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REVIEW ARTICLE

Impactos de grandes barragens na biodiversidade: uma análise cienciométrica

Impact of dams on global biodiversity: A scientometric analysis

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Abstract

The extensive damming of rivers around the world, regardless their economic purpose, has changed the river landscapes and led to serious ecological consequences for the biological organisms associated with these ecosystems. In the present study, a scientometric analysis was performed aiming to assess temporal trends of the scientific production related to environmental concerns about the impact of large dams on biodiversity worldwide. On this context, a bibliographic review of the scientific works of this area, using the research platform "Web of Science" searching for the keywords "dam impact" or "dam effect" and "bio*diversity" in the subject line. The results showed that, despite the publication number increase in the field, these studies are clearly more abundant in temperate regions, which have less biological diversity. Although much of the planned hydroelectric expansion is expected to occur in the tropics, which have most of the world's biodiversity, the biological knowledge about the species in these places is still very little. The lack of studies in these areas may mask the impact intensity and extent of dams on biodiversity and also induce decision-makers to adopt inefficient management strategies.

Keywords: Freshwater ecosystem, review, reservoir.

Resumo

O intenso barramento de rios ao redor do mundo, independentemente da finalidade econômica da barragem, tem alterado paisagens fluviais e ocasionado sérias consequências ecológicas para as espécies associadas a esses ecossistemas. No presente estudo, foi realizada uma análise cienciométrica com o objetivo de verificar tendências temporais na produção científica relacionada à preocupação ambiental com o impacto de grandes barragens sobre a biodiversidade em todo o mundo. Para isso, foi realizado um levantamento bibliográfico da produção científica da área, utilizando a plataforma de pesquisa "Web of Science", buscando pelas palavras-chave "dam impact" ou "dam effect" e "bio*diversity" no campo assunto. Os resultados mostraram que, apesar do aumento de publicações na área, os estudos são claramente mais abundantes em regiões temperadas, as quais possuem menor diversidade biológica. Embora grande parte da expansão hidrelétrica planejada esteja prevista para ocorrer em regiões tropicais, as quais possuem a maior parte da biodiversidade mundial, o conhecimento biológico acerca de espécies nesses locais ainda é escasso. Essa lacuna pode mascarar a intensidade e a extensão dos impactos de barragens sobre a biodiversidade e também induzir tomadores de decisão a adotar estratégias de gestão pouco eficientes.

Palavras-chave: ecossistema aquático, revisão, represamento.

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Introduction

The River Continuum Concept (Vannote *et al.*, 1980) proposes the existence of a gradient of abiotic conditions from the headwaters to the mouth of rivers. However, nowadays few rivers maintain uninterrupted river beds, most of them are intensively regulated by dams (Ward and Stanford, 1983). Currently, river regulations are among the biggest threats against freshwater ecosystems in the world (Dudgeon, 2000; Malmqvist and Rundle, 2002; Dudgeon *et al.*, 2006). The sensitivity of these environments is due to their linear and unidirectional characteristics, so that an impact in one point of the stream may affect miles away downstream (Malmqvist and Rundle, 2002).

Among the various environmental impacts caused by the construction of dams, major concerns are related to the change in the hydrological dynamics (Graf, 2006). The interruption of a river by a dam may affect its hydrology in different ways: reversing the natural dynamics or keeping it constant (without the natural seasonal variation) (Aubry *et al.*, 2013). Overall, dams reduce peak flows in flood periods and increase the minimum flow, homogenizing the river flow throughout the year (Pitlick and Wilcock, 2001; Graf, 2006; Górski *et al.*, 2012). This standardization acts as an environmental disturbance (Bayley, 1995), affecting organisms adapted to the water fluctuations (Malmqvist and Rundle, 2002; Doell *et al.*, 2009), which often trigger spawning migrations (Barthem *et al.*, 1991).

