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Review

Consequences of suppressing natural vegetation in drainage areas for freshwater ecosystem conservation: considerations on the new “Brazilian forest code”

Marcelo Henrique Ongaro Pinheiro[1*], Lucélia Nobre Carvalho[2], Rafael Arruda[2] and Frederico Augusto Guimarães Guilherme[3]

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ABSTRACT

The input of particulate and dissolved organic matter (POM and DOM, respectively) from terrestrial ecosystem drainage basins is an important energy and nutrient source in limnic food chains. Studies indicated that semi-deciduous seasonal forests located in drainage areas in Brazil have the potential to produce 7.5 – 10.3 Mg ha^{-1}/year of POM. The global increase in vegetation destruction, such as forests, threatens this allochthonous resource and can have significant impacts on river and lake communities and food chains. Therefore, it is critical that exploitation and occupation protocols are updated to protect the transition areas between terrestrial and limnic ecosystems. This review highlights the existing knowledge of these ecosystem interactions and proposes responsible sustainable methods for converting the vegetation in drainage basins. This was based on Brazilian ecosystem data and the new “Brazilian Forest Code.” This study also considers the importance of including flood tracks in permanently protected areas to improve Brazilian legislation and protect hydric resources.

Keywords: freshwater biodiversity, freshwater food chains, freshwater resources, riparian forests, watershed

Introduction

According to the United Nations GEO-5 report (United Nations Environment Programme 2012), the global loss in forest cover is occurring at an alarming rate. Although the deforestation rate decreased by approximately 3 million ha/year from 1990 (losses of 16 million ha/year) to 2000 (losses of 13 million ha/year), this is still an insufficient reduction. The destruction of forested areas, stimulated by economic exploitation and demographic expansion (Angelsen & Kaimowitz 1999), should be closely observed. In the past 50 years, a considerable loss of biodiversity and ecosystem impairment has been observed primarily because of non-sustainable agricultural practices (Tilman *et al.* 2002). Watershed vegetation provides an important energy and nutrient input in limnic ecosystems (Lampert & Sommer 2007) and will ultimately lead to its suppression when exploited (Naiman & Decamps 1997; Naiman *et al.* 2000; Aitkenhead-Peterson *et al.* 2003; Bertilsson & Jones 2003; Davies *et al.* 2008). This loss of vegetation threatens food chains through on-going eutrophication, chemical contamination, and sedimentation (Moss 2010).

In 2009, 3.3 and 1.5 billion hectares of land were occupied worldwide by pastures and fields, respectively, of which Latin America and the Caribbean accounted for 27% and 8.4%, respectively (United Nations Environment Programme 2012). Because of the suppression process in natural landscapes for the deployment of agroecosystems, Latin America and Africa were responsible for the highest rates of global deforestation. Brazil comes under increasing pressure from consumers for their commodities, and non-governmental organizations, with their policy for environmental protection, could contribute significantly to the reduction of illegal logging (United Nations Environment Programme 2012).

In this context, discussions prior to the approval of Law 12.651/12, which established the so-called new “Brazilian

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[1] Faculdade de Ciências Integradas do Pontal, Universidade Federal de Uberlândia, Campus Pontal, 38304-402, Ituiutaba, MG, Brazil
[2] Instituto de Ciências Naturais, Humanas e Sociais, Universidade Federal de Mato Grosso, Campus Universitário de Sinop, 78557-267, Sinop, MT, Brazil
3 Instituto de Biociências, Universidade Federal de Goiás, Regional Jataí. BR 364, Km 192, Parque Industrial, 75801-615, Jataí, GO, Brazil
[*] Corresponding author: mhop@pontal.ufu.br

Forest Code," were marked by concerns from conservationists. They warned both civil and political societies about the likely threats to terrestrial and limnic ecosystems if developmental bias takes precedence over sustainability and the preservation of natural resources. These warnings, which were issued to legislators by researchers and specialists in the conservation of Brazilian natural resources, were motivated by the risks arising from a law that proposed to assure "the continuity of national agricultural development." This new legislation would regulate the exploitation of the forest ecosystem, define the extension of riparian and gallery forest cover, and influence the function of limnic ecosystems (Ramírez *et al.* 2008). According to Ab'Saber (2010), the new law may increase the human interference of natural ecosystems and biodiversity by permitting, for example, a reduction in riparian forest cover. The expansion of economic activities such as agriculture, livestock production, and logging that would be sanctioned by the new legislation could lead to considerable environmental impacts on limnic ecosystems and the species that are dependent upon them (Casatti 2010; Tundisi & Tundisi 2010; Magalhães *et al.* 2011; Ferreira *et al.* 2014).

