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Impacts of the Belo Monte hydroelectric dam construction on pioneer vegetation formations along the Xingu River, Pará State, Brazil

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ABSTRACT – (Impacts of the Belo Monte hydroelectric dam construction on pioneer vegetation formations along the Xingu River, Pará State, Brazil). There is an important pioneer vegetation formation along the Xingu River in the area where the Belo Monte hydroelectric dam is being constructed that is highly adapted to a seasonally fluctuating water levels. The aim of this study was to examine the habitat and flora of the pioneer formations in the Belo Monte area. The area was divided in three sections for study purposes (Reservoir, Low Flow, and Control) that were expected to experience different degrees of impact from the dam project. The calculations of habitat losses were based on satellite imagery classifications, and a total of 111 plots were established in the three areas for vegetation sampling. Habitat losses of the pioneer formations will total 89.7% when the project is fully functional. Forty-five of the 72 recorded species are restricted to single areas. Species richness and diversity were significantly lower in the control area. The completion of the Belo Monte reservoir will result in habitat reductions and will consequently reduce the richness and diversity of pioneer formations. Studies suggest monitoring the populations located in the reduced flow area to determine possible impacts resulting from changes in the regional hydrological cycle caused by the Xingu River dam.

Key words - diversity, habitat loss, low flow reservoir, richness

INTRODUCTION

The Belo Monte hydroelectric dam will be built along the lower course of the Xingu River in Pará State and will become the second largest exclusively Brazilian hydroelectric site, with an expected generation of 11000 megawatts of energy (Ibama 2007). There is a special type of vegetation that grows on the riverbanks and islands where the dam is being built that is adapted to cyclical variations in water levels (Cunha 2009). This vegetation is classified as a pioneer formation (IBGE 1992) that is unique and specialized because of the rigorous growth conditions it faces (Cunha 2009). The plants there normally grow within cracks and fissures in the granitic rocks where river sediments accumulate, or on beaches formed by the deposition of sediments brought by pulses of river discharges occurring during annual flooding cycles (Ibama 2007). The main factor maintaining pioneer formation diversity is this hydrological cycle that brings seasonally receding and then flooding waters (Parolin 2001), and these pioneer plant communities have become adapted to survive for long periods of time under conditions of total or partial submersion (Ferreira 2000).

The main environmental impact of hydroelectric dam construction is the flooding of large areas for the formation of reservoirs (Miranda et al. 1988). This flooding results in the decomposition of the flooded vegetation under anaerobic conditions and the deterioration of water quality (Tundisi et al. 2006); changes in the hydrological cycle of the river with serious consequences for conservation and natural resource management (Basso 2000); global climate changes due to the release of greenhouse gases from the reservoirs (Fearnside 1995, 2008, Arfi 2003, Pueyo & Fearnside 2011); local microclimatic changes (Fisch et al. 1990, Sanches & Fisch 2005); losses of the environmental services of terrestrial and aquatic ecosystems; and the loss of biodiversity (Ferreira 2000, Fearnside 2001, Tundisi et al. 2006).

The construction of the Belo Monte hydroelectric dam will form a reservoir called the Xingu River Reservoir, interrupt the fluctuation of the water levels of the Xingu River, and eliminate many of the habitats of pioneer formations (Leme 2007, Cunha 2009). Another impact of this project will be drastic reductions in water flow volumes and the cyclical flooding in the downstream region of the dam and the future reservoir. This stretch is known as the 'Volta Grande' of the Xingu River, one of the most important areas in the lower Amazon basin in terms of its flora, fauna and indigenous and riverine human populations (Cunha 2009). The combination of reduced water volumes and a reduced hydrological cycle along the Xingu River in this area will certainly result in changes in the reproductive life cycles of many plant species and in the pioneer plant formations that have become synchronized with water level fluctuations (Junk & Piedade 2003, Ferreira & Parolin 2007).

An in-depth knowledge of the richness, diversity, and species composition of pioneer plant community formations on the Xingu River is vital for providing

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support to planning and conservation actions that can reduce the environmental impacts of this enterprise (Rodrigues & Leitão Filho 2000, Wu et al. 2003). In this context, the objective of the present study was to describe and compare the richness, diversity, and species compositions of pioneer formations in the area influenced by the Belo Monte hydroelectric project and to quantify future habitat loss resulting from the permanent flooding of the reservoir.

