

ORIGINAL ARTICLE

Impacts on seasonal dry forests located for several years near dams in the Araguari River Basin

Impactos nas florestas sazonais secas localizadas perto de barragens por vários anos na Bacia do Rio Araguari

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Abstract

Several problems are known as consequences due to the construction of large reservoirs. However, few studies evaluated the impacts on forests which had previously been distant from a water source and then happened to be near a dam's water. We compare forests with no dam interference with forests subject to damming impacts in two, four, fifteen and twenty years. We predicted many changes on the forest structure after years near a dam. Our goal was to demonstrate that a few years of proximity to the dams is sufficient to increase the richness, number of trees, basal area and diversity at the sectors located near the dam's water. The dam-affected forests were sampled in two sectors, one near the lakeshore created by dams and one 50 m distant from the lakeshore. For the forest far from the dams the same procedure was used, however, the plots situated on the lower sector obviously had no dam water interference. For each sector we sampled 10 plots of 20x10 m and measure all trees with diameter at breast height with 4.77 cm or more. We compared the number of trees, tree basal area, richness, cumulative number of species, floristic similarity and performed species indicator analysis between all forest sectors. Sectors near dam water for 15 and 20 years are similar to each other and had more trees, basal area, richness, and/or had more species typical of riparian forests.

Keywords: Anthropogenic impacts; Chrono-sequence; Damming; Riparian effect, Species richness; Floristic similarity.

Resumo

Vários problemas são conhecidos devido à construção de grandes reservatórios; no entanto, poucos estudos avaliam os impactos nas florestas que antes estavam distantes de qualquer fonte de água e começaram a ficar próximas à água da barragem. Comparamos florestas sem interferência de barragens com florestas sujeitas a impactos de represas em dois, quatro, quinze e vinte anos. Previmos muitas mudanças na estrutura das florestas após muitos anos de represamento e nosso objetivo foi demonstrar que poucos anos de represamento são suficientes para alterar a estrutura de florestas localizadas em clima sazonal. As florestas afetadas pelas barragens foram amostradas em dois setores, um próximo à margem do lago criado por barragens e um a 50 m de distância da margem do lago. Para florestas não represadas, o mesmo procedimento foi utilizado, no entanto, as parcelas situadas no setor abaixo obviamente não tiveram interferência na água da represa. Para cada setor, amostramos 10 parcelas de 20x10 m e medimos todas as árvores com diâmetro na altura do peito com 4,77 cm ou mais. Comparamos o número de árvores, a área basal das árvores, a riqueza, o número acumulado de espécies, a similaridade florística e realizamos análises de indicadores de espécies entre todos os setores

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florestais. Os setores próximos à água da barragem por 15 e 20 anos são mais semelhantes entre si e tinham mais árvores, área basal, riqueza e / ou tinham mais espécies típicas de matas ciliares.

Palavras-chave: Impactos antropogênicos; Cronosequência; Represamento; Efeito ribeirinho, Riqueza de espécies; Semelhança florística.

INTRODUCTION

Some of the strongest economies in the world, such as the United States, China, Russia, Brazil and Canada depend on the hydroelectric grid for their own development (Kumar et al., 2011). At the same time, the damming of rivers has been identified as one of the most dramatic and widespread deliberate impacts of humans on the natural environment (Nilsson et al., 2005). For energy production, over than 45,000 dams higher than 15 m were constructed in the world, obstructing at least 60% of the fresh water which flows to the oceans (Nilsson et al., 2005). First considered a “clean and cheap” energy, several problems are actually known such as watershed modification (Nilsson; Berggren, 2000), entire aquatic fauna and flora changes (von Sperling, 2012), sediment retention (Vorosmarty et al., 2003; Manyari; Carvalho, 2007), biochemical alterations (von Sperling, 2012), greenhouse gas emissions (St Louis et al., 2000; Wang et al., 2011) and alterations on margins which are near a dam’s water (Sun et al., 2014; Vale et al., 2013, 2015, 2017, Raymundo et al., 2018).

Some recent studies evaluated a dam’s consequences for forests a few years after damming (Gusson et al., 2012; Vale et al., 2017). After vegetation is located near the dam’s water, the soil moisture increases (Vale et al., 2013) and many changes occurs, a phenomenon named “Riparian Effect” (Vale et al., 2015). Riparian effect are the consequences of the proximity of the forest to the water table permanently created by a dam; mainly the increase in forest basal area and the establishment of water-associated species (Vale et al., 2015). These changes in terrestrial environments are critical because plants represent primary producers and are the basic components of most ecosystems (Loreau et al., 2001). However, we know little about what occurs with the vegetation many years after a dam’s construction (see good exceptions in Sun et al., 2014 and Liu et al., 2013). We should expect many flora changes because the inland vegetation has fewer species compared to riparian environments (Brinson, 1990).

Most studies focus on dam impacts on grasses, herbs and shrubs (Mallik & Richardson 2009; Nilsson & Svedmark, 2002) and are concentrated in non-tropical environments with low diversity (Dynesius et al., 2004; Jansson et al., 2000; Nilsson et al., 1997); although most dam constructions occur in high diversity and threatened tropical systems (Johansson & Nilsson 2002; Nilsson et al., 2005; Guo et al., 2007) dominated by trees. Comparisons between dammed and non-dammed rivers are frequent (Nilsson & Svedmark, 2002; Liu et al., 2013; Sun et al., 2014), notwithstanding that chrono-sequence studies with comparisons of dam consequences over the years are nonexistent in tropical environments.