The changing of the flow, caused by a dam construction, has negative consequences, not only for strictly aquatic organisms (Pringle *et al.*, 2000; Górski *et al.*, 2012), but also for vegetation (Ncube *et al.*, 2013), amphibians (Kupferberg *et al.*, 2012) and birds (Wang *et al.*, 2013b). After created, a dam turns the lotic environment into lentic or semi-lentic one, favoring some invasive aquatic species at the expense of those previously there. These hydrological changes may be accentuated when there is more than one dam in the river or in its tributaries (Pitlick and Wilcock, 2001).

The hydrological impacts of the construction of dams are followed by sedimentological changes, which are extremely common and documented (Pennisi, 2004; Graf, 2006; Huang *et al.*, 2013).

Following the hydrological regime, sediment transport also shows a seasonal flow pattern (Huang *et al.*, 2013). Reservoirs act as traps for the sediment, which tends to settle in the bottom of the reservoir due to the increased residence time of the water in the dam (Pitlick and Wilcock, 2001). This effect reduces the deposition amount of available nutrients and sediment downstream from the barrier, causing major structural changes in the aquatic environment (Huang *et al.*, 2013) and decreasing the heterogeneity of the habitat (Pitlick and Wilcock, 2001). Thus, native populations are hindered because they lose refuge, foraging and reproduction habitats. In addition, the water released by the dam, with reduced amounts of sediment, tends to erode the river channel to recover the sediment balance, causing erosion in the river bed (Graf, 2006) and, on a larger scale, coastal erosion (Chen and Zong, 1998).

The water area of the reservoir might have thermal stratification and, if a large volume of biomass was flooded, the decomposition of this material will generate anoxic hypolimnion. The constant release of cold water from the hypolimnion region to the river may reduce both the dissolved oxygen (Preece and Jones, 2002) and the temperature in downstream regions of the dam – this action is called "thermal pollution" by some researchers (Olden and Naiman, 2010). The river temperature also acts as an environmental signal, stimulating spawning, influencing the incubation period, the egg survival and the migration of native fish fauna. Thus, many species may have their reproduction severely affected by this type of pollution (Preece and Jones, 2002; Olden and Naiman, 2010).

Other adverse impacts of dams have also been reported in the literature (Morita and Yamamoto, 2002; Freeman *et al.*, 2003; Millikan, 2011). It is believed that the cumulative effects caused by such developments are greater than the sum of the individual effects (Brismar, 2004). Thus, the aquatic ecosystem may be subject to human pressures from different sources at the same time, such as agriculture, mining and deforestation, affecting biodiversity more than it has been described (Porvari, 1995; Zhang *et al.*, 2011).

A common ecological consequence of all the impacts listed above, especially for the fish fauna, is the change in community composition: local extinction of native species and invasion and establishment of exotic ones (Johnson and Hines, 1999). Countries have built dams in cascades, unplanned, leading to losses of biodiversity and fish biomass (Ziv *et al.*, 2012).

The environmental concern with dam impact on the biodiversity is fairly recent, therefore, we possibly do not know most of the related issues. To quantitatively evaluate the scientific production in this field, a scientometric analysis was performed. Many papers are published concerned only about the impact of reservoirs in the abiotic environment, however, this work sought to know how many scientists are producing works taking the biodiversity into consideration. The objective of the present work was to identify tendencies and biases, and investigate the needs of this study area. Scientometrics is a tool used to quantitatively characterize the scientific output of any area. This type of review enables scientists to identify the development of a research topic over time, the hegemony of any country in a line of research and the scientific progress in an area of interest (Carneiro *et al.*, 2008; Siqueira *et al.*, 2009).

Material and methods

The research platform "Web of Science" and the database from the Institute for Scientific Information Thomson ISI [http://apps.webofknowledge.com] was used for searching the papers. This database is the most used for this kind of search because it includes a high number of scientific journals in different fields. Thus, this database was chosen for the present study because of its comprehensiveness. Articles published from 1980 to 2013 were analyzed in this work. The keywords "dam impact" or "dam effect" and "bio*diversity" were used in the topic field. This field shows publications which abstract, title or keyword contains the searched terms. The abstracts of all papers from this search were read and the papers that showed impact of dam construction and operation on some aspect of biological diversity were selected. All papers were categorized as described in Table 1, taking into account the main aspects of the environment discussed in each paper.