MATERIAL AND METHODS

The study was conducted in the Area of Direct Influence (ADI) of the Belo Monte project in the middle-lower reaches of the Xingu River, Pará State, northern Brazil, where the Belo Monte Hydroelectric Complex is being built. This region has alternating sections of abrupt topographic elevation with altitudinal differences of approximately 100 meters that offer one of the largest hydraulic potentials of the lower Amazon (Radam 1974). According to the international climatic classification system of Köeppen, the predominant climate in this region is humid tropical without a dry season, with a mean air temperature of 26 °C, a mean annual rainfall of 2289 mm, and with a short dry season occurring during August and September with average precipitation rates of 33.4 and 39.3 mm respectively (Ibama 2007).

The pioneer formations in this region are composed of plant communities with shrub, tree and herbaceous layers that develop on sand-covered rock outcrops seasonally flooded by the Xingu River (Cunha 2009) usually as a canopy layer, ranging from 1 to 5 m tall, distributed over small sandy patches on the rocky islands and sandy beaches (Cunha 2009). The lifecycles of the herbaceous species associate with the pioneer formations are synchronized to the periods of receding waters (Junk & Piedade 1993).

The inundation period of the Xingu River occurs from December to June, while the waters recede during the period from July to November (Leme 2007). During flooding, when the river level rises 3-4 m, the plants of these pioneer formations become partially or totally submerged. The plants control the water stress caused by flooding through physiological, morphological, and anatomical adaptations (Ferreira & Parolin 2007). When the river flow decreases considerably, the faults and fractures of rock outcrops form a network of channels through which the water flows quite swiftly, and the plants must resist the hydro-mechanical strength of the current flow. To resist this additional stress, the plants have adaptive mechanisms that allow efficient attachment of their roots to the rock fissures (Ibama 2007).

A plant inventory was conducted in the pioneer formations of the ADI of the Belo Monte Project (52°28’32” to 51°25’55” W and 03°00’09” to 03°37’03” S). The ADI was divided into three areas depending on the type of impact caused by the project: Control (located upstream of the Xingu River Reservoir in an area that will not suffer any impacts of flooding); Reservoir (the reservoir area of the Xingu River behind the dam, which will experience permanent flooding); and Low Flow (located downstream of the dam where the flow of the Xingu River will be reduced) (figure 1). We used TM/Landsat-5 satellite images (orbit/row 225/062, 225/063 and 226/062, 226/063) using three color bands 3(B), 4(R) and 5(G), and spatial resolutions of 30 meters (Leme 2007). The thematic map was produced using ArcGIS 9.2 on a scale of 1:250,000 (ESRI 2006).

To undertake the vegetation inventory, thirty-seven 5 × 20 m plots were established in each of the three areas in the ADI, totaling 111 plots. Every individual in each plot with a stem diameter at breast height ≥ 1 cm was recorded, identified, and measured following the protocol of Leme (2007). Species identifications were performed by the parataxonomist Luiz Carlos Lobato of the Museu Paraense Emilio Goeldi (MPEG) and compared with herbarium samples. The system of species classification adopted followed Engler (1964). All botanic material collected was incorporated in the João Murça Pires Herbarium at the Paraense Emílio Goeldi Museum. The classifications of the pioneer formations in the ADI of the Belo Monte hydroelectric project were performed manually, directly on the computer screen. Calculations of the habitat losses, based on the overlapping distribution of areas occupied by the pioneer vegetation in the Control, Reservoir, and Low Flow areas (totaling 2472 ha, 5043 ha and 16534 ha respectively) of the ADI of the Belo Monte Hydroelectric Complex, were performed using the ArcGis program.