The concerns of researchers and conservationists are clearly recognized when the losses of the original Brazilian vegetation cover that occurred prior to 2004 is examined. The *Cerrado* (Brazilian savanna), a highly threatened Brazilian biome and unique ecoregion, had lost 55% of its original area by 2004, and the Pantanal, a tropical wetland area, saw a 17% suppression of its vegetation (Machado *et al.* 2004; Harris *et al.* 2005; Carranza *et al.* 2014). The area occupied by savannah formations, primary and secondary forests, mangroves, and sandbank vegetation was reduced by 3.8 million hectares (SMA 2005) between 1962 and 2001 in the state of São Paulo alone. Some regions of Brazil have suffered large losses in vegetation cover because of the biofuel agribusiness, which flourishes to the detriment of natural ecosystems (Lewinsohn 2011). All of these recent losses in natural vegetation corroborate the concerns raised about environmental degradation by researchers and activists.

Importance of drainage basins

The vegetation of drainage basins and riparian forests is known for its role in maintaining local biodiversity (Turner *et al.* 2001) and acting as corridors for animal migration (Metzger 2010). Their influence on limnic bodies is also important through the deposition of particulate and dissolved organic matter (POM and DOM, respectively) and nutrients via mineralized accumulated litterfall (Naiman & Decamps 1997; Allan 2004; Moss 2010). POM and nutrients can be transported to these limnic bodies from distant areas by floods as well as by wind (Chapin *et al.* 2002; Baldock 2007; McNeill & Unkovich 2007). Watershed deforestation may lower the DOM and nutrient inflow into rivers, streams, and lakes (Lawton *et al.* 2001). This decrease in nutrients such as nitrogen (N), phosphorus (P), silicon, and organic carbon modifies the chemical composition of the water, thereby influencing food chains and leading to a decrease in primary limnic productivity (Neill *et al.* 2001; Aitkenhead-Peterson *et al.* 2003; Lampert & Sommer 2007).

An equally important function performed by riparian forests is the sequestration of stress agents such as pesticides and fertilizers that come from adjacent agricultural areas (Vaithiyanathan & Correll 1992; Schönborn 2003; Sweeney *et al.* 2004; Wantzen *et al.* 2008; Gücker *et al.* 2009). The riparian forests reduce the harmful disturbance of those stressors on biotic components, maintains limnic body function (Allan 2004; Ramírez *et al.* 2008; Winemiller *et al.* 2008), and maintains the edaphic water percolation that occurs at the margins of rivers and streams (Sternberg 1987). Despite their importance, riparian forests and vegetation in drainage basins are still suffering from deforestation, particularly in tropical regions (Pinay *et al.*1990; Barrela *et al.* 2000).

Natural vegetation suppression in drainage basins can change the chemical characteristics of rivers and streams (Fig. 1; Ramírez *et al.* 2008). Phytoplankton productivity is also affected (Phlips *et al.* 2000) because a lack of tree cover increases solar radiation and water temperatures (Allan 2004). Waterways in deforested areas have significantly decreased levels of nutrients and organic matter (França *et al.* 2009), which influences the structure of limnic habitats and food chains (Araújo-Lima *et al.* 1986; Junk *et al.* 1989; Loverde-Oliveira & Huszar 2007). This interferes with the physiology of invertebrates (Bilby & Likens 1980) and fish (Maia & Chalco 2002; Gomiero *et al.* 2007), particularly in smaller rivers (Vannote *et al.* 1980). In addition, large-scale removal of natural vegetation in flood areas could represent a considerable impact not only on the biota of these plant formations but also on the communities found within limnic bodies. The black water rivers of the Amazon