Only long term studies can demonstrate tree species changes and their probable consequences to communities (Laurance et al., 2006) as trees are long-lived species and changes by disturbances may be slow to be detected. Moreover, most dams are built to generate electricity (Truffer et al., 2003) and are established on mountainous terrain (Nilsson & Berggren 2000) to increase the energy production (Truffer et al., 2003). Thus, we chose to evaluate the effects of four dams on forests located in mountainous terrains in Southeastern Brazil in the Araguari River Basin.

Hillsides had steep slopes and facilitate waterflow reducing the water infiltration into the soil (Sidle et al., 2006) and the rocky soils renders water retention even more difficult. In seasonal environments the forest soil moisture becomes very low in the dry season (Vale et al., 2013). Tree species show adaptation to reduce water loss due to water-stressed conditions, such as leaf loss during the dry season, fruits and seeds with low water content (Murphy & Lugo, 1986) and frequently have a high wood density to prevent drought induced embolism (Choat et al., 2003).

The Latin American forests associated with steep terrain with low water content during 5-6 months are called Seasonally Dry Tropical Forests (SDTF) (Gentry, 1995; Pennington et al., 2009) with the leaf fall surpassing 90% in the dry season of the year and are an excellent subject of study to infer changes in other forests with similar impact. The SDTF are also considered a threatened environment (Espírito-Santo et al., 2009; Miles et al., 2006), so it is

important to evaluate dam impacts on these communities. These forests have a marked dry season with lack of rains, and the water proximity after dam construction means a total change in water relations to the flora with uncertain consequences (Santos & Vale, 2017).

Few years after damming, many trees died due soil moisture increase in these forests (Gusson et al., 2011; Vale et al., 2013), but the effect is more pronounced up to 30 m of distance from the lakeshore (Vale et al., 2015). It is still unknown what occurs to the vegetation after many years of damming influence. In this work, we compare three non-dammed SDTF with four SDTF subject to damming impacts after two, four, fifteen and twenty years. Considering that the new shorelines created by a dam will enhance soil moisture and even small changes of the water regime level induces changes on vegetation structure (Nilsson 1996; Vale et al., 2015, 2017), we predicted that forests subjected to damming by several years will present more changes in the forest structure such as increases in richness, number of trees, basal area and diversity at the sectors located near the dam's water. Our goal is to demonstrate that a few years of proximity to the dams is sufficient to change the forest structure.

MATERIALS AND METHODS

Study areas: The Araguari River is one of the main tributaries of the Paraná River, the second largest river in South America and can be used for chrono-sequence studies. Many dams were constructed in the mountains and hillsides for hydroelectric power production. The natural river channel is now a sequence of lakes extending ~200 km along the Araguari River (Rodrigues & Silva 2012, Lopes et al., 2014, Raymundo et al., 2018). The vegetation which became close to the new margins created by dams are located on these hillsides and did not have water-associated species (Siqueira et al., 2009).

The climate of the study area is Aw according to the Koppen-Geiger classification (Kottek et al., 2006) with a dry winter (April to September) and a rainy summer (October to March), with an average annual temperature of 22 °C and average rainfall of around 1595 mm (Santos & Assunção, 2006).

This study was carried out in seven SDTFs; two located in the Amador Aguiar Dam Complex (18°47' S - 48°08' W e 18°40' S - 42°24' W), one in the Miranda Dam (18°54' S - 48°01' W), one in Nova Ponte Dam (19°00' S - 47°39' W) and three non-dammed SDTF forests in the regions (18°47'S - 48°06'W, 18°48' S - 48°07' W and 18°40' S, 48°24' W – Figure 1). All areas had sloped terrains and the predominant soil types are eutrophic podzolic soil and dystrophic cambisol with basalt outcrops with mica-xist and biotite gneiss (Baccaro et al., 2004).

The Nova Ponte Dam controls the water regime of the other dams, therefore, there are no water fluctuations and no floods in any period of the year on Miranda and Amador Aguiar dams, but this fluctuation is eminent in the Nova Ponte Dam. Near these dam-affected forests there are other three non-dammed SDTFs located distant to any water course and we will use these forests as a control (non-dammed) to verify damming impacts on the four forests located near dams.

The oldest dam (Nova Ponte Dam) was built in 1994, the second (Miranda) in 1998, the third (Amador Aguiar 1) in 2005 and the fourth dam (Amador Aguiar 2) in 2006. The Nova Ponte vegetation survey was made in 2014 (20 years of dam influence, named T20 forest), the Miranda survey occurred in 2013 (15 years of dam influence, named T15 forest), the Amador Aguiar 1 survey occurred in 2009 (4 years of dam influence, named T4) and the Amador Aguiar 2 survey was made in 2008 (2 years of dam influence, named T2). These forests located under the dam's influence were named "dam-affected" forests.

Tree sampling: All the inventories (non-dammed and dam-affected) were carried out in 20 permanent plots of 20x10 m in each area. A total of 10 plots were established close to the lakeshore created by the dam (named "riverside" sector), and remaining plots were set up 50 m distant of the river margin (named "above" sector) (see Figure 2A). The same procedures were taken in the non-dammed forests, however we called them "bellow" sector (the plot located at low altitude, avoiding edges) and "above" sector (set up 50 m distant of the below sector) because these forests had no dam water influence (Figure 2B). All trees with diameter

at breast height (DBH_{1,30}) of at least 4.77 cm were tagged with aluminum tags. Stem diameter was measured at 1.30 m from the ground. For multiple stems, all live stems were measured.



