BOLETIM DO INSTITUTO DE PESCA
ISSN 1678-2305 online version
Review Article

The environmental licensing of hydroelectrics and the interface with migratory fish and aquaculture in Brazil

Mayara Venturini Vidal[1]
Sergio Ricardo Batlouni[1]*

[1]Universidade Estadual Paulista "Júlio de Mesquita Filho", Centro de Aquicultura – Jaboticabal (SP), Brazil.

*Corresponding author: Sergio Ricardo Batlouni, Universidade Estadual Paulista "Júlio de Mesquita Filho", Centro de Aquicultura, Via de Acesso Prof. Paulo Donato Castellane, s/n, CEP: 14884-900 – Jaboticabal (SP), Brazil. E-mail: sergio.ricardo@unesp.br

Received: November 5, 2021
Approved: October 21, 2022

ABSTRACT

In this review, we present a background on the Brazilian Federal Legislation on the environmental licensing of hydroelectric plants focusing on the procedure of the repair of environmental damage caused by dams to migratory fish. To that end, the Brazilian electrical matrix was first addressed, thus highlighting the significant contribution of the energy produced by hydroelectric projects. To better contextualize the characteristics of the legislation, separate sections concerning illustrative reports of the effects of dams on migratory fish and the current panorama of aquaculture in Brazil and in the world were included. In this review, we also present a discussion on the specific legislation concerning a mitigation measure, the "fish restocking programs," which have the potential to promote fishing and aquaculture, but still lack a scientific basis on their effectiveness and correct application. An assessment of this historical process in Brazil indicates that different mitigation measures imposed to obtain operating licenses by hydroelectric plants vary among different hydroelectric projects and that this heterogeneity in the conditions imposed may have effects (of unknown proportions) on local fish communities. Considering the absence of a specific device foreseen in the law that requires the owner or concessionaire of dams in watercourses to provide for fish restocking programs or specific ichthyofauna conservation programs, the issue seems to depend on the discretion of the licensing agency to demand that the hydroelectric plant operators carry out the reintroduction of fish in their reservoirs. This review concludes that there are political and scientific issues to be debated and explored in order to improve public policies on this topic of extreme relevance for society.

Keywords: fish ladder; hydroelectric plants; public policies; rheophilic species.

O licenciamento ambiental de hidrelétricas e a interface com os peixes migratórios e a aquicultura no Brasil

RESUMO

Nesta revisão, apresentamos um histórico da legislação brasileira sobre licenciamento ambiental de usinas hidrelétricas com foco no procedimento de reparação de danos ambientais aos peixes migratórios causados por barramentos. Para tanto, a matriz elétrica brasileira foi inicialmente abordada, destacando a significativa contribuição da energia produzida por projetos hidrelétricos. A fim de melhor contextualizar as características da legislação sobre o tema, foram incluídas seções referentes a relatos ilustrativos acerca dos efeitos das barragens para os peixes migratórios no Brasil e o panorama atual da aquicultura desenvolvida no país e no mundo. Apresentamos também uma discussão sobre a legislação específica relativa a uma medida de mitigação, os "programas de repovoamento de peixes", que têm potencial para promover a pesca e a aquicultura, mas parecem carecer de base científica sobre sua eficácia e correta aplicação. Uma avaliação desse processo histórico no Brasil indicou que as diversas medidas de mitigação impostas a usinas hidrelétricas, para obterem licenças de operação, variam entre os projetos hidrelétricos e que essa heterogeneidade nas condições impostas pode ter efeitos (de proporções desconhecidas) nas comunidades piscícolas locais. Considerando, então, a inexistência de dispositivo específico previsto em lei, que obrigue o proprietário ou a concessionária de barragens em cursos d'água a prever programas de repovoamento de peixes ou de conservação da ictiofauna, a questão parece depender da discricionariedade do órgão licenciador de exigir que os operadores das usinas reintroduzam os peixes em seus reservatórios. Esta revisão mostra que há questões políticas e científicas a serem debatidas e exploradas, visando ao aprimoramento de políticas públicas sobre esse tema de extrema relevância para a sociedade.

Palavras-chave: escada de peixe; usinas hidrelétricas; políticas públicas; espécies reofílicas.

INTRODUCTION

Historically, the energy generated by hydroelectric plants and small hydroelectric plants has been the main source of energy for the Brazilian electrical system (EPE, 2020), and although hydropower is a type of renewable energy, the installation of these projects has effects on nature. In this concern, in the current Brazilian legislation, the environment is considered essential to the quality of life and a public heritage that needs to be protected (Brasil, 1988a), and any human intervention that may cause changes to the environment must be evaluated (Milaré, 2018). In practical terms, competent environmental agencies determine methods of repairing damages through conditions for the licenses (CONAMA, 1997). In addition, after 1988, this theme gained constitutional relevance as the Brazilian Federal Constitution emerged, which provides for everyone's right to an ecologically balanced environment and introduced an exclusive chapter on the environment and other related issues (Brasil, 1988a).

Still in this concern, since the United Nations Conference on the Environment held in 1972, Brazil has sought to include "environmental issues" on its agenda (Karpinski, 2008). Currently, Brazilian Federal Legislation is quite broad with respect to environmental licensing and the repair of damages caused by large undertakings. However, the current legislation regarding environmental licensing procedures at the federal level, Normative Instruction of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) No. 184 of 2008 (IBAMA, 2008) and Normative Instruction IBAMA No. 26 of 2019 (IBAMA, 2019), specifically on the impact caused by the construction of a dam upon the migratory and reproductive process of fish, is implemented at the discretion of the licensing agency, which provides the conditions for obtaining operating licenses for the conservation and maintenance of ichthyofauna by fish restocking programs (CONAMA, 1997).

Thus, the main objective of this review was to present a brief history of the legislation that deals with the environmental licensing procedure of hydroelectric power plants (HPPs) on the repair of damages to migratory fish caused by dams. As a secondary aim, we attempted to fill a gap in the technical and scientific literature about the intersection between environmental legislation on hydroelectric plants and native migratory fish aquaculture and fishing in inland waters. Finally, in order to explore the reasons why fish restocking programs are only carried out by some HPPs, we concluded with a reflection on the intersections among environmental legislation, energy generation, and the impacts of dams on migratory fish inland aquaculture and fishing.