Additionally, information was extracted from the papers about the studied country, the filiation country of first author, the year of paper's publication, the taxa studied and the regions where the studies were developed (tropical or temperate).

In general, the number of published papers in any area tends to grow over time because of the increasing number of researchers. In an attempt to remove this bias, the temporal analysis of publications found was compared to the increase of the number of publications in limnology. This strategy allowed to demonstrate if the concern about the impacts of dams has increased or not compared to other topics within the freshwater biology.

In order to assess the relative importance of the subject 'dam impacts' inside the limnology field, the proportion between the number of publications in limnology and the number of articles found in the first search (about the impacts of dams) was calculated. Moreover, an extra search, using the keywords "freshwater", "biology" and "limnology" in the "Web of Science" platform was performed and compared with our main search (about dam impacts).

Table 1. Impact description of each category and some examples of papers.

Impact category	Impact description	References
Changes in the sediment transport	Reduction of sediment transport to downstream regions and consequence of this for the local fauna; changes in sandbanks; coastal erosion caused by reduced sediment supply.	Lee *et al.* (2009); Svendsen *et al.* (2009); Wang *et al.* (2013a)
Alteration of hydrodynamics	Changes of the flood regime; reducing river flow and water availability.	Abujanra *et al.* (2009); Gauld *et al.* (2013); Greet *et al.* (2013)
Changes in water quality	Eutrophication; anoxia/hypoxia; generation of chemicals substances dangerous to life (for example: H_2S); overgrowth of weeds and its consequences.	Zeng *et al.* (2006); Clark *et al.* (2009); Käiro *et al.* (2012)
Interruption of the river continuum	Reducing/preventing migratory routes; change in population structure of species; interruption of gene flow; population isolation by physical/genetic barrier.	Ward and Stanford (1983); Katano *et al.* (2009); Iacone Santos *et al.* (2013); Weber *et al.* (2013)
Vegetation cover loss	Deforestation caused by dams; loss of endemic forest; death of trees and the absence of regeneration of vegetation; changes in evapotranspiration and its impact on local and regional rainfall.	New and Xie (2008); Naik *et al.* (2011); Egger *et al.* (2012)
Impact on air quality	Release of greenhouse gases caused by turbines and spillways.	Fearnside (1995, 2002, 2005); Gunkel (2009)
Loss or changes of community composition	Local extinction of species; facilitation or introduction of invasive species; change of community composition; reduction of the abundance of native species.	Bredenhand and Samways (2009); Wang *et al.* (2011); Randklev *et al.* (2013)
Impact on the ecosystem	Reduction in decomposition rates; change the food chain; impact on trophic cascade; loss of a guild; change in the competitive interactions or predation; interference in biogeochemical cycles.	Xu *et al.* (2011); Mendoza-Lera *et al.* (2012); Yang and Chen (2013)
Erosions or soil degradation	Erosions, changes in the chemical properties of the soil, seismic changes, landslides, river bed erosion (formation of the 'pool' downstream).	Lu and Higgitt (2000); Wu *et al.* (2013); Zhao *et al.* (2014)
Alterations in temperature dynamics	Water release from hypolimnion or epiliminion causing change the natural temperature of the river; termal stratification.	Sinokrot and Gulliver (2000); Gerecht *et al.* (2011); Yang *et al.* (2012)

Results and discussion

The chosen keywords to search for articles showed a total of 2,339 publications. After a refined analysis of abstracts, 954 papers fitted the objectives of this study. The selection criterion of the papers was the inclusion of some aspect of biodiversity in the study about the impact caused by dams.

The evaluation of all selected articles showed that studies in this area presented a remarkable growth after the nineties, when the proportion of this type of study compared to articles published in limnology showed increasing trend (Figure 1). In the twenty-first century, the proportion of publications exceeded 20% of the freshwater ecology studies. About 72% of the work related to hydropower impacts were published after 2006.