Figure 1. View of the Tijuco River (18°56'34"S 49°26'54"W), Ituiutaba municipality, Minas Gerais state, Brazil. Note the accumulation of sediments in the river as a result of deforestation of riparian forest and slope vegetation.

basin, for example, are darkened by the presence of humic compounds (Leenheer 1980; Moreira-Turcq *et al*. 2003). However, the marked deforestation of local drainage areas interfere directly with DOM input (Sombroek 2000; Moss 2010), thereby reducing the dark color of the water. The dependency of aquatic communities on allochthonous nutrients and energy (Henderson & Walker 1986) makes them vulnerable to deforestation.

The society must consider the disturbance that vegetation suppression will have on endemic species such as the cichlid *Apistogramma pertensis* (Haseman, 1911). This fish is found in Amazon rivers such as the Negro and Tefé that have a high concentration of DOM (humic acids) (Kullander & Ferreira 2005). Increased deforestation will alter the characteristics of these trophic niches in dark water Amazon rivers (Henderson & Walker 1986) and will have a significant impact on the numerous specialized biota associated with these habitats (Wantzen *et al*. 2008). In regions where clear water rivers are typical, such as the Atlantic forest, many endemic fish species such as *Deuterodon iguape* (Eigenmann 1907), *Imparfinis piperatus* (Eigenmann & Norris 1900), and *Hollandichthys multifasciatus* (Eigenmann & Norris 1900) are sensitive to human intrusion (Esteves & Lobón-Cerviá 2001) and may suffer if vegetation loss results in a decrease in allochthonous food resources.

The scarcity of information of the interactions between tropical terrestrial and limnic ecosystems (Wantzen *et al*. 2008), as observed in the Atlantic and Amazon forests and other Brazilian biomes (Ab'Saber 2010), coupled with the rapid expansion of global exploitation of natural resources and the consequential suppression of plants (United Nations Environment Programme 2012) prompted this review. In the following sections, we discuss the potential consequences to riverine environments associated with reduced vegetation cover in drainage basins, thus highlighting the problems related to limnic biota preservation (Ramírez *et al*. 2008). Moreover, we propose criteria for valley occupation protocols by focusing on vegetated areas that are subject to flooding, thus emphasizing a Brazilian case study.

Our review was based on the practical experience and knowledge of the authors as well as published scientific data available from various databases. The objective was to address the theme of ecological changes to limnic environments and the consequences caused by a reduction of vegetation cover in drainage basins. In addition, we used this information as a basis for discussing the importance of floodplain protection as a fundamental practice during the occupation of drainage areas for agricultural and livestock activities.

Drainage basins and nutrient input

The flood pulse concept (Junk *et al*. 1989) predicted the transport of POM, DOM, and nutrients from inundated areas into limnic compartments, which were influenced by a number of factors, including soil and vegetation characteristics, rainfall variation, and relief (Tockner *et al*. 2000). The methods and protocols by which valley bottoms are occupied with agricultural and silvicultural activities should prioritize sustainability when their management protocols are designed. For example, in areas occupied by plains (regions with a low slope), plant formations located beyond the riparian forest but within the river floodplain may be potential sources of energy and nutrients for a limnic system, i.e. they contribute to system function and maintenance of its food chains. To fully understand these functions, differences in litter production and decomposition rates between forest and savannah formations must be understood. Tropical forests often accumulate greater annual quantities of litterfall than savannahs (Tab. 1). This greater litter volume decomposes over relatively short periods, and the high decomposition rate (*k*) (Olson 1963; Morellato 1992; Cunha *et al*. 1993; Backes *et al*. 2005) corresponds to infra-annual periods. One may conclude that high decomposition rates in tropical forests define these litterfalls as important sources of DOM and nutrients. Conversely, the litter produced in savannahs often remains on the soil without decomposing for years at a time (Cianciaruso *et al*. 2006; Valenti *et al*. 2008). Thus, savannah formations adjacent to riparian forests and within inundated areas may supply limnic bodies with large quantities of POM, which is composed mainly of leaves with a large quantity of recalcitrant material such as lignin and cellulose (Bourlière & Hadley 1970; Coutinho 1990).