METHODOLOGY

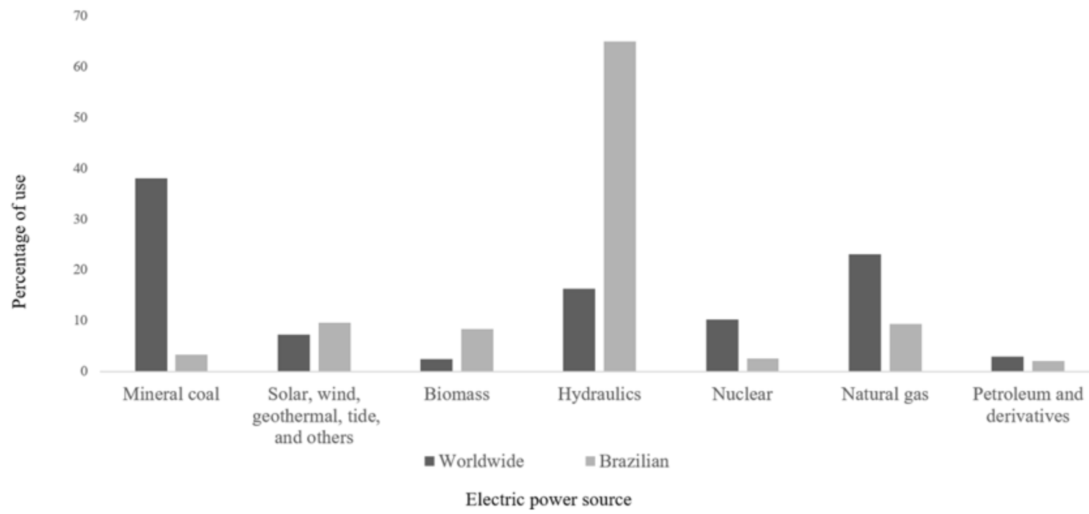
This study is a non-systematized bibliographical and documentary review regarding the Brazilian environmental licensing legislation for HPPs. The study was divided into four sections. In the first section, we contextualize the issue of electricity generation in Brazil with a presentation of current data on the Brazilian energy matrix, pointing out the importance and relevance of electricity generation through hydroelectric plants. In the second section, the main focus of the study was made on a chronological survey of the legislation that deals with this subject. However, given the wide variety of types of hydroelectric plants and the complexity at the levels of legislation (federal, state, and municipal), this review was restricted to the environmental licensing procedure of HPPs that have IBAMA as a licensing body, focusing on the repair of damages to fish communities caused by dams. Since there are no specific databases (along the lines of a conventional review) and laws are not grouped together in a single consultation site, the search was carried out by manually surveying the specific legislation on the subject through direct consultation of different sources of laws, decrees, official orders, the federal constitution, and others relevant.

In the third section, we present the effects of dams (constituents of the structure of hydroelectric plants) on the process of reproductive migration of rheophilic species. The third section is also not a systematic review due to the vastness of the topic (which is the subject of several reviews and was not the focus of this study) and the numerous current reviews on this specific topic. The focus of this section was only to show specific situations in different geographic regions of Brazil, where the effects of dams on dammed rivers were described and can support the context of this review.

In the fourth section, we presented a summarized overview of the current situation of aquaculture in Brazil, also done in a non-systematized way, but with aiming to contextualize the intersection proposed here between environmental legislation on hydroelectric plants, energy generation, aquaculture, and inland fisheries and aquaculture. Finally, in the final considerations, an intersection among the four previous themes was elaborated in an unprecedented way, which discusses the current public policies on environmental legislation for large plants and the discretionary nature of measures to mitigate the environmental impact, especially on migratory fish; the effects of dams on migratory fish species that make up an important source of freshwater fishing and are also used by national aquaculture; a reflection is also presented on a way of mitigating environmental damage known specifically as "fish restocking programs" can contribute both to the preservation of these species and to national aquaculture. Positive, negative, and controversial aspects of the fish stocking process are discussed in order to highlight an important factor that shows that despite the controversial techniques of the fish stocking technique, what determines its application and justifies its implementation by the plants is the discretion of the laws' specific rules on obtaining operating licenses in force in the country.

Section 1: the Brazilian electrical matrix

The electrical matrix of a country is formed by the set of sources available for only the generation of electric energy. Worldwide, electricity generation is based mainly on fossil fuels, such as coal, oil and natural gas, and/or on thermoelectric plants (EPE, 2020) (Figure 1). On the contrary, the Brazilian electrical matrix can be considered "more renewable" than the world matrix because a large part of the electric energy generated in Brazil comes from hydroelectric projects (EPE, 2020) (Figure 1).



Source: adapted from the original figure presented in the EPE book (2020).

Figure 1. World electrical matrix compared to Brazilian electrical matrix.

Regarding the Brazilian electrical matrix, the Energy Research Company carried out a study called the National Energy Plan 2050, which found that historically, hydroelectricity has been the main source of electricity generated for the Brazilian electrical system. Hydroelectricity is a renewable resource associated with other sources, such as wind, solar photovoltaics, and biomass, and it has a prominent international role (EPE, 2020).

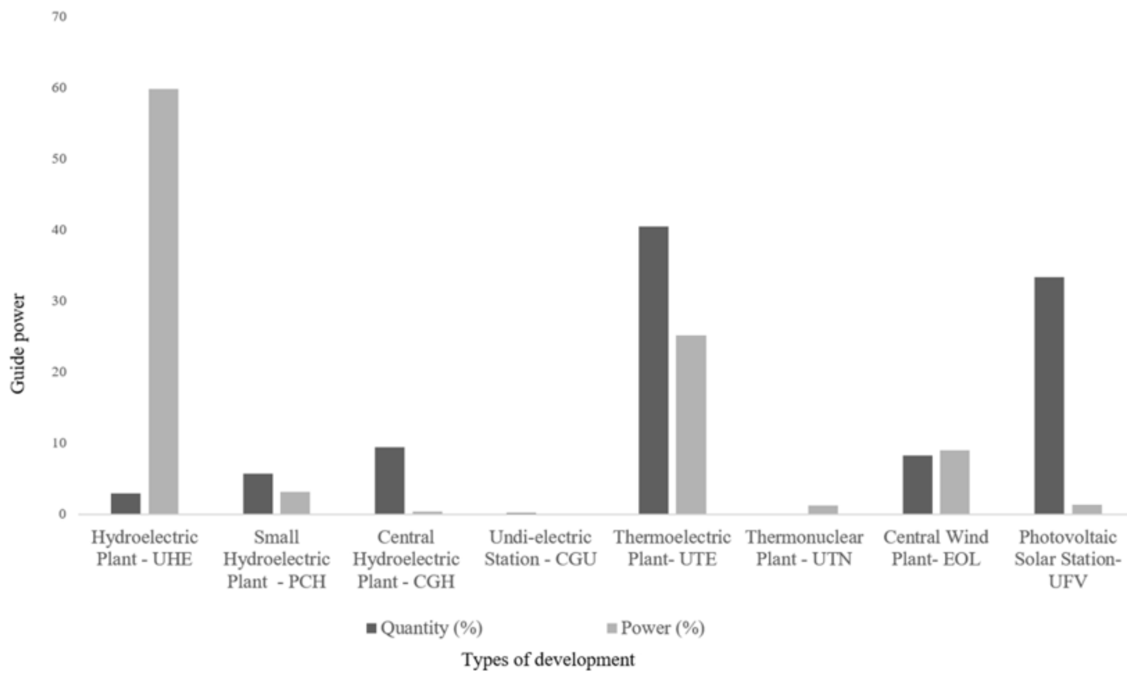
Figure 2 shows that most of the electric energy produced in Brazil comes from HPPs, which represent a significantly smaller number of projects. In Brazil, according to the 2019 Management Information of the National Electric Energy Agency (ANEEL)[1], there are 217 HPPs, 426 small hydroelectric power plants (SHPs), and 698 hydroelectric plants with reduced installed capacity; and together, their installed power (kW) accounts for 63.3% of the total energy produced (ANEEL, 2019) (Figure 2). These three types of hydroelectric projects require dams to function. Considering that this type of enterprise requires the construction of large dams, it is worth mentioning that the dams of hydroelectric plants can cause varying degrees of environmental and socioenvironmental impacts according to the characteristics of each enterprise.

Table 1 describes the different characteristics of hydroelectric generating plants in Brazil. The differentiation is necessary because depending on the framework of the enterprise, it will be subject to a different environmental licensing procedure. As hydroelectric plants with reduced installed capacity and SHPs are generally considered to cause minor environmental damage, they are subject to the simplified environmental licensing procedures and may even be exempt from preparing environmental impact studies/environmental impact reports depending on their characteristics. The environmental licensing procedure for these projects must follow the provisions of CONAMA Resolution No. 237 of 1997, although, depending on their characteristics, they may also follow the provisions of CONAMA Resolution No. 279 of 2001, which defines a simplified environmental report (RAS) and a detailed report for environmental programs (RDPA) (CONAMA, 2001). In addition, they may be subject to state law; therefore, their licensing bodies will differ depending on the municipality/state in which they are located.