A species-area curve was used to evaluate the sufficiency of the numbers of plots in estimating the species richness of the three study areas and their species accumulation curves were obtained by the first-order Jackknife method (Heltshe & Forrester 1983, Belle & Smith 1984) using EstimateS 7.5 software (Colwell 2005). The point where the curve tends to stabilize represents the minimum flora sampling area (Cain et al. 1956). The floristic diversity in each plot, obtained by the Shannon-Weaver diversity index (Magurran 1988), and structural data (relative density and relative frequency of the species) of the three sampling areas were generated using Mata Nativa 2 software (Cientec 2006). Differences in species richness and species diversity between the plots (dependent variables) in the three sampling areas (independent variables) were tested using One-way ANOVA (analysis of variance) at a 5% significance level ($P \leq 0.05$), followed by Tukey’s test used to determine the occurrence of differences between the dependent variables in relation to as variáveis independentes (Zar 1999) using SYSTAT 12 software (Systat 2007).

An adaptation of the Lorenz curve was used to analyze abundance to distributions. The resulting graph showed the cumulative percentage abundance (y-axis) plotted as a function of the percentage number of species (x-axis). The result is a curve from the origin (where 0% of species contain 0% of the abundance), two an upper limit (100% of the species contain 100% of the abundance); the communities that have higher equitability will appear near the diagonal formed by the xy axes of the graph (Pinho & Vasconcelos 1997). The frequency