Most hydropower dams were constructed before the nineties. The USA, for example, had its peak construction of large dams in the sixties (Pringle *et al.*, 2000). This fact may explain why the number of researches interested in environmental impacts of dam construction increased after the nineties. In tropical regions, this expansion of hydropower generation was delayed and started after the seventies (Pringle *et al.*, 2000). China started to grow its hydropower production in 1949, since then, its installed capacity had shown a massive increase. In less than ten years, the goal was to expand the number of large hydroelectric power plants from 21 to 56 (Huang and Yan, 2009).

Another explanation for the growth in publications after the nineties may be because of the history of environmental concern. The book "Silent Spring", published in 1962, was a major milestone in the history of environmental concern. For the first time, a study showed to society the negative influence that human activities may have on the environment. Until then, natural resources were seen as limitless and, therefore, endowed with little value.

From this point, the scientific community turned their eyes to environmental problems and, in 1972, it organized an important conference in Stockholm, about Man and Environment, which generated the report "Limits to growth". However, that environmental concern culminated in the nineties in a meeting with great visibility and support of several countries, the Rio-92 or Eco-92. This meeting probably encouraged researchers around the world to evaluate the anthropic impact in the environment. Some researchers reported that the 1990s marked the real beginning of concern on environmental issues (Dunlap, 1991). Ever since, increasingly attention is paid to environmental impacts and the results in the present work confirm it.

Initially, hydropower was seen as a clean and renewable source by not emitting large amounts of greenhouse gases (GHG) and non-consumptive use of water. Studies now show how the GHG emissions by hydropower can be substantial and especially important in tropical regions (Fearnside, 2002; Barros *et al.*, 2011).

Most of the papers report studies conducted in the USA (19%) and China (19%) (Table 2), countries that also have the highest percentage of affiliated researchers, 22% and 15%, respectively (Table 2). In third place is Brazil, with 8% of all studies about environmental impacts of dams, and 8% of affiliated researchers (Table 2). A direct link between the amount of authors affiliated and the number of articles published in each country was noticed.

These three countries, along with Canada, are the largest hydroelectric power producers in the world, according to data from the Energy Information Administration (EIA, 2012). Thus, the number of studies in the area is connected not only to the amount of researchers related to the topic, but also with the highest amount of hydroelectricity production in each country.

Another important aspect to highlight is the keywords used in the search. The word "dam" was chosen because it refers to large dams, exactly the ones that cause great

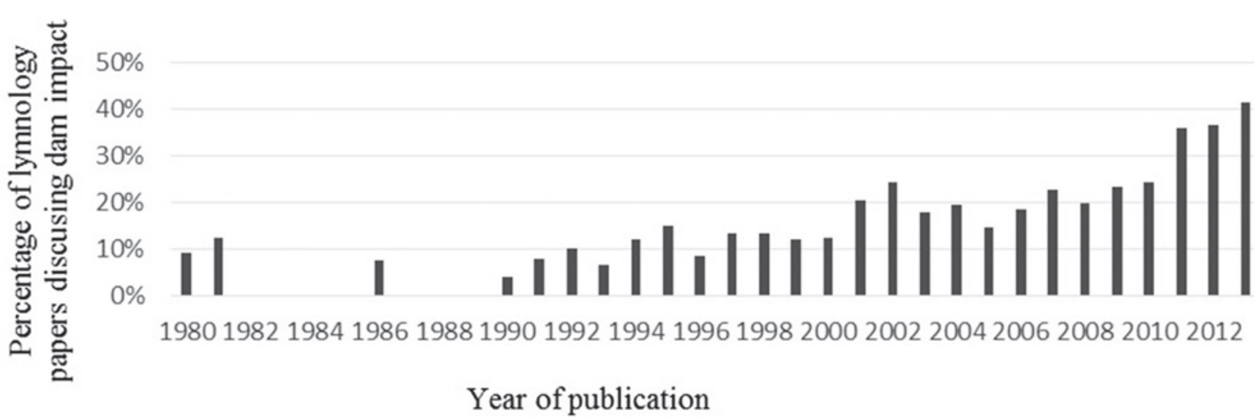

Figure 1. Ratio between the number of papers in limnology (freshwater ecology) and the number of published studies concerned about the impact of dams on the biodiversity.