Section 2: Brazilian Federal Legislation on the Environmental Licensing of Hydroelectric Plants

Environmental licensing in Brazil emerged at the federal level with the advent of Federal Law No. 6.938 of 1981 (Brasil, 1981) (Figure 3), which instituted the National Environmental Policy (PNMA). The requirement for environmental licensing is linked to the fundamental principles of the Environmental Law for Prevention and Precaution, which was enacted to prevent the degradation of the environment (Destefenni, 2004). Environmental licensing stems from the exercise of police power, which is based on the principle of the supremacy of the public interest over the private interest. Thus, if an activity does not meet the norms, criteria, standards, and principles of environmental legislation, it is assumed that the activity is contrary to the public interest and, therefore, should not be licensed (Granziera, 2003). Law No. 6.938 of 1981 also constituted the National Environment System (SISNAMA) and the National Environment Council (CONAMA). In 1986, CONAMA Resolution No. 01 defined environmental impacts, listed the projects that required elaboration by an environmental impact study (EIA) and environmental impact report (RIMA), and established the guidelines for the elaboration

1 Special regime autarchy under the Ministry of Mines and Energy and was created to regulate the Brazilian electricity sector (Law No. 9.427 of 1996 and Decree No. 2.335 of 1997; Brasil, 1996).



Source: adapted from data presented in the 2019 Management Information of the National Electric Energy Agency.

Figure 2. Number of projects in operation in Brazil and power produced.

Table 1. Definitions of the different characteristics of hydroelectric generating plants in Brazil according to ANEEL Normative Resolution No. 875 (ANEEL, 2020a) and 890 (ANEEL, 2020b) of 2020.

ANEEL Normative Resolution No. 875 of 2020	
Abbreviation	**Definitions**
HPP: hydroelectric plant (article 6º)	I – Hydroelectric plants with installed power > 5000 kW and ≤ 50,000 kW, provided they are not SHP and are subject to a concession grant; II – Hydroelectric plants with installed capacity > 50000 kW, subject to concession grant; III – Hydroelectric plants that, regardless of the installed capacity, have been subject to a grant of co-concession or authorization.
SHP: small hydroelectric power plant (article 5º)	I – Hydroelectric plants with an installed power of >5000 kW and ≤ 30000 kW; II – Hydroelectric plants with a reservoir area up to 13 km², excluding the regular riverbed trough.
Hydroelectric plant with reduced installed capacity (article 4º)	Hydroelectric plants with an installed power of ≤ 5000 kW.

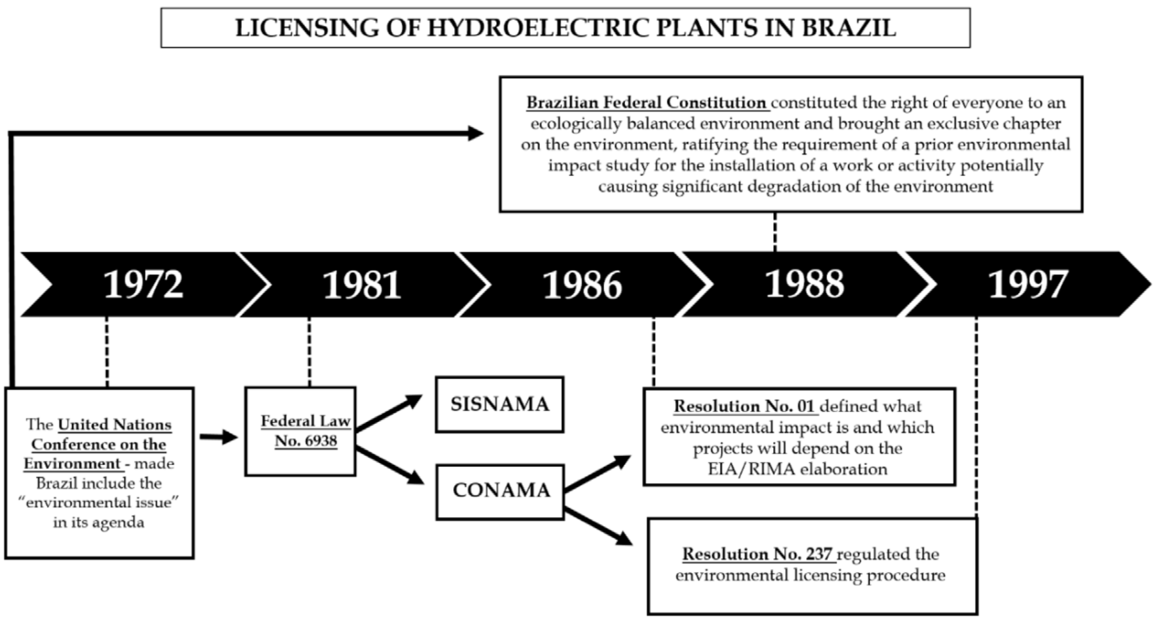
ANEEL: Management Information of the National Electric Energy Agency.

of the referenced EIA/RIMA. Among the listed projects are hydroelectric plants (Figure 3).

Section 2.1: Brazilian Federal Legislation related to water resources for hydroelectric purposes and its intersection with fish fauna, migratory fish, and aquaculture (restocking programs)

The first Brazilian Federal Legislation to deal more specifically with the regulation and exploitation of water resources in the country and the regime of authorizations and concessions for hydroelectric projects was Decree No. 24.643 of 1934 (Brasil, 1934), which is popularly known as the Water Code. The Water Code provides for the regulation of the hydroelectric industry and highlights, in its article 143, the importance of fish for food security. In this article, it is stipulated that all HPPs must meet the requirements for the protection of food sources and the needs of riverside populations, indicating that the conservation and free movement of fish must be maintained (Brasil, 1934). The Water Code remains in force.

In parallel, in 1967, Decree No. 221 on the Protection and Encouragement of Fishing was promulgated (Figure 4). This decree focused on the environmental damage to fauna caused specifically by dams, as provided in Article 36, which states that the owner or concessionaire of dams in water courses is obliged to take measures to protect fauna (Brasil, 1967a). However, this provision was revoked by Law No. 11.959 of 2009 ("The National Policy for the Sustainable Development of Aquaculture and Fisheries and Regulated Fishing Activities"), which did not mention such obligations (Brasil, 2009). It is also



SISNAMA: National Environment System; CONAMA: National Council for the Environment; EIA: Environmental Impact Study; RIMA: Environmental Impact Report.

Figure 3. Summary of the main legal provisions regarding the environmental licensing of hydroelectric plants.