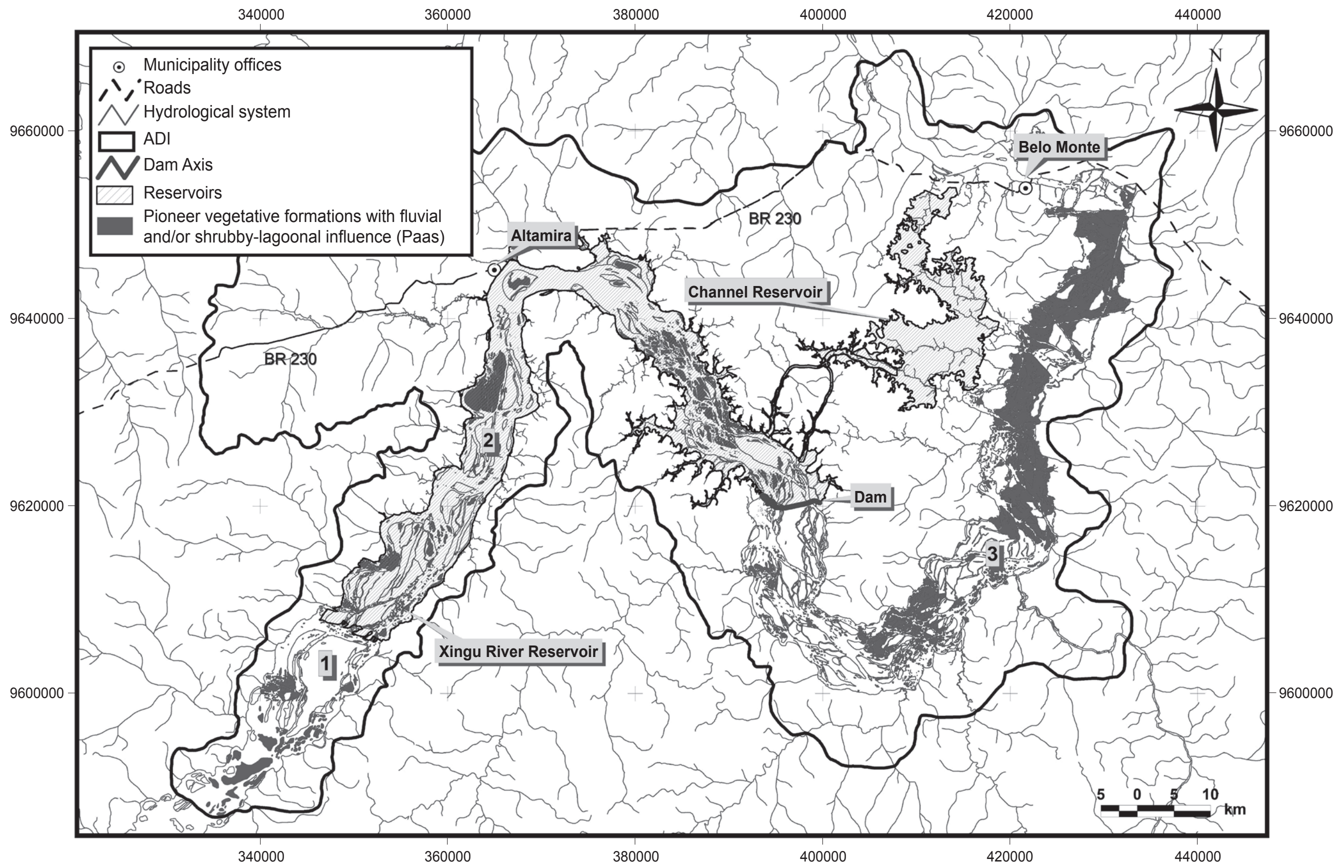

Figure 1. Area of direct influence (ADI) of the Belo Monte project, indicating the three sampling areas of this study, based on the impact levels of the project: (1) Control; (2) Reservoir; (3) Low Flow.

differences of the species common to the three sampling areas were analyzed using the nonparametric Kruskal-Wallis (h) test at a 5% significance level (Zar 1999).

RESULTS AND DISCUSSION

Pioneer formations included within the future area of the Xingu River Reservoir will suffer 21% losses, and the Low Flow areas will lose 68.7%. Only 10.3% of the pioneer formations in the ADI will not be impacted by the construction of the Belo Monte hydroelectric dam. The permanent flooding of pioneer formations in the area of the reservoir will lead to reductions in the flora and fauna. Population responses to habitat losses are slow (Dirzo & Raven 2003, Balmford et al. 2005, Helm et al. 2006), and will result in changes in the distribution patterns of abundance and diversity in pioneer species formations in the ADI.

We sampled 3788 individuals distributed among 72 species in three areas inventoried. The richnesses were 37, 37 and 42 species in Control, Reservoir and Low Flow areas respectively (figure 2). The collection curves

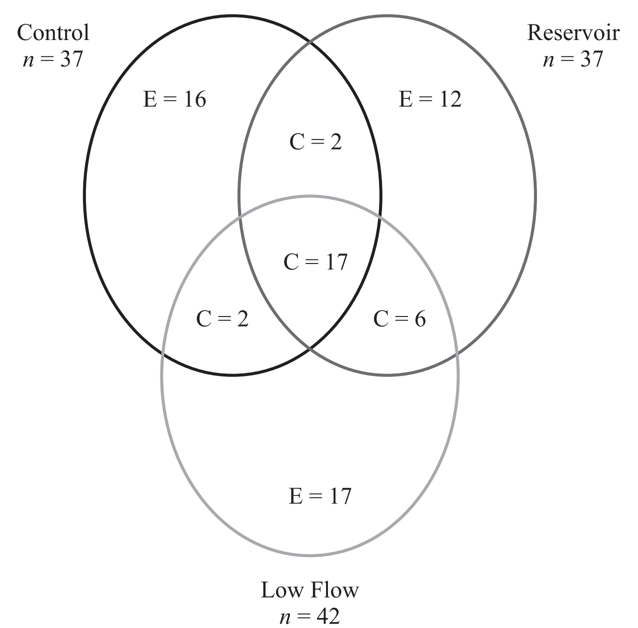

Figure 2. Venn diagram showing the total numbers of species recorded in the three areas (*n*), the numbers of unique species (E), and those common (C) two the Control, Reservoir, and Low Flow periods. Areas shown in figure 1.

showed a clear tendency to approach the asymptote in the three sampling areas (figure 3). The Jackknife richness estimator determined that 72%, 78% and 71% of the species in the Control, Reservoir, and Low Flow areas were sampled respectively, indicating that this study was sufficient to estimate the local species richnesses of the communities in these three areas (Heltshe & Forrester 1983, Ferreira et al. 2011).

There were significant differences in richness ($F_{[2,111]} = 8.28$; $P = 0.0001$) and diversity ($F_{[2,111]} = 6.784$; $P = 0.002$) between the three areas. Richness and species diversity were significantly lower in the Control area plots than in the Reservoir and Low Flow areas (which were not different from each other) (figure 4). The low species richness and diversity parameters of pioneer formations in the Control area could have important implications for species conservation since this area may not be adequate to offset the environmental impacts of the construction of the Belo Monte Hydroelectric Project. Cunha (2009) conducted a floristic survey in the Xingu River (upstream from the influence of the Belo Monte project to the confluence with the Iriri River) and demonstrated that this region had less species richness and diversity than the downstream areas that regularly experienced flooding and would suffer heavy impacts when the flow of the Xingu River is reduced.

