Review Article

LANDSCAPE CHANGES AND HABITAT FRAGMENTATION ASSOCIATED WITH HIDROELECTRIC PLANTS RESERVOIRS: INSIGHTS AND PERSPECTIVES FROM A CENTRAL BRAZILIAN CASE HISTORY

MUDANÇAS NA PAISAGEM E FRAGMENTAÇÃO DE HABITATS ASSOCIADAS A RESERVATÓRIOS DE USINAS HIDRELÉTRICAS: INSIGHTS E PERSPECTIVAS DE UM ESTUDO DE CASO NO BRASIL CENTRAL

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ABSTRACT: Dams are important sources of hydroelectric power and many are being built in Brazil without a clear understanding of the environmental consequences. Here we review the biological impacts of these construction and discuss a particular case history in the Araguari river basin. Many studies showed structural changes in plant and animal populations, both in temporal and spatial scale, and works about the negative impacts of hydroelectric power plants have intensified over the years. However, the detailed consequences of the landscape fragmentation imposed by dams on plant and animal populations are still unclear. A reservoir creates a huge lakeshore, isolating areas previously connected, and transforming the environment in a mosaic of fragmented habitats. This new discontinuity can modify local biodiversity and affect important processes to fauna and flora maintenance, such as dispersal and migration ability. The new conditions imposed by a reservoir also increase soil moisture, temperature, light incidence and air speed, which alter plant communities located on the lakeshore of these dams. We carried out some such studies on forests affected by dams located on the Araguari River basin and some of them showed changes in the arboreal communities and on the regeneration of seedlings, saplings and young trees after damming, suggesting modifications on structure, composition and functions of these forests.

KEYWORDS: Dam. Fragmentation. Ecosystem services. Paranaiba river basin.

INTRODUCTION

The construction of dams for hydroelectric power has been carried out in many Brazilian regions without a clear understanding of the environmental consequences. The hydroelectric plants (HEP) construction causes forest fragmentation with isolation of plants and animals populations (NILSSON, 1996; HUMBORG et al., 1997; JANSSON et al., 2000). The riparian forests, which are usually continuous along the rivers, become isolated due to dams construction (NILSSON; BERGGREN, 2000). These constructions can restrict gene flow of plants and animals, eroding the genetic and functional diversity over the years, exposing these populations to severe environmental changes. Here we revise some of the ideas and experiences on the impact of hydroelectric plants reservoirs on natural landscapes with the focus on some specific situations in Central Brazil.

Urbanization and industrialization in recent decades, associated with technological advances, have increased the demand for electricity. Hydroelectric power nowadays has represented 16% of all energy produced in the world (EVANS et al., 2009) and almost 80% of the electricity produced to Brazil (ONS, 2006). The power generation expansion is supposed to include new areas such as the Amazon basin, which responds, together with the North Atlantic/Northeast basin, for only 1.5% of the Brazilian installed generation plants. It has been estimated that in the coming years, at least 50% of the electricity generation expansion in Brazil will be hydroelectric, mainly from investment in small hydropower plants (SHP), which in theory would cause less impact to the environment and can supply small municipalities (ANEEL, 2002).

The installation of reservoirs imposes significant changes to the water basin functioning both in temporal and spatial scale (JANSSON et al., 2000). The dam and its reservoir significantly alter the physical, chemical and biological ecosystems in the region (GROVE et al., 1998). After the dam closure, the water level rises fast, reaching the planned level and causing plant mortality by anoxia (FEARNSIDE, 2002; WHITE, 2007). Moreover, to hydroelectric use, the level of the reservoir fluctuates, which influence the hills stability

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(TRUFFER et al., 2003), causing landslides on the shores of the lake (CENTURION et al., 2001) and causing tree fall and changing habitats.

Due to its importance, a range of 100 meters wide around the shore of artificial lakes created by HEP is considered as Permanent Preservation Areas (PPAs). These areas provide important environmental functions such as control of geological stability and soils protection, and preserve water resources, landscape, and biodiversity, and they should also conserve and promote gene flow of flora and fauna (NAIMAN; DECAMPS, 1997; NILSSON; BERGREEN, 2000; GUNDERSEN et al., 2010). These PPAs cannot be modified by human populations and usually no intervention is allowed. The riparian vegetation is the natural defense of these landscapes and improves soil structure, protecting it against the rainfall impacts (KILEY; SCHNEIDER, 2005; HUBBLE et al., 2010), slowing down water runoff by increasing the surface friction and groundwater infiltration (GUO et al., 2007).