The *Cerrado* (Brazilian savannah) comprises tropical vegetation composed of different vegetation types that are frequently found on dystrophic soils (Oliveira-Filho & Ratter 2002). One edaphic feature of the *Cerrado* is the low availability of soil nutrients. According to the hypothesis of "oligotrophic scleromorphism" (Arens 1958; Coutinho 1990), this could produce plant structures with recalcitrant characteristics, such as leaves and twigs that are more rigid from lignin and cellulose accumulation. The slow litter decomposition in *Cerrado* limnic bodies (Gonçalves *et al*. 2007) favors leaf accumulation on the bottom of lotic and lentic systems (Tockner *et al*. 2000) because POM is being continuously deposited (Moretti *et al*. 2009). This environment benefits detritivores (Wantzen & Wagner 2006), and limnic disturbance may interfere with the biota diversity (Lampert & Sommer 2007; Jacobsen *et al*. 2008). Aquatic organisms show a variety of feeding preferences, and they have adapted to the low nutritional value of this accumulated litterfall (Graça & Canhoto 2006). For example, insect and crustacean larvae are stimulated by nutritional quality, abundance, and chemical characteristics of POM when searching for food (Rincón & Martínez 2006; Janke & Trivinho-Strixino 2007; Moretti *et al*. 2009; Wood *et al*. 2012). Therefore, the chemical composition of the litterfall influences aquatic food chains because nitrogen concentration varies and there are limited nutrients for phytoplankton productivity (Hecky & Kilham 1988; Vitousek & Howarth 199l; Garnier 2004).

Table 1. Production of particulate organic matter (POM) or total litterfall, nitrogen (N) and phosphorus (P) levels, and respective N:P ratios in several regions of Brazil. Values are in mg ha^{-1}/year. Vegetation formation (VF) is as follows: semi-deciduous seasonal forest (sf), dense ombrophilous forest (of), gallery forest (gf), and *cerrado* (cd).

POM	N	P	N:P	VF	Sites	References
10.3	0.21	0.01	21	sf	Pantanal, MT	(Haase 1999)[*]
9.40	0.18	0.01	18	sf	São Paulo, SP	(Meguro *et al*. 1979)
9.28	0.12	0.07	2	of	Maracá, AM	(Scott *et al*. 1992)
8.76	0.13	0.01	13	gf	Pantanal, MT	(Haase 1999)[#]
8.64	0.19	0.007	27	sf	Rio Claro, SP	(Pagano 1989a; Pagano 1989b)
8.30	0.15	0.003	50	of	Manaus, AM	(Luizão 1989)
8.04	0.11	0.003	37	of	Capitão Poço, PA	(Dantas & Phillipson 1989)[♠]
7.47	0.14	0.01	14	sf	Pantanal, MT	(Haase 1999)[‡]
7.01	0.16	0.01	16	of	Santo André, SP	(Domingos *et al*. 1997)
6.31	0.1	0.004	25	of	Ilha do Cardoso, SP	(Moraes *et al*. 1999)
5.04	0.07	0.004	17	of	Capitão Poço, PA	(Dantas & Phillipson 1989)[ϕ]
4.86	0.06	0.005	12	cd	Pantanal, MT	(Haase 1999)[♦]

Plots 3FE[*]; 1FE[#]; 7NS[‡]; 5ND[♦]; primary forest[♠]; secondary forest[ϕ]

Influence of different vegetation types

The N:P ratio of the various vegetation types (Tab. 1) differs under the influence of both biotic and abiotic factors, such as the nutrient use strategies of different plant species (McGroddy *et al*. 2004) and soil features such as texture (Vasconcelos & Luizão 2004). Thus, it may be presumed that these formations will interfere with the evolutionary processes of limnic communities. In general, terrestrial systems provide a limited source of nutrients for limnic bodies (Moss 2010), supplying just enough nutrients to maintain limnic food chains.