Figure 1. Location of four dams (AA1 = Amador Aguiar 1, AA2 = Amador Aguiar 2, MI = Miranda, NO = Nova Ponte), three non-dammed (ND) forests located 50 m distant from the dam’s water (ND1, ND2, ND3) and four forests located near the dam’s water in distinct times of dam’s water influence (T2, T4, T15, T20).

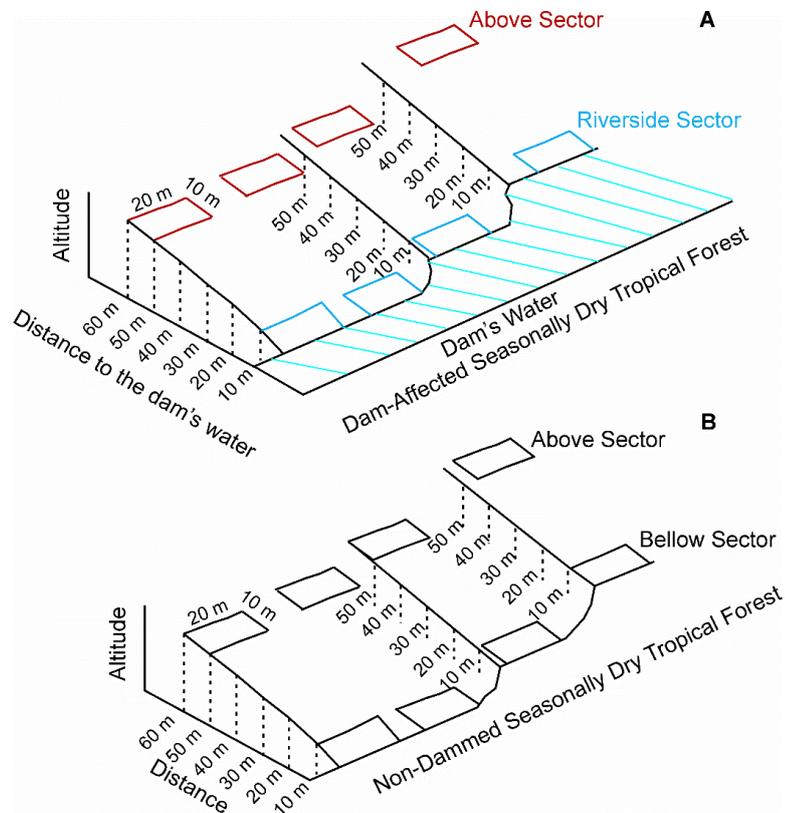


Figure 2. Plot scheme used to obtain tree community samples in the four dam-affected forests (A) and in the three non-dammed forests (B).

Analysis

After the inventories, the number of trees, basal area and richness of all forest sectors were compared using Analysis of Variance (ANOVA) followed by a Tukey test. These data were submitted to the Lilliefors Normality tests (Appendix 1) and all follow a normal distribution. Here we try to evidence differences between non-dammed and dam-affected forests. For these analyses we used the Systat 10.2 program (Wilkinson, 2002).

The floristic similarity between the sectors in each forest was compared using Jaccard's coefficient for presence/absence species data and the Morisita-Horn for species abundance to infer floristic and structural changes in forests. The floristic similarity between the sample plots located in both forest sectors were compared using Jaccard's coefficient and Morisita-Horn too. With these values we made an Analysis of Variance (ANOVA) followed by a Tukey test between all forests sectors. These data were submitted to Lilliefors Normality tests (Appendix 1) and all follow a normal distribution.

We used two multivariate techniques to analyse these data in an attempt to identify a dam's consequence for forests. First we made two cluster analysis with an agglomerate hierarchical classification by UPGMA (Unweighted Pair-Groups Method using Arithmetic Averages). The first cluster was made with the Jaccard's coefficient, as a measure of similarity, with binary data (presence/absence of species) in each sector. The second one was made with Morisita-horn as a measure of similarity, with the number of trees in each sector. Then, we made a divisive hierarchical classification by Two-Way Indicator Species Analysis (TWINSPAN) (Hill, 1979).

The species richness of each sampling unit was estimated based on bootstrap estimator and the results plotted in a rarefaction curve. For this analysis data were randomized 1000 times. For this analysis we used the Estimates program 7.5 (Colwell 2005).

RESULTS AND DISCUSSION

Most of our predictions were correct but some of the dam's water consequences are still unclear. We predicted many changes on the forest structure mainly after many years of damming: increase in richness, number of trees, basal area and diversity in the sectors located near the dam's water. Actually our predictions are correct, but not always and not for distinct times of a dam's water influence. In the long-time dam-affected forests, the changes due dam's influence were much higher for some parameters, but not for all parameters evaluated.

Forest Structure: The non-dammed forests and the dam-affected forests in two (T2) and four (T4) years had no differences in the number of trees, basal area and richness (Figure 3). The riverside sectors had a higher number of trees and basal than above (Figure 3a and 3b) at T15 and in the number of trees and richness at T20 (Figure 3a and 3c).

Forest structure: The forests sectors located close to the dam's water (riverside sectors) has more trees, basal area and/or richness, but not necessarily all parameters changes, even after many years of a dam's influence. Tree basal area, density of trees and richness near a dam's water are higher compared to water-distant sectors. After 15-20 years these values were more pronounced compared to forests with 2-4 years of dam's water influence. Other studies evidence the water access to trees and saplings increased the density and / or basal area and / or richness of these forests just a few (2-3-4) years after damming (Vale et al., 2014, 2015; Lopes et al., 2015), but the changes are larger according to the time of influence of the dam. In a study carried out in China, the richness of trees increased in areas affected by the waters of the dam (Liu et al., 2013) demonstrating that the effect occurred with different forest types.