However, despite the PPAs environmental protection services, the discussion about the negative impacts of hydroelectric power plants had intensified over the years. Changes in flow regime and its environmental consequences were the most published. The transformation of lotic (running water) to lentic aquatic environment (standing water) may favor the proliferation of disease vectors (GUIMARÃES et al., 1997; PATZ et al., 2000; FEARNISIDE, 2001), hinders fish migration (AGOSTINHO et al., 1994; FEARNSIDE, 2001; FEARNISIDE, 2005; JOY; DEATH, 2001), and favors the loss of ecological diversity in regions affected by these developments (TERBORGH et al., 1997). However, the terrestrial habitats and ecosystems fragmentation due to the implementation of multiple dams and their consequences on plants and animals populations are little known and are yet to be studied for Brazilian HEP.

Habitat and ecosystem fragmentation – impacts on the flora and fauna

The fragmentation is the process of breakdown of an environmental unit in fragments, more or less isolated. Around the HEP reservoirs, for example, these fragments end up with very distinct environmental conditions than those existing before dam installation. The overall process of habitat fragmentation is possibly the most profound and widespread change caused by man to the environment (COLLINGE, 1996). Many natural habitats, before almost continuous landscapes, were transformed into a mosaic, consisting of isolated patches of original habitat. The distribution of fragments across the landscape and the types of landscape elements that separate or connect them determine the isolation degree of populations in these fragments (FISCHER; LINDENMAYER, 2007).

Currently, several rivers in the world (approximately two thirds of the world's greatest rivers) are regulated and fragmented by dams, with hydrologic regime and landscape changes (NILSSON et al., 2005). The damming and reservoir flooded areas form a mosaic of distinct and isolated fragments, severing connections and threatening preservation of plants and animal populations (HUMBORG et al., 1997; NILSSON; BERGREEN, 2000). Thus, the discontinuity between the fragments formed by the damming can modify local biodiversity. The process of dispersal and migration between continuous areas is usually interrupted (JANSSON et al., 2000). With area loss, a decrease of faunal carrying capacity of these fragments to sustain viable populations also decreases (NILSSON; BERGREEN, 2000). Furthermore, since the fragment faunal diversity determines the possibility of the species movements between these fragments, the establishment of new trees in the matrix itself, by animal dispersion process or by seed rain, is also interrupted (PIVELLO et al, 2006).

Besides the discontinuity and fragmentation process, the survival and reproduction of plant populations are usually affected by edge changes (edge effect; MURCIA, 1995), as those edge areas come in contact with different surrounding matrix, including contact with water from the dam. Two important consequences of dam creation are the increase in soil moisture (GUSSON et al., 2011) and wind on the lakeshore, which alter forest microclimate and soil moisture (LAURENCE et al., 2002). In these places, there are changes in soil and air temperature, light incidence, water deficit, and air speed (LAURENCE et al., 2002). Recent studies with plant communities in hydroelectric plants show high mature trees death rate in areas near reservoirs, just few years after damming, due to changes in soil moisture (JOHANSSON; NILSSON, 2002).

Plant species that occur near HEP reservoirs (and near the water) may suffer local extinction, when soil moisture goes up after damming (NILSSON; BERGREEN, 2000). On the other hand, some dams create course sections were the river water has a reduced flow (SRF) due to technical requirements for the best hydroelectric use. In these sections, there are also changes in moisture conditions, but the soil becomes drier. In both cases, the initial plant species tend to modify their leaf size and branch weight, which enhance the rates of carbon assimilation after the environmental changes to its occurrence area (VALLADARES et al., 2007). These acclimations reflect the plant capacity to adapt to this variable environment. Those plants with no effective acclimation may disappear locally. Since plants are sessile organisms, they cannot move actively to escape from disturbance, and represent one of the first groups of organisms to suffer the consequences of human disturbance (FEARNSIDE, 2002; WHITE, 2007). In these cases, the early life stages of plants species appear to have the most intense and immediate responses to damming and fragmentation, which could affect the future composition (diversity) of forest (GUSSON et al., 2011).

The changes in species composition and structure of the forest may also influence changes in local fauna and thus on the entire ecosystem (ecosystems fragmentation), due to animal-plant interactions (SEKERCIOGLU, 2011). Thus, if some plant species are replaced in a particular forest, animal species that depend on them to feed will suffer a decrease of population density (DIRZO; MIRANDA, 1991), an event called defaunation (NORRIS et al., 2011). Therefore, the plants can be considered good indicators of various changes in natural ecosystems.

