isolation (Figure 1).

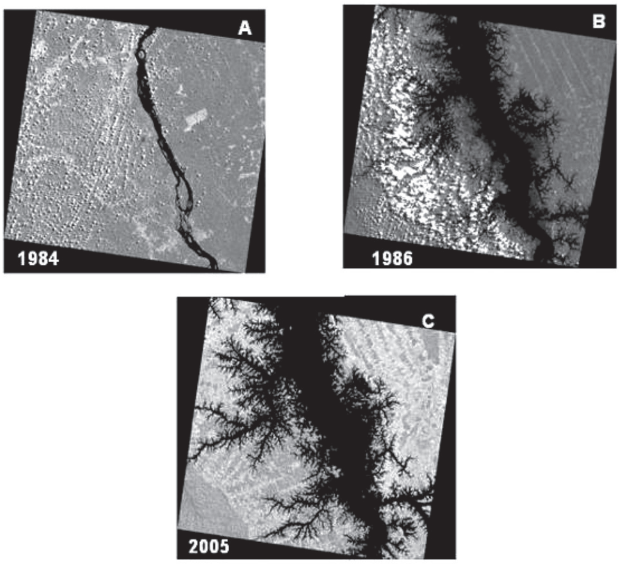

Figure 1 - Sequence of satellite images showing the Tocantins river before the construction of Tucurui Dam (A) in 1984, during the process of filling of the lake in 1986 (B) and the actual shape of the lake, showing thousand of islands since 2005 (C).

The climate of the region is characterized by marked seasonality with a rainy season from December to May and a dry season from June to November. Annual precipitation varies between 1800 - 2300 mm (Morais *et al.* 2005), with a yearly average temperature of 24^{0}C (Eletronorte 2000).

Site selection

We used a satellite image to choose seventeen islands on the right margin of the Tucuruí reservoir (Figure 2). The criterions for inclusion were size, shape, degree of isolation, and conservation status of the island. We selected small-medium size, completely isolated, near rounded and relatively undisturbed islands. The elevations of the islands from the margin to the interior varied from 8 to 31 meters (19.5 ± 6.2 m) and was it determined using GPS (Garmin Map 76CS). The shape index (SI) was calculated using the formula SI=Perimeter of island/√area of island x 4 (Hermann *et al.* 2005).

On each island two plots of 5 x 40 m were laid out, one plot at 30 m from the margin, and the other in the interior of the island at more than 100 m from the margin. In the plots, counts and measurements were made of all trees and vines with Diameter at Breast Height (DBH) ≥ 5 cm. Dead