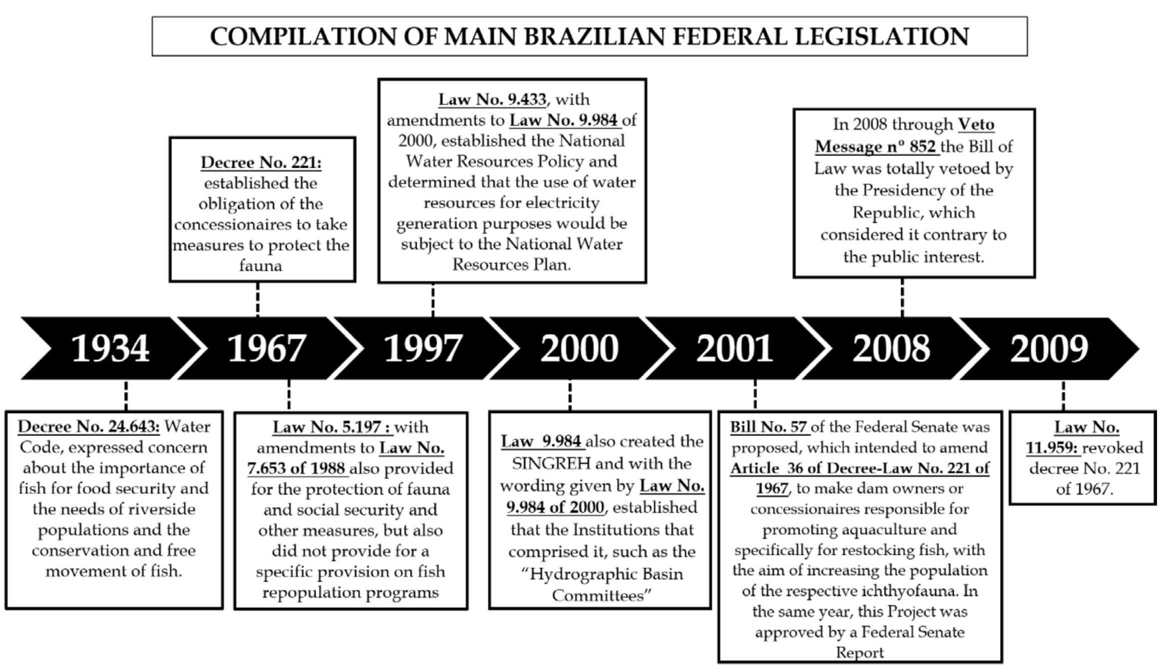


Figure 4. Brazilian Federal Legislation related to water resources for hydroelectric purposes and its intersection with fish fauna, migratory fish, and aquaculture (restocking programs).

important to note that Law No. 5.197 of 1967 (Brasil, 1967b) and the amendments to Law No. 7.653 of 1988 are provided for the protection of fauna and other measures, but they did not provide specific measurements concerning fish restocking programs or aquaculture (Brasil, 1988b), which in fact occurred with Federal Senate Bill No. 57, as discussed later.

Furthermore, Law No. 9.433 of 1997 established the National Water Resources Policy and determined which activities can be granted rights to use water resources for hydroelectric purposes and indicated that the use of water resources for the purposes of generating electricity would be subject to the National Water Resources Plan. This law also created the National Water Resources Management System (SINGREH), and with the wording of Law No. 9.984 of 2000, the institutions included within this system included the "National Water Resources Council," "National Water Agency," "Resource Council of Water Resources of the States and Federal District," and "River Basin Committees." Moreover, the agencies that oversee the management of water resources were determined, including the water agencies at the federal and state levels and within the federal district and municipal government bodies. Among the SINGREH agencies that are important for the subject of this research, Hydrographic Basin Committees must be mentioned, and their area of expertise was defined in Article 37 (Brasil, 1997a; 1997b) (Figure 4).

In 2001, an unsuccessful attempt to amend Decree-Law No. 221 of 1967 could have made a direct association between dam construction and aquaculture. On this occasion, Federal Senate Bill No. 57 (which intended to amend Article 36 of Decree-Law No. 221 of 1967) was proposed to hold dam owners or concessionaires responsible for promoting aquaculture and specifically for depositing fish in the reservoir. To increase the population of ichthyofauna species, the following wording was introduced:

> The owners and concession holders of dams, in accordance with the determinations of the competent body in their areas of activity, are responsible for: I — fostering aquaculture; and II — depositing fish in the reservoir with the purpose of increasing the population of ichthyofauna species (Senado Federal, 2001a).

To justify the change, the author claimed that the production and distribution of fry carried out according to the criteria established by the competent body would contribute to both maintaining fishing activity and improving the diet of the local population, especially the low-income population (Senado Federal, 2001a). This project was approved by the Federal Senate, considering that the project had evident merit in terms of social and economic aspects and encouraging the preservation of the environment.

In addition, it was pointed out by the author that several other previously published laws corroborated the matter at hand. For instance, Law No. 8.171 of 1991, i.e., the so-called Agricultural Law, provided a policy for the sector in Article 25, in which power plants were tasked with implementing programs to stimulate activities that support fish reproduction (Brasil, 1991). Still in this context, the Decree No. 221 of 1967 determined that public power plants should encourage the creation of federal, state, and municipal biodiversity and aquaculture stations to provide technical assistance to private individuals (Brasil, 1967a); and IBAMA Ordinance No. 145 of 1998 established rules for the introduction, reintroduction, and transfer of fish, crustaceans, mollusks, and aquatic macrophytes for aquaculture purposes (IBAMA, 1998). In addition, Law No. 3,824 of 1960 made it mandatory to remove and clean the dam hydraulic basins and indicated that areas considered necessary for the protection of ichthyofauna and reserves essential to guarantee fish farming would be reserved at the discretion of the technicians (Brasil, 1960). Finally, the Federal Senate stated that the construction of dams alters the environment and frequently impairs the reproduction of fish, thereby affecting riverside populations that previously had a complementary economic activity with fishing (Senado Federal, 2001b). However, in 2008, Senate Bill No. 57 of 2001 was completely vetoed by the Presidency of the Republic, which is considered to be contrary to the public interest:

> Veto Message No. 852/2008: "The bill deals indistinctly with all dams and establishes a general obligation to promote fish farming, while such activity is not always possible or technically recommended. In addition, it is an obligation that will cause increased costs for the construction and operation of hydroelectric plants, which will certainly be reflected in the tariffs that the concessionaire will offer to build, operate and maintain these dams. Ultimately, it is the captive consumer of electricity that will pay for these costs, which is contrary to the objective of reasonable tariffs. For item I of the proposed device, it should be noted that the activity of promoting aquaculture is the responsibility of the state. In this case, the Special Secretariat for Aquaculture and Fisheries, an organ of the Presidency of the Republic, is competent to formulate and comply with these guidelines in accordance with Art. 23 of Law No. 10.683, of May 28, 2003, and it is not convenient to confer such attribution to the individual. That should not even be the intention of the project, which, having been proposed in 2001 before the creation of the Secretariat and its related attribution of incentive to fishing, had its object harmed (Presidência da República, 2008).

So, considering the absence of a device foreseen in the law that requires the owner or concessionaire of dams in watercourses to provide for fish restocking programs or specific ichthyofauna conservation programs, the issue seems to depend on the discretion of the licensing agency to demand that the hydroelectric plant operators carry out the reintroduction of fish in their reservoirs.

Section 3: Illustrative examples on the effect of dams on fish communities

The effect of dams on fish communities, especially on fishing in Brazil, is summarized here due to the large number of studies and recent reviews on this issue (Petrere Jr. et al., 2002; Agostinho et al., 2008; Agostinho et al., 2010; Garcez et al., 2011; Vitule et al., 2011; Agostinho et al., 2016; Pimentel et al., 2020). As previously mentioned, the topic was not done through a systematic review, as we focused only on selected descriptions that brought illustrative cases about the impact of dams on the abundance of migratory fish and their migratory process.

We must also emphasize that SHPs have theoretically been considered less harmful to rivers. However, Couto et al. (2021) raised an important question regarding the lower power amounts generated by SHPs in relation to HPPs. According to these authors, the larger number of SHP units that need to be installed can compromise and fragment a larger number of basins. Moreover, these projects, which present an estimated future growth of 21%, will also need to be analyzed and planned based on these aspects (Couto et al., 2021). Still in this context, another related concern is the fracturing of the longitudinal continuity of rivers. In a recent study, Zambaldi and Pompeu (2020) showed that a greater number of migratory species in southeastern Brazil are found in stretches over 100 km without fragmentation. However, by simulating future scenarios, the authors showed a possible increase in stretches of only 50 km, which is inadequate for the maintenance of migratory species.