In riverside sectors the number of trees became 60% higher in 15 years of damming and 95% for basal area compared to non-dammed forests, showing structural changes due to damming. The non-dammed dry forests had a mean of about 1300 trees.ha⁻¹ and 14m².ha⁻¹ of basal area and the riverside sectors of dam-affected forests surpassed 1900 tree.ha⁻¹ (T20) and 2700 trees.ha⁻¹ (T15), and had more than 21 m².ha⁻¹ (T20) and 37 m².ha⁻¹ (T15) of basal area. These densities are higher and the basal areas are similar to nearby riparian forests (Rodrigues et al., 2010).

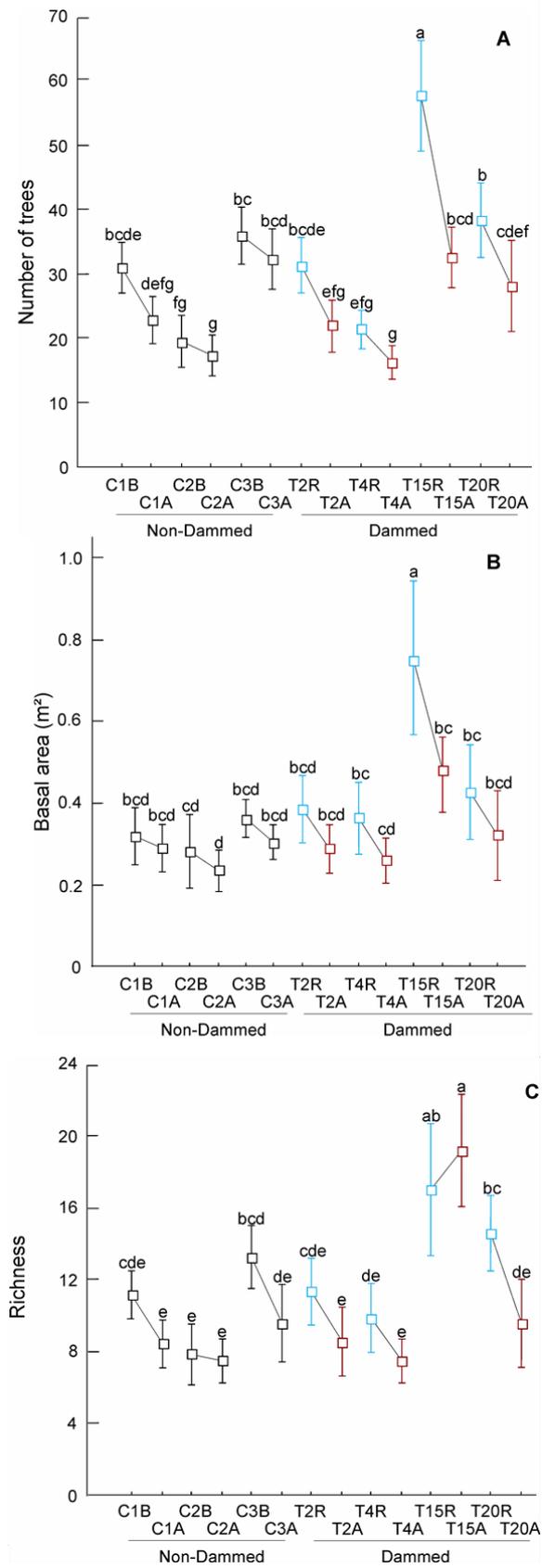


Figure 3. Analysis of variance of Number of trees (A), Basal area (B) and Richness (C) in three non-dammed affected forests and four dam-affected forests. C1, C2, C3 = control non-dammed forests, T2, T4, T15, T20 = dam-affected forests, A = above sector, B = below sector, R = Riverside sector. Small letters represents pos-hoc Tukey test differences.

The frontier between a dam's water and the forest is now an edge, and the death of some big trees due to drowning and anoxic soils (Vale et al., 2013) open spaces for the colonization of generalist light demanding species. This is a possible reason from the high density of trees in the riverside sectors. Many fast-growth light-demanding species such as *Myrsine umbelata* Mart., *Rhamnidium elaeocarpum* Reissek and *Piper aduncum* L., were found with high density in T15-T20 forests. In this way, after 15-20 years of damming effect, the forest structure and floristic changes can be considered high.

A dam's water enhances the soil moisture to at least 50 cm depth to at least 50% and was beneficial to non-associated water species (Vale et al., 2013). This increase in moisture compensates for the lack of water available to plants in the dry season making the environment less stressful, reduces the chance of root desiccation and increases plant basal area (Vale et al., 2013). Seasonally Dry Tropical Forests (STDF) are deficient in water supply (Pennington et al., 2009) due to the rain shortage in the drought season. This is the major factor which limits tree establishment for such forests which, however had a high soil fertility (Kilca et al., 2009; Siqueira et al., 2009). With water availability, many trees which otherwise would die in the dry season, or at least stop growing, can become larger and thicker (Vale et al., 2013) as many important reactions in the plant metabolism depend of water, such as is the case for photosynthesis.