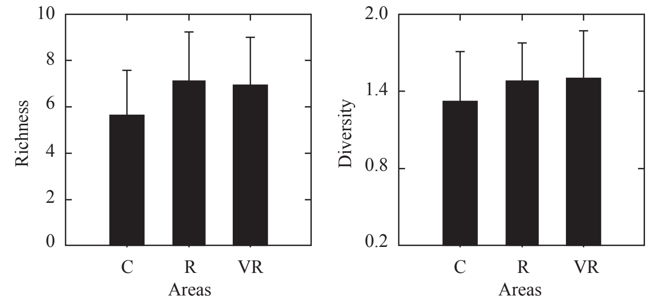

Figure 4. Mean and standard error of the richness and species diversities of the three sampling areas shown in figure 1: Control (C); Reservoir (R); Low Flow (LF).

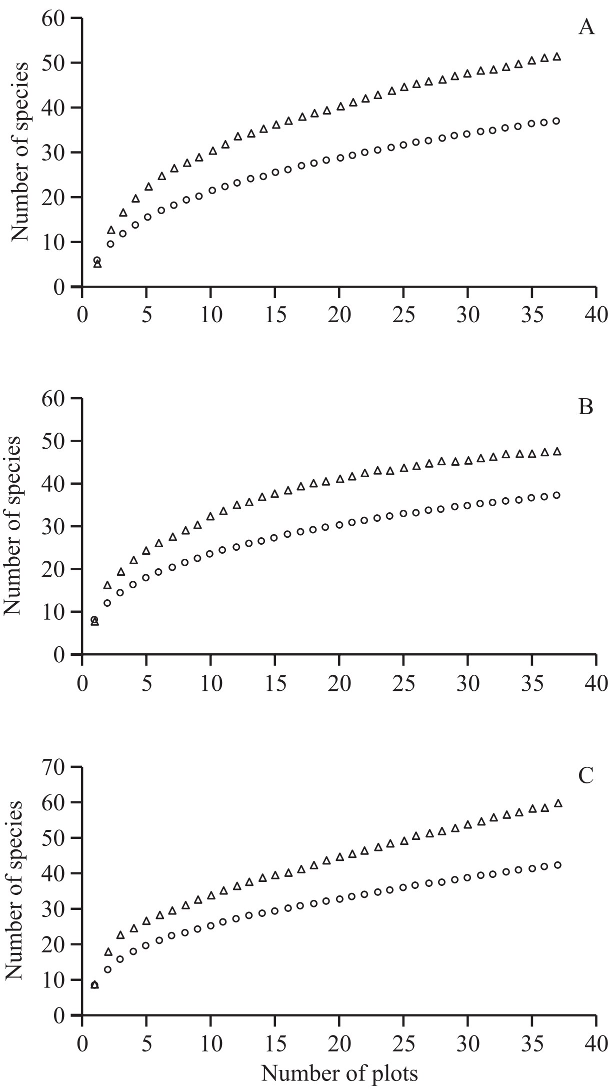

Figure 3. Collector Curves for the Control (A), Reservoir (B), and Low Flow (C) shown in figure 1.

One of the most important characteristics of pioneer formations in the ADI of the Belo Monte Hydroelectric Project is that few species demonstrated high abundance and most, in fact, had very low abundances. It appears that about 70% to 80% of species represent about 10 to 20% of the total individuals sampled in three sampling areas – clearly indicating great inequalities in the distributions of species abundances, with just a few species being dominant in all three communities (figure 5). Another important aspect was the large numbers of species restricted to just one sampling area. Of the 72 species found (table 1), only 17 were common to all three sampling areas, with most of the other species being less