Evolutionary responses to various food sources define feeding niches (Pianka 2000). Therefore, changes in the quality of available food may considerably affect limnic food chains and communities. A number of factors, including temperature and variation in rainfall, influence the production and decomposition of plant matter. The example below demonstrates the significant environmental impact that vegetation suppression in river basins can have on limnic food chains. The clearing of a 100 ha of semi-deciduous seasonal forest led to an annual decrease of 1030 mg of POM, 210 mg of N, and 1 mg of P from the soil compartment [Tab. 1; Haase 1999]. When this forest patch flooded, the loss of these nutrients and POM greatly affected the associated limnic system and interfered with the dynamics of the aquatic trophic chain.

The reforestation of natural vegetation in floodplains beyond the riparian vegetation with species used in agricultural or forestry activities can also significantly impact aquatic biota not only through the reduction of accumulated litterfall but also by changing the chemical quality of the litterfall produced by the anthropogenic ecosystems. Many agricultural and forestry ecosystems produce smaller amounts of litter than natural ecosystems. Moreover, the plant biomass deposited on the agroforestry ecosystems soil is lower in nitrogen and phosphorus concentrations. This is an ecological disturbance to freshwater food chains because of the lower nutrient input that is necessary to sustain biota longevity. An exception was the cultivation of pearl millet *Pennisetum glaucum* (L.) (Boer *et al*. 2007) that showed the amount of POM produced in 100 hectares equaled 1080 mg, and 12 mg to N and 2 mg to P (Tab. 2). These values were similar to those observed in some natural ecosystems (Tab. 1). Nevertheless, values for gum *Eucalyptus dunnii* (Maiden) (Corrêa *et al*. 2013) and loblolly pine *Pinus taeda* (L.) reforestations (Schumacher *et al*. 2008) indicated that these values were still below those observed in natural ecosystems, particularly N (0.03 mg.ha^{-1}) for both tree species.

The chemical characteristics of litterfall produced by pine species *Pinus* (L.) reflects high levels of organic compounds that result in decomposition difficulty (Barnes *et al*. 1997) and very low decomposition rates (Olson 1963). Therefore, the time required for complete needleleaf decomposition would be considerably higher than the decomposition rates of litter accumulated in tropical forests. This information suggests that the replacement of natural vegetation formations, present in rivers and streams subject to flooding, with species used in agricultural or forestry activities over the years, interferes considerably with biota longevity and limnic food chains.

Protocol improvement: the Brazilian case

The so-called permanent protection areas of Brazil (*Áreas de Proteção Permanente* [APP]) were first created in the Forest Code of 1965 (Law 4.771/65) and included vegetation areas on the margins of Brazilian lakes and riv-

Table 2. Production of particulate organic matter (POM) or total litter and nutrient (N, P) soil input by litterfall deposition in agroforestry ecosystems in different regions of Brazil. Notations: nitrogen (N), phosphorus (P) levels, and respective N:P ratios in several agroforestry ecosystems (AF) of different regions of Brazil. Values are in Mg ha^{-1}/year. Abbreviated genera: *Eucalyptus*, *Pinus*.

POM	N	P	N:P	AF	Sites	References
7.8	0.16	0.01	16	*Sabia*	Itambé, PE	(Ferreira *et al.* 2007)
5.8	0.1	0.003	33	Black-wattle	Butiá, RS	(Schumacher *et al.* 2003)
10.2	0.07	0.003	23	*E. grandis*	Bofete, SP	(Kolm & Poggiani 2003)
4.1	0.03	0.001	30	*E. dunnii*	Alegrete, RS	(Corrêa *et al.* 2013)
-	0.02	0.001	20	E. saligna	Itatinga, SP	(Câmara *et al.* 2000)
-	0.01	0.001	10	*P. taeda*	Cambará do Sul, RS	(Viera & Schumacher 2010)
4.5	0.03	0.002	15	P. taeda	Cambará do Sul, RS	(Schumacher *et al.* 2008)
5.9	0.1	0.007	14	Cocoa	Itajuípe, BA	(Fontes *et al.* 2014)[1]
4.6	0.08	0.006	13	Cocoa	Itajuípe, BA	(Fontes *et al.* 2014)[2]
10.8	0.12	0.02	6	Pearl millet	Rio Verde, GO	(Boer *et al.* 2007)
8.7	0.13	0,02	6	Finger millet	Rio Verde, GO	(Boer *et al.* 2007)
2.9	0.05	0.007	7	Amaranthus	Rio Verde, GO	(Boer *et al.* 2007)