Thus, the installation of hydroelectric plants modifies the natural landscape, transforming it into a mosaic of fragmented patches. This discontinuity in the landscape implies profound changes in population structure of flora and fauna. Some groups, those most exigent of resources and conditions (rare and/or endemic, specialist plant and animal species), are more likely to local extinction than others generalist species groups (GUSSON et al., 2011). In this perspective, there is a need for more detailed studies to analyze and understand the main consequences for the conservation and management of populations of flora and fauna after hydroelectric plants installation. Cases such as the multiple dams of the Araguari river basin in southeastern Brazil are natural experiments that should be further explored.

Historically, hydroelectric plants in Brazil were large and concentrated along large rivers basin with high water flow and hydroelectric potential in order to justify investment both in damming structure but also in transmission grid and operation. About 60% of installed hydroelectric capacity in Brazil is located in the Paraná River basin (Southeastern Brazil). This large basin includes the sub-basins of the Rivers Grande, Paranapanema, Tietê/Iguaçu and Paranaíba. The river Araguari is inserted in the Paranaíba sub-basin and it is located in the western portion of the State of Minas Gerais, running mostly across the Triângulo Mineiro region. This sub-basin covers a geographical area of approximately 21,000 km^2, comprising the territories of 20 municipalities in Minas Gerais state. The Araguari has a total length of 475 km from its spring in the municipality of São Roque de Minas, in the Parque Nacional da Serra da Canastra, to its outfall in the Paranaíba river (ANA, 2012). The Araguari potential energy is already being exploited along its entire length, with four medium size hydroelectric plants (HEP) of Nova Ponte, Miranda and the recently installed HEP Amador Aguiar I and II (Figure 1, Table 1).

Table 1. Characteristics of the Hydroelectric plants installed along the River Araguari, in the Triângulo Mineiro region, state of Minas Gerais, Brazil.

	Installation year	**Operation year**	**Dam area (Km^2)**	**Installed capacity (MW)**
Nova Ponte	1987	1994	299.0	510
Miranda	1990	1998	51.6	408
Amador Aguiar I	2003	2006	18.0	240
Amador Aguiar II	2005	2008	46.0	210

The first studies for hydroelectric use of the Araguari river were conducted between 1965 and 1987. The first hydroelectric plant installed was Nova Ponte in 1987, still the largest on the Araguari river and located furthest upstream (SILVA, 2009). Besides generating electricity, this plant aimed to regulate the river flow, allowing the construction of the remaining plants downstream. The Miranda HEP was the second on the Araguari river, built in 1990 (FLAUZINO, 2008). This complex also comprises the hydroelectric Amador Aguiar I (SIQUEIRA et al., 2009) and Amador Aguiar II (KILCA et al., 2011), planned and built downstream from Miranda (Figure 1).

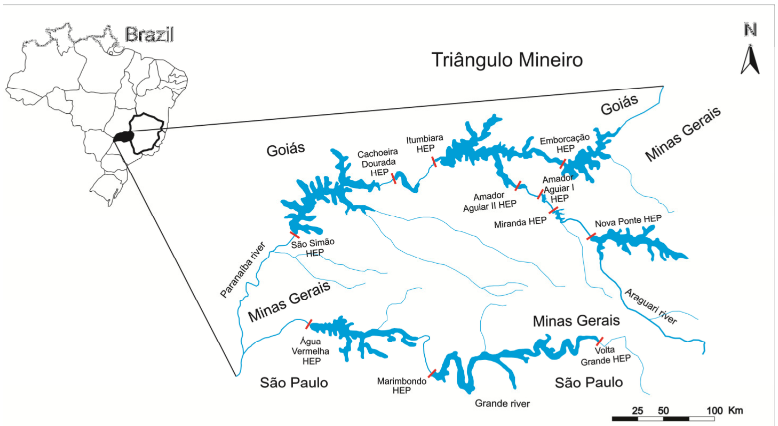

Figure 1. Triângulo Mineiro region with the location of Hydroelectric plants (HEP) installed along the Araguari and neighbour river basins, state of Minas Gerais, Brazil.

Since the dam construction on Araguari River Basin, many environmental studies were made on the dam influence area. The pattern of influence of the damming process in the area (Figure 2) involved flooding of riparian forest areas (actually cut down before flooding) and breakdown of the continuity among forest areas. Moreover, some dry forest patches were brought near the reservoir shore and were submitted to changes in moisture conditions. At least two studies confirmed the soil moisture increase, especially during the dry season, for forests located near the Araguari Dam reservoirs, causing many vegetation changes (GUSSON et al., 2011; VALE, 2012). Gusson et al. (2011) showed several changes on the regeneration layer of two typical dry forest species: *Myracrodruon urundeuva* Allemão and *Anadenanthera colubrina* (Vell.) Brenan. The first one was much more negatively affected by damming, and many seedlings, saplings and young trees died after the dam's construction. However, many new trees of *A. colubrina* established themselves on the same areas. As these two species are very similar in the environment, both canopy, deciduous and abiotically dispersed trees, the landscape theoretically would not loose its ecosystem functions. Otherwise, on the same forests, a recent thesis study (VALE, 2012) shows the establishment of animal dispersed species adapted to high moisture environments, such as *Protium heptaphyllum* (Aubl) Marth., *Cecropia pachystachya* Trécul and *Inga sessilis* (Vell) Mart. These changes have led to species composition, structure and ecosystem functioning changes in these forests. These changes may lead also to general landscape changes, as reduced carrying capacity for the fauna and restriction to seed dispersal and faunal migration.