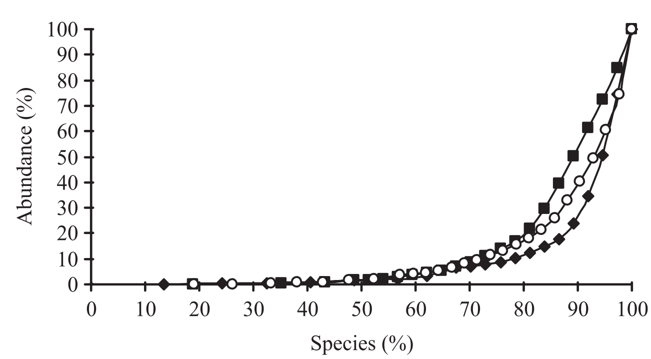

Figure 5. Abundance distribution of the Control, Reservoir, and Low Flow areas (–◆– = Control; –■– = Reservoir; –○– = Low Flow) shown in figure 1.

Table 1. Relative density (RD) total species in the study area according to their occurrences in the three sampling areas shown in figure 1: Control (C), Reservoir (R) Low Flow (LF) (MG = record numbers of the fertile reference material collected and incorporated into the Museu Paraense Emílio Goeldi herbarium; in bold face – species with the highest RD in the study area).

Family/species		RD (%)				MG
		C	R	LF	Total	
Araceae	*Montrichardia linifera* (Arruda) Schott	0.53			0.16	
Boraginaceae	*Rotula pohlii* (Kuhlm.) E.F.Guim. & Mautone	0.09			0.03	
Capparaceae	*Crataeva benthamii* Eichler			1.37	0.58	191532
Celastraceae	*Salacia impressifolia* (Miers) A.C.Sm.	0.09			0.03	
Chrysobalanaceae	*Couepia cataractae* Ducke	21.80	10.18	8.73	13.04	191543
	Couepia longipendula Pilg.		0.10		0.03	
	Couepia paraensis (Mart. & Zucc.) Benth. ex Hook. f.		0.19		0.05	191544/201793
	Hirtella sp.			0.06	0.03	
	Licania apetala (E.Mey.) Fritsch			0.06	0.03	191547/201838
	Licania canescens Benoist			0.31	0.13	
	Licania lata J.F.Macbr.	0.09			0.03	
	Licania leptostachya Benth.	1.32	2.66	3.12	2.46	191546
Combretaceae	*Buchenavia grandis* Ducke	2.21			0.66	
	Buchenavia oxycarpa (Mart.) Eichler	0.88	7.61	4.55	4.30	191550
	Combretum sp.	0.09			0.03	191551
	Terminalia dichotoma G.Mey		0.10		0.03	191552
Convolvulaceae	*Maripa reticulata* Ducke		0.10		0.03	
Erythroxylaceae	*Erythroxylum spruceanum* Peyr			0.50	0.21	191508
Euphorbiaceae	*Mabea caudata* Pax & K.Hoffm.			0.19	0.08	
	Mabea paniculata Spruce ex Benth.	0.35			0.11	191540/201830
	Piranhea trifoliata Baill.	1.41	0.19	1.68	1.19	191486
	Sapium duckei Huber ex Huft.		0.19		0.05	
Guttiferae	*Calophyllum brasiliense* Cambess.	0.35	0.48		0.24	
Leguminosae-Caesalpinioideae	*Campsiandra comosa* Benth. var. *laurifolia* (Benth.) R.S.Cowan	5.74	10.66	6.80	7.55	191493
	Chamaecrista negrensis (H.S.Irwin) H.S.Irwin & Barneby	0.53			0.16	
	Chamaecrista serpens (L.) Greene	0.53			0.16	191492
	Cynometra bauhiniifolia Benth.	0.35		0.06	0.13	191491
	Cynometra cuneata Tul.	0.09			0.03	
	Cynometra marginata Benth.	0.44			0.13	
	Macrolobium acaciifolium (Benth.) Benth.		0.19		0.05	
	Macrolobium sp.		0.10	0.06	0.05	
Leguminosae-Mimosoideae	*Zygia cauliflora* (Willd.) Killip	2.65	1.81	2.31	2.27	
	Zygia sp.			0.06	0.03	191490
Leguminosae-Papilionoideae	*Acosmium nitens* (Vogel) Yakovlev	2.74	4.47	1.68	2.77	
	Clitoria amazonum Mart. ex Benth.		0.48		0.13	
	Dalbergia inundata Spruce ex Benth.		0.67	1.87	0.98	
	Machaerium aristulatum (Spruce ex Benth.) Ducke			0.37	0.16	191496/201792
	Machaerium lunatum (L.f.) Ducke			0.06	0.03	
	Pterocarpus amazonicus Huber	0.18	2.85	0.69	1.14	191498
	Robinia sp.		0.10	0.50	0.24	191489
	Swartzia leptopetala Benth.		9.90	10.79	7.31	191494
Malpighiaceae	*Mascagnia benthamiana* (Griseb.) W.R.Anderson	0.26			0.08	
Malvaceae	*Gaya scopulorum* Krapov.	1.85	0.38	1.12	1.14	191536/201800
Meliaceae	*Trichilia singularis* C.DC.			0.31	0.13	191535