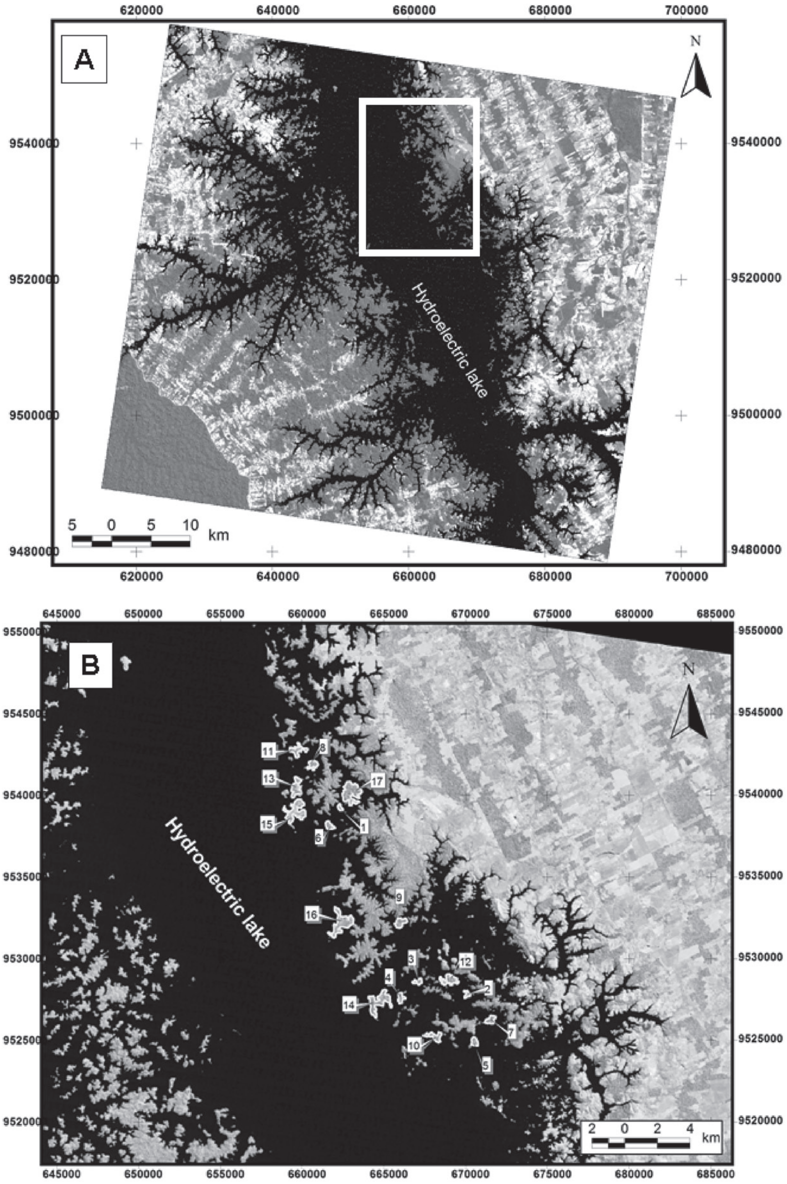

Figure 2 - Satellite image of the Tucuruí reservoir (A) showing in detail the 17 islands used in this study (B).

trees, both standing and fallen, were counted, and damage to trees (broken crown or trunk) was quantified. Within each plot, two subplots of 1 m by 1 m were laid out to measure seedlings until 30 cm in height. The forest cover of each plot was estimated using a digital camera and calculated using the geographic information program Arcview 3.3 (ESRI 2002).

Statistical analyses

Paired t-tests were used to test differences in tree density, tree basal area, seedling density, and forest cover of plots (dependent variables) in the two conditions (margin and interior of islands). Vine density and dead tree and damage were analyzed using the Wilcoxon non-parametric test. Ancova was used to test if the size and the shape of islands influenced the mean tree densities at island margins or interiors. Habitat type was a category variable, while island area and shape index (SI) was continuous variables and were tested separately. All analysis was performed in Systat 10 (Wilkinson 1986).

RESULTS AND DISCUSSION

All islands used in this study were characterized by large trees of 20 to 27 m height, and an understory dominated by several palm species. The sizes of selected islands varied from 7.9 to 102.6 hectares and the shape index varied from 1.12 to 2.09 (Table 1).

Table 1 - Size (hectares), altitude (m) and shape index of the studied islands in the Tucuruí dam.

Island number	Size (ha)	Altitude (m)	Shape index
1	7.9	10	1.12
2	10.1	15	1.42
3	12.9	31	1.27
4	16.6	17	1.38
5	16.8	15	1.07
6	17.6	18	1.13
7	21.4	25	1.15
8	22.4	18	1.41
9	28.8	17	1.17
10	29.7	28	1.66
11	35.3	18	1.91
12	41.6	27	1.85
13	47.6	19	1.57
14	90.2	8	2.05
15	91.3	20	2.09
16	99.1	26	1.92
17	102.6	19	1.69

Mean tree density (t=2.033, P=0.06), basal area (t=1.072; P=0.299), seedling density (t=-0.278, P=0.785) and forest cover (t=-1.003, P=0,397) were not significantly different between marginal and interior island plots (Table 2).

Tree densities were not significantly different between marginal and interior island plots in relation to island size (Ancova: $F_{[1,31]}$=0.095; P=0.760) and island shape index (SI) (Ancova: $F_{[1,31]}$=0.022; P=0.884).

No significant differences were found in liana density (Z=-1.922, P=0.06), dead tree (Z=-1.699, P=0.09) or tree damage (Z=-1.599, P=0.119) between marginal and interior island plots. The liana density varied from 0 to 7 in marginal to 0 to 4 in interior island plots; dead tree varied 0 to 6 in marginal to 0 to 6 in interior island plots; tree damage varied 1 to 15 in marginal to 0 to 9 in interior island plots.