Table 2. Number of papers published by countries from 1980 to 2013 and number of affiliated authors in each country*.

Country	Papers published		First's author affiliation	
	N	%	*N*	%
USA	185	19	211	22
China	182	19	149	15
Brazil	76	8	74	8
Australia	43	5	44	5
Canada	27	3	52	5
Portugal	25	3	25	3
South Africa	23	2	20	2
Japan	23	2	29	3
Spain	20	2	30	3
Poland	20	2	20	2
France	17	2	45	5

Note: (*) List of the ten countries with the largest number of papers published.

impact on biodiversity. The three countries with the highest number of publications have hydroelectric plants with large reservoirs, unlike countries in Europe, for example. In addition, in countries such as Brazil, the government requires companies to conduct environmental studies, and due to this fact, there is a reasonable number of publications in the area.

Regarding the number of publications in the area worldwide, more than 70% of all published studies were produced in temperate regions (Figure 2). The recent development of this type of energy in tropical regions and the smaller quantities of dams (Pringle *et al.*, 2000) may support this result.

A worrying consequence of this is the use of work done in temperate regions to support decisions in tropical regions. For example, the use of "fish ladders" was a method developed for mitigating the impact on salmon in temperate regions. However, the lack of in-depth studies on the biological diversity of tropical countries (generally poorer and with lower investments in this area) led to the use of these fishways in tropical environments without adjustments for the tropical biota (Mallen-Cooper and Brand, 2007).

In tropical countries, these "fish ladders" should be proposed with caution, as it has been shown in many studies developed in Brazil (Agostinho *et al.*, 2002; Agostinho *et al.*, 2007; Pelicice and Agostinho, 2008), since the ladder might not work properly and may bring more problems than solutions (Agostinho *et al.*, 2011; Pelicice and Agostinho, 2012).

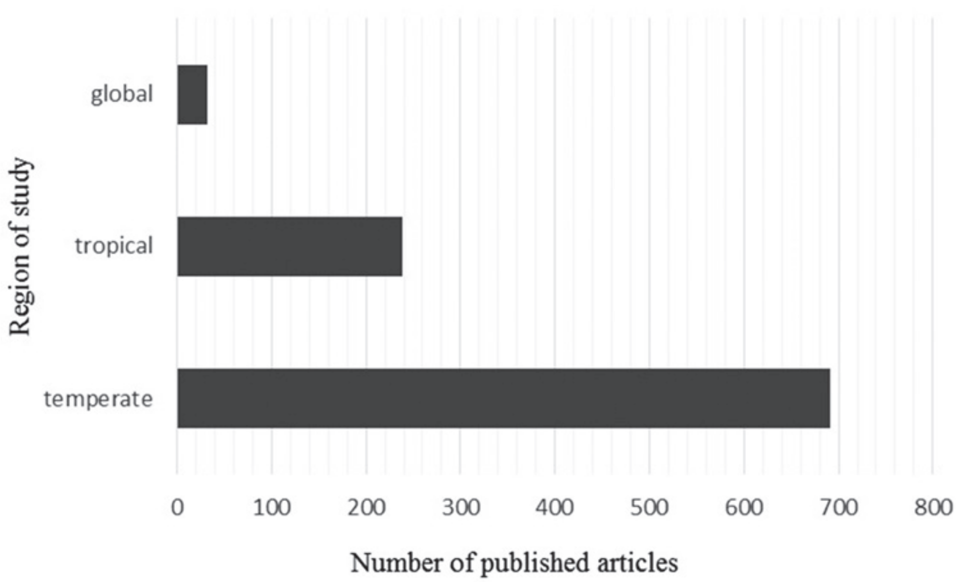

Figure 2. Number of studies published about dam impacts on biodiversity in each region of the planet.
Note: *Global* indicates review papers that consider countries of both regions.

Life in tropical regions are possibly more vulnerable to large reservoirs constructions than life in temperate regions (Barros *et al.*, 2011; Fearnside, 2002; Pringle *et al.*, 2000), considering their great biodiversity, the singularities of each one, the species not yet described and the complex ecological standards (Pelicice *et al.*, 2014).