continue

continuation

Family/species		RD (%)				MG
		C	R	LF	Total	
Myrtaceae	*Campomanesia grandiflora* (Aubl.) Sagot		0.48		0.13	
	Eugenia belemitana McVaugh	0.44			0.13	
	Eugenia biflora (L.) DC.			0.12	0.05	
	Eugenia inundata DC.		0.19	0.19	0.13	191511/197270
	Eugenia patens Poir	0.71	0.86	6.61	3.25	191512/201827
	Eugenia sp.			0.44	0.18	
	Eugenia tapacumensis O.Berg			0.06	0.03	
	Myrciaria floribunda (H.West ex Willd.) O.Berg	**23.39**	11.04	**24.19**	**20.30**	
	Psidium paraense O.Berg	14.83	**14.94**	1.43	9.19	201829
	Psidium verrucosum Barb.Rodr.			0.56	0.24	
Palmae	*Astrocaryum jauari* Mart.		0.76		0.21	
Polygonaceae	*Coccoloba acuminata* H.B.K. var. *pubescens* Lind.			0.25	0.11	
	Coccoloba densifrons Mart. ex Meisn.			0.12	0.05	
	Ruprechtia brachysepala Meisn.		0.10	0.12	0.08	
	Ruprechtia sp.	2.74	2.38	2.24	2.43	
	Symmeria paniculata Benth.	1.32	1.52	1.75	1.56	191507
Rubiaceae	*Anisomeris preslii* K.Schum.			0.56	0.24	201834
	Genipa spruceana Steyerm.	0.44	0.95	0.31	0.53	191522
	Palicourea quadrifolia (Rudge) DC.	0.26	0.57		0.24	
	Retiniphyllum schomburgkii (Benth.) Müll.Arg.		0.10		0.03	
	Stachyarrhena spicata Hook.f.	0.26		0.25	0.18	191521/197203
Rutaceae	*Esenbeckia almawillia* Kaastra	0.26			0.08	
Sapindaceae	*Allophylus floribundus* (Poepp.) Radlk.	0.18			0.05	
Sapotaceae	*Pouteria procera* (Mart.) T.D.Penn.		0.67		0.18	
	Sarcaulus brasiliensis (A.DC.) Eyma	0.62			0.18	
Simarubaceae	*Simaba guianensis* Aubl.	0.18	0.19	0.06	0.13	201807
Tiliaceae	*Vasivaea alchorneoides* Baill.		0.29		0.08	191548
Verbenaceae	*Vitex duckei* Huber	9.80	11.61	13.47	11.85	
Total (%)		100	100	100	100	

abundant and also restricted to just one or two areas; 16 (22.2% of total) occurred only in the Control area, 12 (16.7% of total) only in the Reservoir area, and 17 (23.6% of total) only in the Low Flow area (figure 2). Therefore, about 62.5% of the species were characterized by low abundances and distributions and were restricted to a particular area (and considered rare in the study area).

With the permanent flooding of the Reservoir area of the Xingu River, the 12 species restricted to this section (and that have low abundances) may well become locally extinct. Lyons et al. (2005) report that less abundant species are often ignored in diversity studies, but significantly contribute to ecosystem functioning. These species can act as key species in the dynamics of soil resources through nutrient retention and cycling (Lyons et al. 2005) and may also be important in community resistance to invasion by new species (Lyons & Schwartz 2001).