Other tropical forests with no water limitation (such as Atlantic forests and Amazonian forest) have a basal area of over 25 m².ha⁻¹ and frequently exceed 30 m².ha⁻¹ while deciduous forests rarely exceed 25 m².ha⁻¹ and commonly had about 20 m².ha⁻¹ (Oliveira et al., 2014). In general, the basal area of riparian forests is as large as or larger than upland forests (Brinson, 1990) and the same occurs in a dam-affected forest, at least, in sectors located closest do the dam's water. Nevertheless, even enhancing the biomass accumulation does not compensate for the carbon lost by flooding of an original riparian vegetation (Vale et al., 2013).

Strong impacts tend to change a forest structure strongly, and this tends to stabilize over the years (Aide et al., 1995; Chazdon et al., 2005). However, the high structural values on forests affected by damming for a long time, does not mean stabilization. The T20 forest is a distinct case. The Nova Ponte Dam is the higher power plant in altitude and is located further upstream of the others dams. This dam regulates the water to the other dams (where T2, T4 and T15 forests are located) and the water levels of Nova Ponte Dam fluctuates largely. Therefore, in dry seasons, the water table frequently becomes 10-20 m distant from the forest edge and probably minimizes some of the water benefits effects for the trees. This same factor should influence other results, such as richness and similarity.

Similarity and Heterogeneity: The Jaccard similarity between sectors from the same forest were 58% for C1, 63% for C2 and 59% for C3, 47% for T2, 51% for T4 and T15 and 40% for T20. The Morisita-Horn similarity between sectors from the same forest were 91% for C1, 90% for C2, 84% for C3, 90% for T2, 89% for T4, 66% for T15 and 81% for T20. This means that the Jaccard similarity index for the dam-affected forests T2, T4, T15 and T20 were 10% less as compared to the non-dammed forest (Figure 4). For T20 the changes were more drastic and the similarity was 20% lower than a non-dammed forest. The Morisita-Horn similarity for T15 forest sectors had the lowest values and it means that the dam-affected forest can become very distinct in many years of impacts. This means not only changes on the flora but also into the dominant species in sectors near the dam.

The ANOVA between forest sectors shows no differences between non-dammed forests and dam-affected forests T2 and T4 (Figure 4). However, the Jaccard's ($DF = 6; F = 25.2; P < 0.001$) and the Morisita-Horn ($DF = 6; F = 25.8; P < 0.001$) were lower in the dam-affected T15 and T20 forests confirmed by the post-hoc Tukey test. It means that the forest sector located near the dam's margin became similarly distinct from sectors located far away from the dam's water (Figure 4). The UPGMA cluster based on Jaccard similarity index evidenced two groups (Figure 5a). The first division separated the forests impacted by dams for many years (T15 and T20) from the non-dammed and forests impacted shortly (non-dammed, T2 and T4 - Figure 5a). This means that a few years of damming did not change the species composition, but after many years of damming water influence, the differences are enhanced.

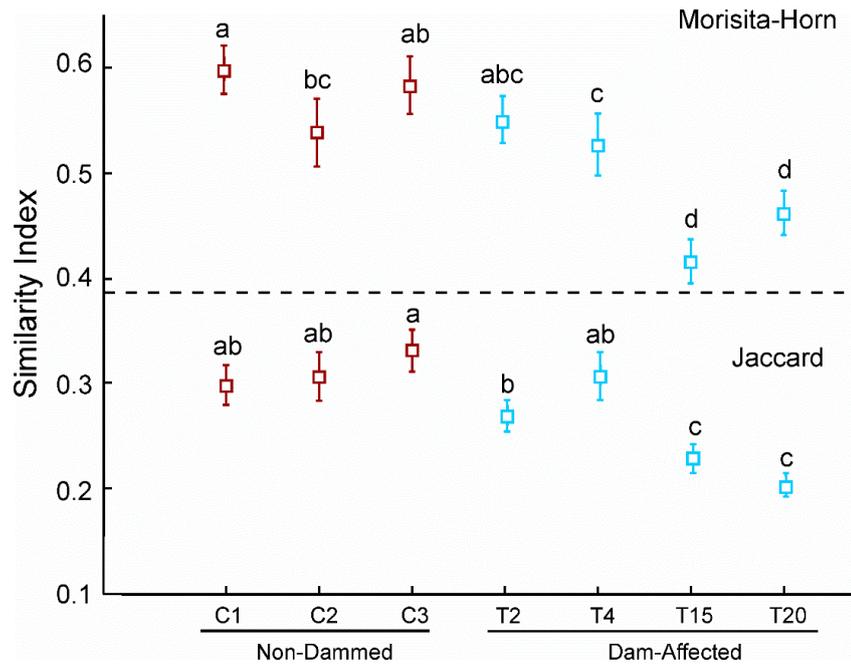


Figure 4. Analysis of variance between similarity of above-below sectors for non-dammed forests and above-riverside sectors for dam-affected forests for the presence-absence Jaccard Similarity Index and abundance Morisita-Horn Similarity index. C1, C2, C3 = control non-dammed forests, T2, T4, T15, T20 = dam-affected forests, A = above sector, B = below sector, R = Riverside sector.