Below we cite some examples, especially in cases where we have developed some studies, as in the case of the Tucuruí Dam (Hainfellner et al., 2019), where many particularities are observed in each case, which involve numerous variables: type of dam, rainfall, climate, local social contexts, and mainly the migratory stretches of the river that each species occupy. An important topic to be addressed is the momentary abundance of species that is frequently observed after the installation of hydroelectric plants. A very well-studied case of HPPs is the two installed HPPs in the Madeira River in 2012, namely, Jirau [Porto Velho, Rondônia (9° 15′ 51,8″ S, 64° 38′ 30,8″ O)] and Santo Antônio [Porto Velho, Rondônia (8° 48′ 04″ S, 63° 56′ 59,8″ O)], that showed that one of the main effects of the installation of a power plan on fish communities was a change in the pattern of occurrence of species according to rain rhythms, which was mainly based on the flood and dry phases (Freitas et al., 2020). In this case, before the dam was installed, there was a clear correlation between the abundance of species and rain rhythms. However, after the dam was installed, this correlation weakened, and a clear pattern of oscillations, such as that from before the dam, could not be observed. The increase in the frequency of migrating species after the dam was installed was also highlighted, which indicated that this greater momentary abundance was related to the inability of species to migrate downstream (Freitas et al., 2020). In such situations, although this process causes a momentary increase in the abundance of these species, it will certainly provoke a future impact on the young forms produced in that section of the river.

Another important aspect is that, specifically, dams change the movements and consequently the spawning sites of different populations of different native fish species. Mérona et al. (2010) reported that inhibited migration is one of the main factors affecting fish communities after the elevation of the Tucuruí Dam [Tucuruí, Pará (3° 49′ 56″ S, 49° 38′ 59″ O)]. However, in this case, the presence of the dam accentuated the isolation of the downstream zone, thus preventing upstream displacements of migratory species and limiting the recolonization of the downstream area by juveniles from the upstream area (Mérona et al., 2010). In this reservoir, the schools of mapará, *Hypophthalmus* spp. and curimbatá, *Prochilodus* spp., two very important migratory species, suffered impacts from the dam but for different reasons (details in Mérona et al., 2010). While the curimbatá was among the migratory species most affected by the fact that the closure of the river prevents its upward reproductive migration and limits its recolonization in the downstream from upstream, the same reason cannot be attributed to the reduction in the abundance of mapará, as it carried out its entire migratory cycle in the downstream area, so it is very likely that there was also a decrease in plankton production due to a degradation of the aquatic environment (Mérona et al., 2010). Still concerning maparás, a fish that we studied due to its high potential for integrated aquaculture purposes for being planktivorous, in the same area reported by Mérona et al. (2010), we published a study in 2019 where maparás were observed upstream and downstream the dam, but in the immediate downstream portion very close to the dam, spawned individuals were not found, and only mature females were observed (absence of spawning) (Hainfellner et al., 2019). We also observed that some females found downstream from the dam, however at a slightly greater distance, indeed had postovulatory follicles, indicating that they had spawned in those areas, but not in the dam area (Hainfellner et al., 2019).

Among many other negative effects, the effect of dams on the water level should be mentioned, as demonstrated in southern Brazil in the reservoirs of the Itá and Machadinho plants in the upper Uruguay River (Lima et al., 2017). Similar to the other studies mentioned, the authors highlighted the interference of the dams on the recruitment of young individuals and also pointed out that the negative effect was more intense on species that spawn in nests than on one species that release semi-dense eggs. We believe that this damage is observed in many dams, especially in cases where it is necessary to interfere with lake volumes due to droughts; however, in many cases, this type of damage has not been researched and described.

We must also mention that fish passages, mainly in the form of ladders, are among the mitigation measures implemented in some dams to solve the impediment caused by dams to schools of migratory fish seeking to travel upstream during migratory reproductive movements. The subject is addressed in two important studies (Godinho and Kynard, 2008; Pelicice and Agostinho, 2008). According to the authors, upstream fish migration is important, even if there are no more spawning or nursery habitats in the upstream portion, and effective fish passages with appropriate designs are one of the main issues to be developed to allow fish to migrate properly (Godinho and Kynard, 2008). On the contrary, according to Pelicice and Agostinho (2008), the implementation of fish passages needs to be considered when evaluating the specific conditions of each river stretch because depending on the conditions, such passages may be harmful to fish populations, especially if the conditions for the survival of species in the upstream stretches are not observed (Pelicice and Agostinho, 2008). The subject seems to be quite controversial and of worldwide importance; however, as different study environments present numerous particularities, different conclusions are commonly found.

Section 4: Overview of aquaculture in Brazil

Marine and freshwater food systems have a crucial and growing role in providing billions of people with essential protein and nutrients, as well as livelihoods and other services, assisting society in overcoming hunger, malnutrition, and poverty (FAO, 2022a). Aquatic foods are a rich source of protein with multiple nutrients. Plant (60%) and animal proteins (40%) contribute to the global average daily intake in 2019. From animal proteins, the main sources are dairy (10%), aquatic foods (7%), poultry (7%), pig meat (5%), bovine (4%), and other (7%) (FAO, 2022b).

The contribution of fisheries and aquaculture will have to increase according to 2030 Agenda for Sustainable Development. Future projections predict increasing challenges as a result of conflict, climate change, and, of course, the evolving COVID-19 pandemic (FAO, 2022b). The increase in aquatic food consumption has been mainly made possible by a significant increase in aquaculture production (FAO, 2022a; 2002b).

Global production of aquatic animals was estimated to have reached about 178 million tons in 2020, of which 82 million tons came from aquaculture production (FAO, 2022b). In 2020, 90 (51%) million tons of fish from capture fisheries and 88.0 million tons of fish from aquaculture (49%) were produced (FAO, 2022b). Of the total production, 63% came from marine waters (70% and 30% from capture and aquaculture, respectively) and 37% from inland waters (83% and 17% from aquaculture and capture, respectively). Inland aquaculture contributed to 54.5 million tons [against 11.5 million tons from inland capture: mostly from Asia (64%) and Africa (28%)]. These data illustrate the importance of freshwater aquaculture, which in the case of Brazil accounts for almost 100% of pisciculture production (FAO, 2022b).

In 2020, Brazil was the 12º country in the inland water capture ranking with 0.22 million tons and China is the 1º with 1.80 million tons (FAO, 2022b). With regard to overall aquaculture production, Brazil is the 13th largest producer of aquatic animals in the world with 630,000 tons and the 8º largest producer of fish by inland aquaculture with 552,000 thousand tons in 2020 (FAO, 2022b).

In Brazil, freshwater fish is predominantly produced, followed by marine shrimp. The main farmed species are Nile tilapia (*Oreochromis niloticus*), tambaqui (*Colossoma macropomum*), and the Pacific white leg shrimp (*Litopenaeus vannamei*). Other species have great local socioeconomic importance (Valenti et al., 2021). Data from PEIXE-BR indicate that in 2021, the production data in Brazil are even higher than those of the FAO (2022a), that is, 841,005 tons of farmed fish (freshwater fish), which represents a growth of 4.7% over 2020 production (PEIXE-BR, 2022). However, with regard to native fish, 262,370 tons were produced (31.2% of the total), which represents a decrease of 5.85% compared to 2020 (PEIXE-BR, 2022). This gradual decline that has been observed in recent years has multidisciplinary explanations, including the cultural aspect of low fish consumption in Brazil, national infrastructure issues that still make undertakings difficult and the lack of official programs to support farming (PEIXE-BR, 2022), and recently, market difficulties, including the negative effects of the pandemic (FAO, 2022b).