In the Low Flow area, situated downstream from the hydroelectric reservoir, the main impact of the dam complex will be drastic decreases in the flow of the Xingu River and alterations in the cyclical fluctuation of the river between low and flood waters. Seventeen species are restricted to this section and it is estimated that its area will decrease in size by 68.7%. This reduction will have serious consequences for community dynamics because the fruiting and seed release patterns of many plant species are linked to fluctuating river levels (Ferreira & Parolin 2007).

Fruits and seeds that are normally dispersed by water inundating the pioneer formations of the Xingu River during the flooding season may not be dispersed, and animal species that depend on those fruits and seeds will likewise be affected. However, hydrological simulations of the project show that the islands colonized by pioneer formations be flooded during the rainy season by the

Xingu River with average flow rate of 4000 m^3 day^{-1} (Ibama 2007), which may minimize the environmental impacts of dam related flow reductions on the biological cycles of many plant species. The main impact will be associated with changes in the flooding cycle of the Xingu River that will be severely changed with the completion of the dam.

Changes in the hydrological cycles of the Xingu River will directly affect the plant and animal communities adapted to its annual cyclical fluctuation (Junk & Mello 1987, Parolin 2001). However, only one study monitoring the reproductive cycle of pioneer formation species in the Low Flow zone will allow to examine the environmental impact caused by the reduction and alteration of the natural flooding cycles in this area.

Of the 17 species that occurred in all three sampling areas, only *Myrciaria floribunda* (h = 11.622, P = 0.003), *Couepia cataractae* (h = 6.413, P = 0.04), and *Eugenia patens* (h = 6.082, P = 0.048) showed significant differences in their frequencies between the three areas (table 2). Of these species, *Myrciaria floribunda* (Myrtaceae) is the most abundant and frequent in all three sampling areas. Its fruits are an important food source for fish such as tambaqui (*Colossoma macropomum*), pacu (*Mylossoma* spp.), matrinchã (*Brycon cephalus*), and curimatã (*Prochilodus nigricans*), which, in turn, contribute to seed dispersal (Peters & Vasquez 1987).

Table 2. Results of the Kruskal-Wallis test (h), significance level (P) and relative density (RD) of 17 species common to all three sampling areas shown in figure 1.

Species	*h*	*P*	RD
Acosmium nitens	1.031	0.598	2.77
Buchenavia oxycarpa	0.146	0.933	4.3
Campsiandra comosa	1.631	0.442	7.55
Couepia cataractae	6.413	0.04	13.04
Eugenia patens	6.082	0.048	3.25
Genipa spruceana	5.145	0.076	0.53
Herissantia sp.	3.071	0.215	1.14
Licania leptostachya	3.757	0.153	2.46
Myrciaria floribunda	11.622	0.003	20.3
Piranhea trifoliata	3.012	0.222	1.19
Psidium paraense	2.456	0.293	9.19
Pterocarpus amazonicus	1.075	0.584	1.14
Ruprechtia sp.	3.023	0.221	2.43
Simaba guianensis	0	1	0.13
Symmeria paniculata	1.483	0.476	1.56
Vitex duckei	3.269	0.195	11.85
Zygia cauliflora	0.261	0.878	2.27
Total (%)	--	--	85.08

With the loss of habitat along stretches of the Xingu River Reservoir, many individuals of *Myrciaria floribunda* will be eliminated and the remaining specimens will be largely restricted to the Low Flow region. The animals that depend on this species for food can be expected to suffer population reductions (Bender et al. 1998).

The results of the present study indicated that as few species demonstrated high abundance, environmental changes related to the construction of Belo Monte Reservoir will result in changes in these distribution patterns and, consequently, in regional species composition, richness, and diversity. The Control area, which will not directly suffer from the impacts of the construction of Belo Monte Hydroelectric Project may not be fully qualified to offset impacts to the flooded areas (approximately 89.7% of the total area now occupied by pioneer formations).

As many species are restricted to a particular area, studies on their geographical distributions and the ecological conditions determining their presence will be important. We also suggest that studies be carried out to monitor the plant and animal populations located in the Low Flow area in order to detect biotic impacts expected from changes in the hydrological cycle of that section of the Xingu River that will be caused by the construction of Belo Monte hydroelectric dam.

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