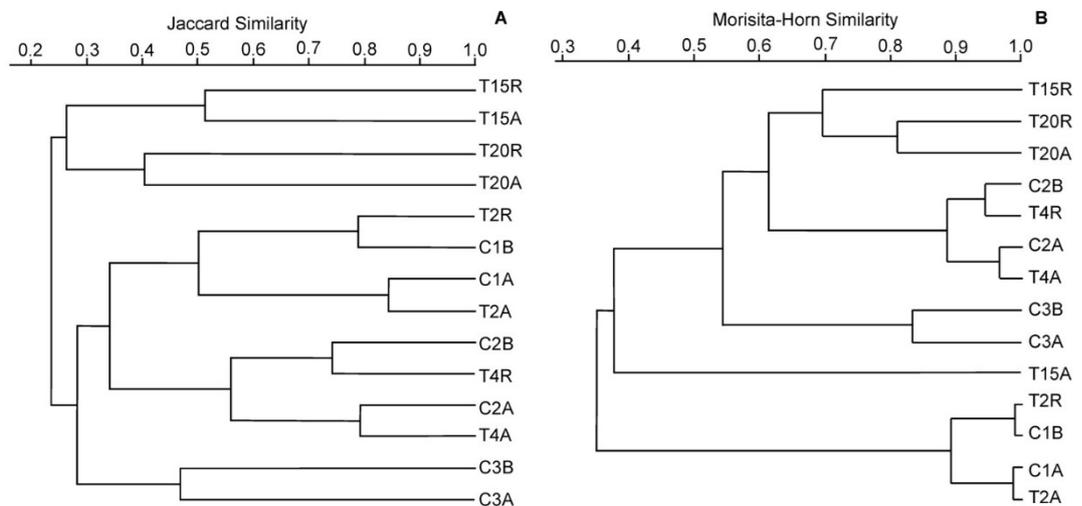


Figure 5. A and B Similarity cluster yielded by UPGMA Jaccard (A) and Morisita-Horn (B) similarity indexes for non-dammed and dam-affected forests. C1, C2, C3 = control non-dammed forests, T2, T4, T15, T20 = dam-affected forests, A = above sector, B = below sector, R = Riverside sector.

The UPGMA cluster based on Morisita-Horn similarity index did not separate the forests into two cohesive groups, but forms a gradient of variation between the forests and the sectors (Figure 5b). Again, dammed forest (both sectors near the artificial lake and T20 above) were grouped together, but not in T15 (Figure 5b). The non-dammed forests and forests impacted for a short time formed three other groups and did not increase damming water influence on the structure of these forests (Figure 5b).

The TWINSPLAN first division analysis showed the formation of four groups (Figure 6). The first division separated the C1 and T2 forests from the other sectors with an eigenvalue of 0.312. The species *Aloysia virgata* (Ruiz & Pav.) Juss. was the indicator species of the C1 and T2 forests (Figure 6). The second division separated the forests impacted by dams for many years (T15A, T15R and T20R) from the other forests with an eigenvalue of 0.416 (Figure 6). The

species *Allophylus sericeus* Radlk. was the indicator species of this group. The third division separated the T20A from the rest of the forests with eigenvalue of 0.418. *Annona sylvatica* A. St.-Hil. was the indicator species of this group (Figure 6).

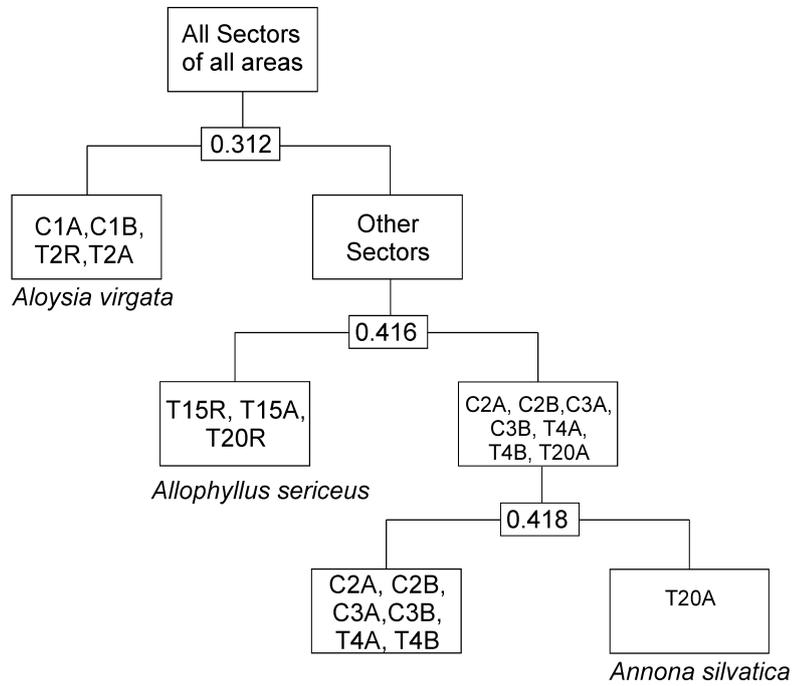


Figure 6. Two way indicator species analysis for three non-dammed and four dam-affected forests sectors. The species indicator species are highlighted.

The estimator evidence differences between the sectors located near the dam’s water (riverside) in comparison to those located distant from the dam’s water above (Figure 7). All dam-affected forests (T2, T4, T15 and T20) had higher values of species on riverside sector (in none of these the rarefaction curve stabilizes; see dotted lines – Figure 7). The sectors located distant from the dam’s margin of dam-affected forests (see continuous lines – Figure 7) are always very similar to the non-dammed forests (an exception was the T15 distant sector forest) and it means low differences even after 20 years of water containment for most cases. To the contrary, in all riverside sectors (T2, T4, T15 and T20) the richness values were much larger than in non-dammed forests and in above dam-affected sectors.

Unlike density and tree basal area, similarity can inform about quality changes due to damming. The most dramatic change possibly occurred in the species composition. In non-dammed forests the similarity between the sectors was about 60%, however in all dam-affected forests the similarity differences between riverside and above sectors were near or below 50%. This means a reduction in 10% of similarity only two years of dam’s influence; but after 20 years of damming the difference was about 20%.