Furthermore, the reasons for the inconsistent production of these native species are complex and multidisciplinary (Valenti et al., 2021), and interference in this scenario, as several social (preference for animal protein from another source) and economic (relatively high price of fish meat due to the general increase in consumer costs and prices), leads the consumer to choose cheaper proteins. We highlight that in Brazil, the relatively low annual per capita consumption of fish [10.19 kg. year^{-1} according to Seafood Brasil (2021)], associated with the lack of consolidated production packages (especially due to an inconstant and uncertain supply of fingerlings) (MPA, 2014), is still a bottleneck for increasing the production of native fish.

In a recent review of the current situation of national aquaculture, Valenti et al. (2021) pointed out that Brazil is rich in natural resources suitable for the production of aquatic organisms and has a domestic market and specialized human material to support the growth of aquaculture. However, the researchers pointed out that aquaculture is concentrated in a few species and is not enough to meet the current national demand for fish, since approximately 350,000 tons are annually imported every year, a number that represents a deficit in the trade balance of 1.2 billion (Valenti et al., 2021). It is also noteworthy that the current market consumes at least 50% of aquaculture production (Valenti et al., 2021).

According to Valenti et al. (2021), the largest volume of production comes from small farmers, since the country has more than 200,000 registered fish farms. In this scenario, it is necessary to develop an economically sustainable aquaculture to support a perennial industry. In this scenario, new technologies, involving innovations to solve old problems, are imperative (FAO, 2022a).

According to the Ministry of Fisheries and Aquaculture (MPA) report published in 2014, in Brazil, the participation of native species in fish farming is below 20.0%, while in Asia, where the world's largest fish production is concentrated, around 95.0% of crops are based on species native to that continent (MPA, 2014). The explanation for the fact that the main species bred in captivity in the country are exotic (tilapia) is more related to the existence of basic information (easy reproductive management, genetic improvement, protocols for sexual inversion, production chain) for their creation than for its characteristics (MPA, 2014). Therefore, information on specific aspects of the production of native species, such as efficiency in the production of fingerlings, and technological packages involving all stages of cultivation (from egg to slaughter) still need to be defined.

FINAL CONSIDERATIONS

We have already demonstrated that dams affect riverside communities by causing damage to fish populations, and we must now highlight that aquaculture in Brazil, despite having enormous potential, still has comparatively low results (FAO, 2022a), mainly concerning native fish (PEIXE-BR, 2022). According to data from this association in the past 5 years, the Brazilian production of native species has been gradually reducing due to numerous issues ranging from environmental to health issues, which discourage growth in the activity (PEIXE-BR, 2022).

The intersection here is the occurrence of reports of decline for both the aquaculture production of native migratory species and the abundance of native migratory fish in rivers interrupted by dams. In this concern, as discussed before, currently Brazilian federal law is quite broad with respect to environmental licensing and the repair of damages caused by large enterprises. However, the damage caused by the construction of a dam in hydroelectric projects by preventing and/or harming the migratory and reproductive process of fish is not specifically governed by legal provisions. Therefore, the matter is left to the discretion of the licensing agency, which may make decisions based on the EIA/RIMA, which in turn may not contain specific actions on this concern as a condition for obtaining the operating license.

Moreover, some Brazilian migratory fish species still do not have safe and totally predictable protocols for producing fingerlings (Sato et al., 2020). Regardless of the protocol employed, the reproduction of pacu, for instance, in captivity shows flaws in ovulation, which is one of the main limitations for its production (Criscuolo-Urbinati et al., 2012; Schorer et al., 2016; Kuradomi and Batlouni, 2018). In recent decades, failures in the reproduction of diverse species of migratory fish, mainly pacu, were evaluated whose success in reproduction is still unpredictable (Criscuolo-Urbinati et al., 2012; Pereira et al., 2017; Kuradomi and Batlouni, 2018; Hainfellner et al., 2019; Borella et al., 2020; de Souza et al., 2020; Roza de Abreu et al., 2021). Reproductive failures in native fish lead to huge financial losses (Valenti et al., 2021).

Failure to fish and the consequent scarcity of fishing resources cause an imbalance in the ecosystem and can have an impact on the food security of the riverside populations, which use these resources both for their own consumption and as a source of income. In this way, linking hydroelectric ventures to the fishing industry established in the letter of the law would be a valuable form of public policy to guarantee that damage caused by dams to the reproduction of fish is repaired and ensure that communities that depend on fishing in the affected areas have food security.

One of the ways to promote aquaculture and protein production is the improvement of public policies that deal with the theme of the use of reservoirs created for energy generation and on the existing regulation on the repair of environmental damage, especially on the migratory native fish fauna. The discretion of the laws that deal with how to mitigate environmental damage means that, in practice, the form of mitigation varies greatly between projects. Thus, it is observed that some hydroelectric plants and small hydroelectric plants carry out fish restocking programs and others do not, for instance. Restocking programs, if done properly, can be an alternative to restore populations affected by the dam, but to be effective and well executed, it needs to be accompanied by programs to control predatory fishing and restoration of riparian vegetation, among others. Scientific studies on the effectiveness, risks, and correct operation of fish restocking programs for Brazilian species need to be carried out. Even so, fish farming indirectly has a direct interface with aquaculture, as the millions of native fish fingerlings released by aquaculture enterprises are normally produced in private fish farming stations contracted by hydroelectric plants or in fish farms maintained by the hydrelectric plants themselves (Valenti et al., 2021). The production of fingerlings of native species encourages the activity, contributing to fishing and the entire aquaculture production chain, generating jobs, consuming feed, hormones, and fertilizers, and contributes to the production of these species, which has recorded a sharp decline in the latter (Valenti et al., 2021).

Finally, considering the Brazilian electrical matrix is more renewable than the world matrix, but dams can cause environmental damage. Brazilian legislation and licensing agencies must be concerned with repairing such damage, such as to ichthyofauna. However, as stated in this review, although several laws generally deal with the environmental licensing of HPPs and the protection of the environment, none of them necessarily requires the concessionaires of hydroelectric plants to carry out ichthyofauna conservation programs. Thus, it is up to the licensing agency to establish such regulations as a condition for operating licenses for these projects. Failure to carry out programs related to the preservation of ichthyofauna can cause an imbalance in the ecosystem and a reduction/scarcity of fishing resources, which can have an impact on the food security of the riverside populations that use these resources both for their own consumption and as a source of income. In this way, linking hydroelectric enterprises to the implementation of programs for the preservation of ichthyofauna established by law would be a valuable public policy to guarantee that damage caused by dams to the reproduction of fish is repaired and ensure the food security of the communities that depend on fisheries in the affected areas. One of the ways of mitigating the environmental damage specifically caused to native migratory fish is fish restocking programs. These programs, if well conducted, can simultaneously increase the abundance of these species in dammed rivers and promote the aquaculture of native species, which will provide the fry to be released in fishery programs.

CONFLICT OF INTERESTS

Nothing to declare.

FINANCIAL SUPPORT

Nothing to declare.

AUTHOR'S CONTRIBUTIONS

Vidal, M.V.: conceptualization, project administration, data curation, formal analysis, investigation, methodology, writing — original draft, writing — review & editing. Batlouni, S.R.: conceptualization, supervision, writing — review & editing.

REFERENCES

Agência Nacional de Energia Elétrica (ANEEL). 2019. Informações gerenciais março 2019. Brasil: Ministério de Minas e Energia. Available at: https://www.aneel.gov.br/informacoes-gerenciais. Accessed on: Apr. 26, 2021.