The observed lack of significant differences in the dependent variables, between the edge and interior of islands, supports the core-area model (Laurance and Yensen 1991). Small to medium size islands in the Tucuruí dam are characterized by a marked variation in shape index (1 to 2), and have a steep topography near the shoreline and a narrow and flat forest floor at the center of each island. The high shape index and peculiar topography are associated with the matrix habitat (water), which probably extends edge effects to the island centers independently of the island size, giving the interior similar physical microclimatic conditions as the edges. Previous studies carried out in the Central Amazon found significant differences in vegetation structure (Ferreira and Laurance 1997) and litter fall production (Vasconcelos and Luizão 2004) between marginal and interior plots in the fragmentation landscapes. These Central Amazon fragments are shaped as squares and consequently have a shape index close to 1. These characteristics are likely to have had a strong influence on the results found by Ferreira and Laurance (1997).

Ecological implications for reservoir islands

Such a finding could have great impact on the conservation of local biodiversity, since the forest structure of the islands analyzed in this study indicates that edge effects extend for the entire islands (Figure 3).

Table 2 - Mean and Standard Deviation of tree density, tree basal area, seedling density, and forest cover in the marginal and interior plots of the studied islands in the Tucuruí dam.

Variables measured	Mean and Standard Deviation	
	Marginal plots	Interior plots
tree density (200 m^2)	42.1 ± 7.0 individuals	36.9 ± 10.4 individuals
Basal area (200 m^2)	9.4 ± 0.3 cm	8.0 ± 3.7 cm
Seedling density (200 m^2)	13.7 ± 9.8 individuals	14.4 ± 7.4 individuals
Forest cover (%)	82.3 ± 7.3%	89.3 ± 3.7 %

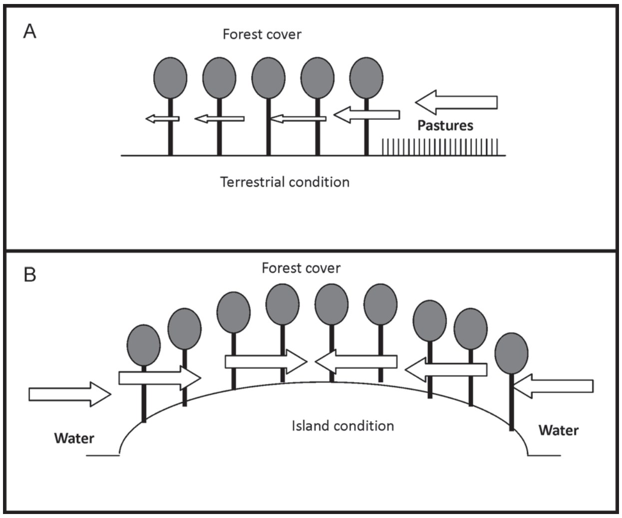

Figure 3 - Edge effect in two situations: terrestrial region with flat topography (A) and an island in the Tucuruí reservoir (B). Arrows of different sizes indicate relative decrease of the edge effects in relation to distance.

In the long term this may lead to alterations in patterns of species richness, diversity, and floristic composition of plant communities, because isolated forest fragments do not sustain the same species richness and diversity originally found in surrounding unfragmented primary forests (Murcia 1995; Laurance 1998). Changes in forest structure can also affect ecological processes such as pollination, predator territorial behavior, and animals' dietary habits (Laurance 1991), resulting in a fall in plant and animal diversity and, in extreme cases, local defaunation (Turner 1996). In a study made at an artificial island in Guri Lake, Venezuela, found high number of dead saplings in all island sizes, while the number of dead trees was negatively associated with area size (Terborgh *et al.* 2006). These results were attributed to herbivores, as they imply that the impact is more severe at earlier stages of regeneration.

By definition, the dominant matrix in all reservoir islands is water. This may create an ecological barrier that impedes the recolonization by many animal species that may be important to tree pollination or seed dispersal (Filho e Metzger 2006).

The results of this study are particularly worrying as the islands resulting from the creation of hydroeletric reservoirs in Amazonia have been proposed to act as protected areas for the conservation of forest biodiversity in the region.

CONCLUSIONS

Some care should be used in extending these results. The largest island used in this study was only 103 hectares in size, and larger islands on both sides of the Tucuruí reservoir should be investigated to determine if their interior portions have edge-like microclimatic conditions and are adequate to maintain viable populations of species. Another possible interpretation of the data obtained in this study is that the edge effects do not have much importance in the Tucurui island. However, this study does not really allow to determine whether this is the case or not. To further understand the functioning of forests on artificial islands, we suggest long-term floristic and biodiversity monitoring, using permanent plots on islands of different sizes, shapes, and degrees of isolation to study how edge effects and isolation affects the maintenance of local biodiversity.

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