The establishment of water-associated species such as *Cecropia pachystachya* Trécul., *Inga sessilis* (Vell.) Mart., *Cheilochlinium cognatum* (Miers) A.C. Sm., *Protium heptaphyllum* (Aubl.) Marchand, *Piper aduncum* L. contributed to these similarity differences. The increase of soil moisture due a dam, which can reach 50 cm of soil depth (Vale et al., 2013) allows the germination and establishment of various kind of seeds and clearly enhances the establishment of species which may not support the intense dry season. The indicator species from the dam-affected forests, *Allophylus sericeus* Radlk. and *Annona sylvatica* A. St.-Hil. for example, are flood-tolerant and inhabit environments with humid soils commonly found in moisture forests (Martins, 2007; Braga et al., 2015). The dam’s water creates a new condition of water supplies that enhances environmental heterogeneity and divides the community into two main communities: a “riparian-dry forest”

(riverside sectors), and a common dry forest (a water stressed forest – above sector) 50 m-distant from the dam's water (more similar to a common dry forest).

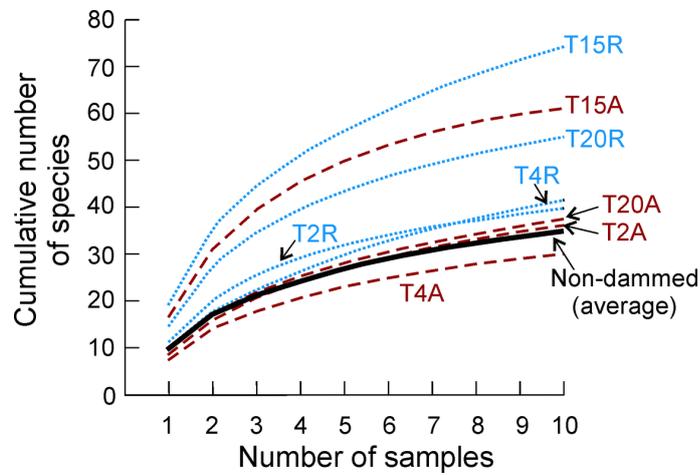


Figure 7. Rarefaction curve of the cumulative number of species estimated by Bootstrap estimator for non-dammed and dam-affected forests sectors. Black line = average curve for non-dammed forests, T2, T4, T15, T20 = dam-affected forests, A = above sector, R = Riverside sector.

We can infer that dam impact alters the floristic composition and/or structure, but it is difficult to understand the trajectory after many years of disturbance, as the changes may be more pronounced in floristic composition or can be more structural. In all cases, some water associated species and light demanding species will become established and the dominance of dry-associated species will be reduced in riverside sectors. This means a reduction on the dry forest occupation in environments close to dams, which will be diminished to a narrow strip of the original area and thus threatening these systems much more than previously to the dams. To keep these forest areas and their ecological benefits we believe that more than 50 m of forest should be preserved in order to protect the riparian strips and the original dry forest.

The changes due to damming become evident when the estimated richness and how a different impact can alter the communities are compared. For all dam-affected forests the riverside sectors' estimated richness was higher than the non-dammed forests and the sectors distant to the dam (above sectors). Riparian systems commonly show high heterogeneity perpendicular to the watercourse (Rodrigues & Nave 2000; Ribeiro & Walter, 2001) and high richness compared to inland patches; however, this occurs naturally in the environment. In the present case the heterogeneity occurred due a human impact which increased the water supply allowing new species to get established near the dam. Even in T20, where the dam's water not always reaches the flood level, the occurrence of water-associated species shows the dam's influence over the years. Therefore, damming can be considered a continuous disturbance.

Differently from freezes, storms or bushfires; the damming water supply is continuous near the forest, providing water to the forest margins and transforming them gradually into a new environment, becoming closer to a riparian system. This modification of a dry forest into a riparian forest probably will not be complete. For example, some important species of dry environments even after 15, 20 years still persist on patches near the dam with high abundance; however now without their initial dominance. They are still important, but not with the same number of trees or tree basal area. It is still not clear what will happen to these forests after 50 and 100 years; but we believe it will be into a stabilization of a mature forest. Many works show that the damming influences is strong in the first years of impact but stabilize over the years (Vale et al., 2014, 2015, 2017).

Such an effect is clear for the aquatic vegetation (Moura Júnior et al., 2011); fishes (Azami et al., 2012) and invertebrates (Rezende et al., 2009; Patz et al., 2000), trees (Vale et al., 2015) and saplings (Vale et al., 2014). However, trees are long lived biological entities and this

stabilization seems to take many years. The dams' consequences for flora were also known in temperate environments, where it was shown that the river impact led to fewer tree species than in non-dammed forests (Jansson et al., 2000; Nilsson & Svedmark, 2002; Dynesius et al., 2004). Riparian forests in this region have more species than the expected richness in all dam-affected forests; and thus we conclude that these forests will never become similar in their flora richness in comparison to a natural and common riparian forest. Natural riparian zones are among the most diverse, dynamic, and complex habitats in the world's continents (Naiman; Decamps, 1997) mainly because riparian systems have many factors that increase the heterogeneity and chances for many species to occur, such as flood and topography (Liu et al., 2013; Jansson et al., 2005).