The analysis of the impacts of all classes addressed by the papers selected showed that about one quarter of the studies (24%) reported species loss and turnover (Table 3). Among the works that have examined a specific group (Figure 3), fish were the most studied organisms (57% of articles). The most assessed impacts in fish were related to loss of connectivity with the river, and with loss or change in species composition.

The number of studies assessing dam impact on biodiversity was small, considering the amount of studies evaluating only abiotic aspects, according to some authors, due to the fact that we have scarce biological data available for the most of freshwater ecosystems, then it is easier to study only abiotic factors (Revenga *et al.*, 2005). Therefore, if we want to find out the hydropower consequences on biodiversity, more empirical studies with affected species are necessary. The biological knowledge of river ecosystems is scarce, especially in developing countries in tropical regions, which also hold most of the biodiversity. Any deeper study of these regions shows its unknown richness of aquatic fauna in tropical regions (Queiroz, 2013).

The lack of ecological studies on river ecosystems may mask the extent and intensity of the impacts caused by dams. Despite the increase in publications in recent years, these are clearly more abundant in temperate regions and mainly analyze the abiotic environment. More researches are needed on freshwater organisms in tropical environments, especially given the impending energy expansion of the hydropower sector in these locations (Pringle *et al.*, 2000). This gap in tropical environments leads to applying the same mitigation measures that are used in temperate environments. The characteristics of the local wildlife then

Table 3. Number and percentage of papers published within each sub-theme compared to total number of studies reviewed.

Impact category	Number of papers published	Percentage %
Loss or changes in species composition	247	26
Alteration of hydrodynamics	209	22
Changing in the sediment transport	131	14
Interruption of the river continuum	121	13
Changes in water quality	82	9
Impact on the ecosystem	77	8
Erosions or soil degradation	25	3
Alterations in temperature dynamics	25	3
Vegetation cover loss	23	2
Impact on air quality	14	1
All studies analyzed	954	100

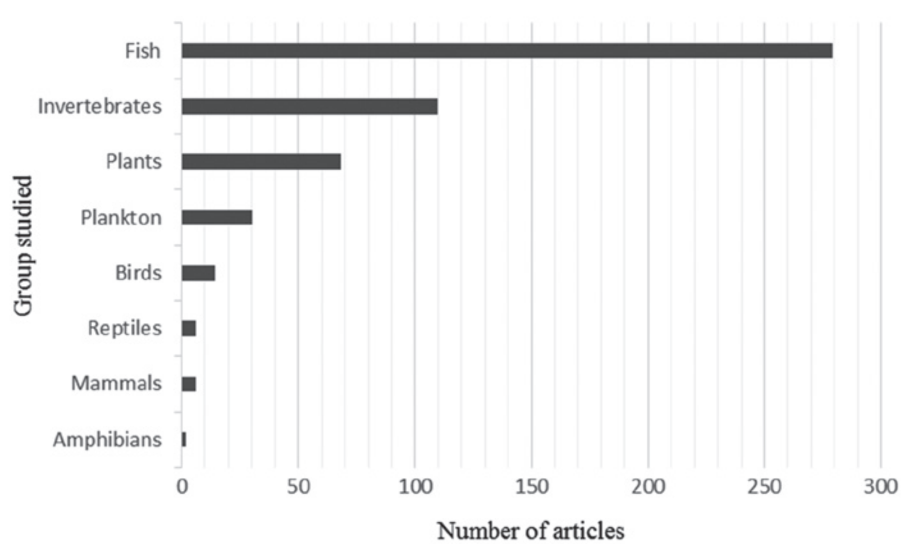

Figure 3. Number of studies concerned with an organism or focus group.

are not considered and those systems become inefficient and, in some cases, may act as ecological traps (Pelicice and Agostinho, 2008).

It was once thought that hydropower generation was a 'clean energy' because of the supposedly low greenhouse gases emissions and also because it is a renewable resource. Currently, we know that the reality is much more complex and that hydropower may and in fact release greenhouse gases, which lead to direct losses of biodiversity through all the changes exposed here in this study.

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