[1] Cocoa under natural vegetation (*cabruca*);
[2] Cocoa under *Erythrina glauca* as vegetation cover.

ers. The size of these protected areas was based on the size of the limnic bodies themselves. A recent paper by Metzger (2010) corroborated the criteria and parameters used by this law; however, an increase in the size of some protected areas is required.

Neither the old nor the new law considered important characteristics such as the slope of the river body margins. However, the flood pulse concept (Junk *et al.* 1989) showed that the relief of water margins was one of the most important factors in determining the flooding extent (Tockner *et al.* 2000). Therefore, the slope of areas close to limnic bodies and the extent of the inundations are important factors that determine erosion and sedimentation risks. The slope profile also influences the amount of POM, DOM, and nutrients that make their way into limnic bodies.

Vegetation located beyond the riverine forests may strongly contribute to the transport of organic material into limnic bodies (Richey *et al.* 1990). The legislation that regulates the size and exploitation of riparian forests must not only consider the extent of the marginal areas but also the factors that influence the flood pulse (relief of the terrain), extent of the river basins, and soil characteristics. The protocols adopted by the new "Brazilian Forest Code" should be modified based on these considerations to guarantee an unaffected interaction between terrestrial and limnic ecosystems and facilitate the survival of plant and animal species therein.

Ensuring input continuity

Because of the highly complex nature of ecosystem interactions considered in this study (Junk *et al.* 2014), the above proposition may sound overly simplistic (Palmer & Febria 2012; Woodward *et al.* 2012). However, including the described topographic approach would increase the number of parameters currently considered by the Brazilian law. Moreover, other factors that also influence POM and DOM inputs into limnic bodies, such as soil and chemical characteristics, ground slope, and inundation level, would be used to decide the occupation of valley bottoms. In order for the proposed changes to be effective (Woodward *et al.* 2012), their application in different Brazilian rural communities must be feasible.

A continuous supply of POM, DOM, and nutrients from the vegetation of drainage basins must be protected for Brazilian waterways. Thus, the current "Brazilian Forest Code" should adopt an additional extension method that considers flood pulses. The protection of additional vegetation strips is essential to guarantee the on-going transport of energy and nutrients into limnic ecosystems because inundations can extend beyond the limits established by the present law. Variations in production periods and flood strength occur, thereby making it difficult to quantify these inputs (Wantzen *et al.* 2008). However, an understanding of their transport patterns into limnic bodies will provide indispensable information on the influence that vegetation in drainage areas has on the functioning of limnic ecosystems.

Final considerations

The influx of POM, DOM, and nutrients into limnic systems from the accumulated litterfall and decomposition in drainage areas varies in intensity and duration. These characteristics should be considered in proposals for the management of valley bottoms. If the law adopted an addition to the riparian strips to include those areas affected by annual floods as defined by slope relief, this single measure would significantly promote aquatic food chain permanence and biodiversity. In addition, there would be benefits to terrestrial ecosystems through the protection of unique forest formations. Furthermore, ecological corridors could be more easily implemented in regions heavily deforested by the expansion of agribusiness activities.

Reforestation costs by implementing the principles that we stand for could be circumvented in two ways: (1) allowing natural re-vegetation, thus ensuring that the seed bank or allochthonous propagules can help in the recovery of suppressed vegetation; and (2) simple land protection by adding them to the APP strips and renouncing some of the taxes paid by landowners. There are possibilities where new areas to be added to the respective APP's would cover many hectares. This strategy could bring a considerably reduced economic gain to the owners through the decrease of arable land or pastures. In these cases, we suggest that the services provided by the interaction between terrestrial and limnic ecosystems are calculated and reverted to the owners who had already planted the areas and reduced grazing.

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