Agência Nacional de Energia Elétrica (ANEEL). 2020a. Resolução Normativa nº 875, de 10 de março de 2020. Estabelece os requisitos e procedimentos necessários à aprovação dos Estudos de Inventário Hidrelétrico de bacias hidrográficas, à obtenção de outorga de autorização para exploração de aproveitamentos hidrelétricos, à comunicação de implantação de Central Geradora Hidrelétrica com Capacidade Instalada Reduzida e à aprovação de Estudos de Viabilidade Técnica e Econômica de Usina Hidrelétrica sujeita à concessão. Diário Oficial da União, Seção 1(51): 60.

Agência Nacional de Energia Elétrica (ANEEL). 2020b. Resolução Normativa nº 890, de 21 de junho de 2020. Retifica a Resolução Normativa nº 875, de 10 de março de 2020, que estabeleceu, de forma consolidada, as normas referentes aos procedimentos e requisitos para realização de estudos de inventário hidrelétrico de bacias hidrográficas, exploração e outorga de empreendimentos hidrelétricos. Diário Oficial da União, Seção 1(141): 45.

Agostinho, A.A.; Gomes, L.C.; Santos, N.C.L.; Ortega, J.C.G.; Pelicice, F.M. 2016. Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. Fisheries Research, 173(Part 1): 26-36. https://doi.org/10.1016/j.fishres.2015.04.006

Agostinho, A.A.; Pelicice, F.M.; Gomes, L.C. 2008. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. Brazilian Journal of Biology, 68(4 Suppl.): 1119-1132. https://doi.org/10.1590/S1519-69842008000500019

Agostinho, A.A.; Pelicice, F.M.; Gomes, L.C.; Júlio Jr., H.F. 2010. Reservoir fish stocking: when one plus one may be less than two. Natureza & Conservação, 8(2): 103-111. https://doi.org/10.4322/natcon.00802001

Associação Brasileira da Piscicultura (PEIXE-BR). 2022. Anuário 2022 Peixe-BR da Piscicultura. Anuário Brasileiro da Piscicultura PEIXE-BR.

Borella, M.I.; Chehade, C.; Costa, F.G.; Jesus, L.W.O.; Cassel, M.; Batlouni, S.R. 2020. The brain-pituitary-gonad axis and the gametogenesis. Biology and Physiology of Freshwater Neotropical Fish, 315-341. https://doi.org/10.1016/B978-0-12-815872-2.00014-2

Brasil. 1934. Decreto nº 24.643, de 10 de julho de 1934. Decreta o Código de Águas. Diário Oficial da União, Seção 1: 14738.

Brasil. 1960. Lei nº 3.824, de 23 de novembro de 1960. Torna obrigatória a destoca e consequente limpeza das bacias hidráulicas dos açudes, represas ou lagos artificiais. Diário Oficial da União, Seção 1: 15221.

Brasil. 1967a. Decreto nº 221, de 28 de fevereiro de 1967. Dispõe sobre a proteção e estímulos à pesca e dá outras providências. Diário Oficial da União, Seção 1: 2413.

Brasil. 1967b. Lei nº 5.197, de 3 de janeiro de 1967. Dispõe sobre a proteção à fauna e dá outras providências. Diário Oficial da União, Seção 1: 177.

Brasil. 1981. Lei Federal nº 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional do Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. Diário Oficial da União, Seção 1: 16509.

Brasil. 1988a. Constituição da República Federativa do Brasil. Diário Oficial da União, Seção 1(191-A): 1.

Brasil. 1988b. Lei nº 7.653, de 12 de fevereiro de 1988. Altera a redação dos arts. 18, 27, 33 e 34 da Lei nº 5.197, de 3 de janeiro de 1967, que dispõe sobre a proteção à fauna, e dá outras providências. Diário Oficial da União, Seção 1: 2689.

Brasil. 1991. Lei nº 8.171 de 17 de janeiro de 1991. Dispõe sobre a política agrícola. Diário Oficial da União, Seção 1: 1330.

Brasil. 1996. Lei nº 9.427, de 26 de dezembro de 1996. Institui a Agência Nacional de Energia Elétrica - ANEEL, disciplina o regime das concessões de serviços públicos de energia elétrica e dá outras providências. Diário Oficial da União, Seção 1: 28653.

Brasil. 1997a. Decreto nº 2.335, de 6 de outubro de 1997. Constitui a Agência Nacional de Energia Elétrica - ANEEL, autarquia sob regime especial, aprova sua Estrutura Regimental e o Quadro Demonstrativo dos Cargos em Comissão e Funções de Confiança e dá outras providências. Diário Oficial da União, Seção 1: 22377.

Brasil. 1997b. Lei nº 9.433, de 8 de janeiro de 1997. Institui a Política Nacional de Recursos Hídricos, cria o Sistema Nacional de Gerenciamento de Recursos Hídricos, regulamenta o inciso XIX do art. 21 da Constituição Federal, e altera o art. 1º da Lei nº 8.001, de 13 de março de 1990, que modificou a Lei nº 7.990, de 28 de dezembro de 1989. Diário Oficial da União, Seção 1: 470.

Brasil. 2009. Lei nº 11.959, de 29 de junho de 2009. Dispõe sobre a Política Nacional de Desenvolvimento Sustentável da Aquicultura e da Pesca, regula as atividades pesqueiras, revoga a Lei no 7.679, de 23 de novembro de 1988, e dispositivos do Decreto-Lei no 221, de 28 de fevereiro de 1967, e dá outras providências. Diário Oficial da União, Seção 1: 1.

Conselho Nacional do Meio Ambiente (CONAMA). 1986. Resolução nº 1, de 23 de janeiro de 1986. Dispõesobrecritériosbásicos e diretrizes gerais para avaliação de impacto Ambiental. Diário Oficial da União, Seção 1: 2548-2549.

Conselho Nacional do Meio Ambiente (CONAMA). 1997. Resolução nº 237, de 19 de dezembro de 1997. Dispõe sobre a revisão e complementação dos procedimentos e critérios utilizados para o licenciamento Ambiental. Diário Oficial da União, Seção 1(247): 30841-30843.

Conselho Nacional do Meio Ambiente (CONAMA). 2001. Resolução nº 279, de 27 de junho de 2001. Estabelece procedimentos para o licenciamento ambiental simplificado de empreendimentos elétricos com pequeno potencial de impacto Ambiental. Diário Oficial da União, Seção 1(125-E): 165-166.

Couto, T.B.A.; Messager, M.L.; Olden, J.D. 2021. Safeguarding migratory fish via strategic planning of future small hydropower in Brazil. Nature Sustainability, 4: 409-416. https://doi.org/10.1038/s41893-020-00665-4

Criscuolo-Urbinati, E.; Kuradomi, R.Y.; Urbinati, E.C.; Batlouni, S.R. 2012. The administration of exogenous prostaglandin may improve ovulation in pacu (*Piaractus mesopotamicus*). Theriogenology, 78(9): 2087-2094. https://doi.org/10.1016/j.theriogenology.2012.08.001

de Souza, T.G.; Kuradomi, R.Y.; Rodrigues, S.M.; Batlouni, S.R. 2020. Wild induced spawning with different dose of mGnRHa and metoclopramide or carp pituitary extract. Animal Reproduction, 17(1): e20190078. https://doi.org/10.21451/1984-3143-AR2019-0078

Destefenni, M. 2004. Direito penal e licenciamento ambiental. São Paulo: Memória Jurídica.