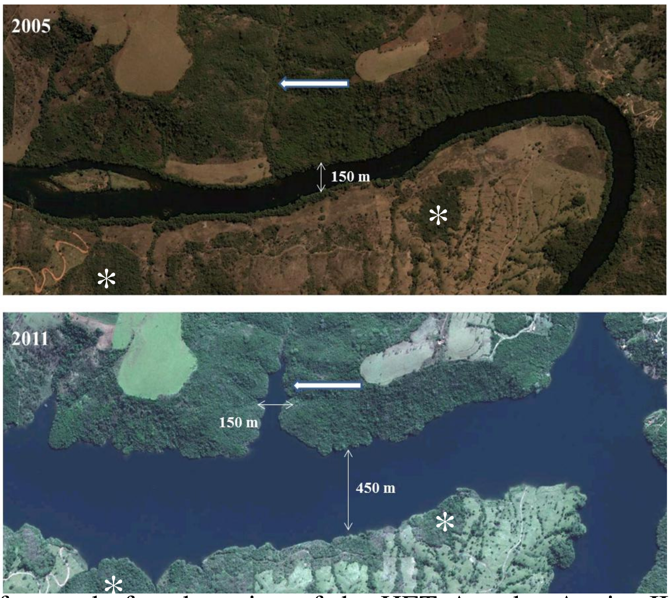

Figure 2. Satellite images before and after damming of the HET Amador Aguiar II, state of Minas Gerais. Arrows indicate habitat discontinuity after flooding. Notice also the dry forest patch brought near the reservoir shore (*).

Conclusive remarks

The benefits of energy generation by the construction of hydroelectric power plants in the country are clear and relevant in the face of a growing demand in all sectors of the economy in Brazil. However, during the process of implementation of these major projects, it should be given serious consideration to the environmental impact studies and mechanisms of licensing required by existing state agencies so that the direct and indirect consequences for biodiversity are minimized. The loss of genetic diversity of fauna and flora populations, and the drastic changes of ecosystem functions directly affected by these developments raises an alert for the acceptance of development demands without considering sustainability issues and future benefits for the maintenance of these ecosystems. The Araguari river studies provide an overview of the prospects and trends for Central Brazilian region HEP reservoirs and reinforce the need of careful planning and continuous monitoring to minimize habitat and diversity loss.

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RESUMO: Represas são importantes fontes de energia hidroelétrica, porém muitas estão sendo construídas sem um conhecimento claro dos impactos ambientais. Muitos estudos mostraram que plantas e animais modificam sua estrutura, tanto em escala temporal quanto espacial, logo os estudos sobre as consequências negativas das represas têm se intensificado nos últimos anos. No entanto muitas consequências em populações de plantas e animais são pouco conhecidas, sobretudo a fragmentação da paisagem imposta pelo represamento. Um reservatório cria um grande lago que isola áreas, antes conectadas pela continuidade terrestre e transforma o ambiente em um mosaico de habitats fragmentados. Esta descontinuidade pode modificar a biodiversidade local e afetar importantes processos da manutenção de fauna e flora, assim como dispersão e capacidade de migração das espécies. As novas condições impostas pelo reservatório ainda aumentam a umidade do solo, a temperatura, a incidência de luz, e a velocidade do ar, que alteram a comunidade de plantas localizadas ás margens do lago afetado por essas represas. Portanto, novos estudos vêm sendo necessários para entender a complexidade das modificações na paisagem e ecossistemas após a construção de represas, e assim muitas investigações estão sendo realizadas na bacia do Rio Araguari. Estes estudos têm mostrado severas modificações nas comunidades arbóreas e na regeneração de plântulas e árvores jovens após o represamento, sugerindo modificações na estrutura, composição e funcionamento destas florestas.

PALAVRAS-CHAVE: Reservatórios artificiais. Adaptação. Serviços ecossistêmicos. Bacia do Rio Paranaíba.

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