General conclusions and/or themes for future researches are: For T15 the richness surpasses the richness of all forest (except for the close to the dam strip). Does this mean that for some forest the damming water can reach 50 m of distance from the dam/forest edge? According to our experience we believe that the answer should be: yes. Each forest, even if very similar in structure and flora, had its own topography. Probably even with many expected consequences of dam impacts, each forest can react in distinct ways and distance from the dam's water. New studies may elucidate better the distance up to where the impact can reach. In this study, the impacts were very clear at 10 m of distance from dam's water but can reach up to 30 m (Vale et al., 2013, 2014, 2017); and we found forest changes even 50-60 m distant from the dam's water. In order for the dry forest to maintain its original flora the protection area should be greater; at least 60-70 m distant; a much greater value observed than given in the present Brazilian legislation – Brasil 2012 – New Forestry Code) which protects only 30 m distant from a dam's water. Based on our results, we need much more of a protected area.

Many studies in impacted forests demonstrated structural changes a few years after great disturbances like storms (Walker 1991; Burslem et al., 1995; Pascarella et al., 2004; Laurance et al., 2006); fragmentation due to edge effects (Laurance et al., 2002, 2006); timber removal (Guariguata et al., 2008) and severe dry periods (Chazdon et al., 2005); nevertheless with a forest structure recovery and composition over the years (Chazdon et al., 2007). Here we showed that the dam's consequences are continuous and difficult to foresee without a long-time period of monitoring. This is a key problem because the extremely diverse tropical systems are affected by dams (Nilsson et al., 2005) and all forests in the tropics which suffer similar overflow after damming tend to present high species changes.

CONCLUSION

Changes in the hydrological regime caused by dam's start a secondary succession phase with establishment of many water associated species and light demanding species and changes the dry forests into artificial riparian forests (called "Riparian Effect"; Vale et al., 2015). Hence the dry forest near a dam turns into a riparian-edge-forest but still similar to a dry forest in certain aspects even after 20 years. These forests have a higher richness of species, dense and thicker basal area than a common dry forest, but still with less richness, dense and thicker than a common riparian forest. Thus we can infer that these forests, after 15, 20 years turn into a kind of "transition" of a dry-edge-riparian system. However, more than 50 m of distance from the dam's water the forests can still maintain their forest structural properties; but not always. The increase in species richness and diversity does not mean a "total" conversion of these dry forests into a typical riparian forest due to the maintenance of most species on the community, and with few species being lost.

These forests may not be considered as common and natural riparian forests as they present less density, tree basal area and richness than a natural riparian forest does. The increase in richness and diversity can not overcome the loss of species drowned by the damming. This increase in richness may be treated as one more impact of dams to the flora. However, unlike other transitory disturbances (winds, intense dry periods, cold), damming is a permanent alteration and transforms the landscape into another scenario, probably with major long-term consequences for the environment, and therefore we consider this "riparian-deciduous forest" as a transition between the deciduous forest and the water containment forest.

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APPENDIX 1

Normality test for number of trees, basal area and richness data by sector. ND = non-dammed, B = below sector, T2= forest located near dam's water for two years, T4= forest located near dam's water for four years, T15= forest located near dam's water for 15 years, T20= forest located near dam's water for 20 years,

Number of trees	ND1 B	ND1 A	ND2 B	ND2 A	ND3 B	ND3 A	T2 B	T2 A	T4 B	T4 A	T15 B	T15 A	T20 B	T20 A
Lilliefors L	0,1559	0,2117	0,1637	0,1759	0,2	0,1643	0,1339	0,2004	0,1805	0,2502	0,1598	0,2641	0,153	0,1438
p(normal)	0,6961	0,2268	0,6217	0,5049	0,3034	0,6153	0,8784	0,3002	0,4625	0,07225	0,6588	0,04531	0,7232	0,804
Basal Area	ND1 B	ND1 A	ND2 B	ND2 A	ND3 B	ND3 A	T2 B	T2 A	T4 B	T4 A	T15 B	T15 A	T20 B	T20 A
Lilliefors L	0,2437	0,1948	0,1507	0,1837	0,2254	0,1773	0,1593	0,2083	0,1293	0,147	0,2427	0,1698	0,1777	0,1807
p(normal)	0,08932	0,3427	0,7443	0,4345	0,1556	0,4919	0,6636	0,2476	0,9074	0,7772	0,09228	0,5631	0,4888	0,4608
Richness	ND1 B	ND1 A	ND2 B	ND2 A	ND3 B	ND3 A	T2 B	T2 A	T4 B	T4 A	T15 B	T15 A	T20 B	T20 A
Lilliefors L	0,2316	0,209	0,175	0,2146	0,2487	0,148	0,1396	0,2126	0,1851	0,209	0,2507	0,2051	0,189	0,2176
p(normal)	0,1296	0,2431	0,5136	0,2097	0,07601	0,7679	0,8375	0,2213	0,4217	0,2431	0,07111	0,2681	0,3889	0,1934

Normality tests based on forest sectors similarity. ND = non-dammed, B = below sector, T2= forest located near dam's water for two years, T4= forest located near dam's water for four years, T15= forest located near dam's water for 15 years, T20= forest located near dam's water for 20 years,

Jaccard	ND1	ND2	ND3	T2	T4	T15	T20
Lilliefors L	0,1044	0,1349	0,09459	0,111	0,1322	0,09204	0,1392
p(normal)	0,5436	0,1989	0,699	0,442	0,1925	0,7383	0,1392
Morisita	ND1	ND2	ND3	T2	T4	T15	T20
Lilliefors L	0,1114	0,106	0,1185	0,1361	0,121	0,1466	0,1011
p(normal)	0,4362	0,5184	0,3388	0,1613	0,3089	0,09613	0,5957