Empresa de Pesquisa Energética (EPE). 2020. Plano Nacional de Energia 2050. Brasil: EPE. Available at: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/Plano-Nacional-de-Energia-2050. Accessed: Apr. 26, 2021.

Food and Agriculture Organization (FAO). 2022a. FAO Fisheries and Aquaculture Division. Rome: FAO. https://doi.org/10.4060/cb8609en

Food and Agriculture Organization (FAO). 2022b. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome: FAO. https://doi.org/10.4060/cc0461en

Freitas, H.C.P.; Doria, C.R.C.; Sousa, R.G.C. 2020. Hydroelectric dams from madeira river seasonally impacts the fisheries production in the guaporé basin (Rondônia, Brazil). Boletim do Instituto de Pesca, 46(4): e601. https://doi.org/10.20950/1678-2305.2020.46.4.601

Garcez, R.; Calcagnotto, D.; Toledo, L.F.A. 2011. Population structure of the migratory fish *Prochilodus lineatus* (Characiformes) from Rio Grande basin (Brazil), an area fragmented by dams. Aquatic Conservation: Marine and Freshwater Ecosystems, 21(3): 268-275. https://doi.org/10.1002/aqc.1176

Godinho, A.L.; Kynard, B. 2008. Migratory fishes of Brazil: life history and fish passage needs. River research and Application, 25(6): 702-712. https://doi.org/10.1002/rra.1180

Granziera, M.L.M. 2003. Direito das águas: disciplina jurídica das águas doces. 2ª ed. São Paulo: Atlas.

Hainfellner, P.; Kuradomi, R.Y.; de Souza, T.G.; Sato, R.T.; Figueiredo-Ariki, D.G.; Freitas, G.A.; Queiroz, L.; Valenti, W.C.; Moraes-Valenti, P.; Ge, W.; Batlouni, S.R. 2019. Reproductive cycle of the Amazonian planktivorous catfish *Hypophthalmus marginatus* (Siluriformes, Pimelodidae). Aquaculture Research, 50(11): 3382-3391. https://doi.org/10.1111/are.14296

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). 1998. Portaria nº 145-N, de 29 de outubro de 1998. Estabelece normas para a introdução, reintrodução e transferência de peixes, crustáceos, moluscos e macrófitas aquáticas para fins de aquicultura, excluindo-se as espécies animais ornamentais. Diário Oficial da União, Seção 1(30): 14.

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). 2008. Instrução Normativa nº 184, de 17 de julho de 2008. Estabelece, no âmbito desta Autarquia, os procedimentos para o licenciamento ambiental federal. Diário Oficial da União, Seção 1: 71.

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). 2019. Instrução Normativa nº 26, de 6 de dezembro de 2019. Institui o Sistema de Gestão do Licenciamento Ambiental Federal - SisG-LAF. Diário Oficial da União, Seção 1(247): 45.

Karpinski, C. 2008. Hidrelétricas e legislação ambiental brasileira nas décadas de 1980-90. Revista Percursos, 9(2): 71-84.

Kuradomi, R.Y.; Batlouni, S.R. 2018. PGF2α and gonadal steroid plasma levels of successful and unsuccessful spawning *Piaractus mesopotamicus* (Teleostei, Characiformes) females. Aquaculture International, 26: 1083-1094. https://doi.org/10.1007/s10499-018-0269-8

Lima, F.T.; Reynalte-Tataje, D.A.; Zaniboni-Filho, E. 2017. Effects of reservoirs water level variations on fish recruitment. Neotropical Ichthyology, 15(3): e160084. https://doi.org/10.1590/1982-0224-20160084

Mérona, B.; Juras, A.A.; Santos, G.M.; Cintra, I.H.A. 2010. Os peixes e a pesca no baixo Rio Tocantins: vinte anos depois da UHE Tucuruí. Belém, Eletrobrás Eletronorte.

Milaré, E. 2018. Direito do Ambiente. 11ª ed. São Paulo: Thomson Reuters Brasil.

Ministério da Pesca e Aquicultura (MPA). 2014. 1º Anuário brasileiro da pesca e aquicultura. Brasil: Ministério da Pesca e Aquicultura, 132 p.

Pelicice, F.M.; Agostinho, A.A. 2008. Fish-passage facilities as ecological traps in large neotropical rivers. Conservation Biology, 22(1): 180-188. https://doi.org/10.1111/j.1523-1739.2007.00849.x

Pereira, T.S.B.; Boscolo, C.N.P.; Moreira, R.G.; Batlouni, S.R. 2017. The use of mGnRHa provokes ovulation but not viable embryos in *Leporinus macrocephalus*. Aquaculture International, 25: 515-529. https://doi.org/10.1007/s10499-016-0049-2

Petrere Jr., M.; Agostinho, A.A.; Okada, E.K.; Júlio Jr., H.F. 2002. Review of the Fisheries in the Brazilian Portion of the Paraná/Pantanal Basin. Management and Ecology of Lake and Reservoir Fisheries, 123-143. https://doi.org/10.1002/9780470995679.ch11

Pimentel, J.S.M.; Ludwig, S.; Resende, L.C.; Brandão-Dias, P.F.P.; Pereira, A.H.; Abreu, N.L.; Rosse, I.C.; Martins, A.P.V.; Facchin, S.; Lopes, J.M.; Santos, G.B.; Alves, C.B.M.; Kalapothakis, E. 2020. Genetic evaluation of migratory fish: Implications for conservation and stocking programs. Ecology and Evolution, 10(19): 10314-10324. https://doi.org/10.1002/ece3.6231

Presidência da República. 2008. Mensagem de Veto nº 852, de 5 de novembro de 2008. Available at: http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2008/Msg/VET/VET-852-08.htm. Accessed on: Mar. 29, 2021.

Roza de Abreu, M.; Silva, L.M.J.; Figueiredo-Ariki, D.G.; Sato, R.T.; Kuradomi, R.Y.; Batlouni, S.R. 2021. Reproductive performance of lambari (*Astyanax altiparanae*) in a seminatural system using different protocols. Aquaculture Research, 52(2): 471-483. https://doi.org/10.1111/are.14905

Sato, R.T.; Kuradomi, R.Y.; Calil, M.C.; Silva, L.M.J.; Roza de Abreu, M.; Figueirede-Ariki, D.G.; Freitas, G.A.; Batlouni, S.R. 2020. Resumption and progression of meiosis and circulating levels of steroids and prostaglandin F2α of *Piaractus mesopotamicus* induced by hypophysation with prostaglandin F2α. Aquaculture Research, 52(3): 1026-1037. https://doi.org/10.1111/are.14957

Schorer, M.; Moreira, R.G.; Batlouni, S.R. 2016. Selection of pacu females to hormonal induction: Effect of age and of evaluation methods. Boletim do Instituto de Pesca, 42(4): 901-923. https://doi.org/10.20950/1678-2305.2016v42n4p901

Seafood Brasil. 2021. Você sabe quanto o brasileiro realmente come de pescado? Available at: https://www.seafoodbrasil.com.br/voce-sabe-quanto-o-brasileiro-realmente-come-de-pescado. Accessed on: Apr. 10, 2022.

Senado Federal. 2001a. Projeto de Lei nº 57, de 30 de agosto de 2001. Altera o art. 36 do Decreto-Lei nº 221, de 28 de fevereiro de 1967, que dispõe sobre a proteção e estímulos à pesca e dá outras providências. Available at: https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=32901. Accessed on: Apr. 15, 2021.

Senado Federal. 2001b. Relatório sobre o Projeto de Lei nº 57, de 30 de agosto de 2001. Available at: https://www25.senado.leg.br/web/atividade/materias/-/materia/46872. Accessed on: Mar. 29, 2021.

Valenti, W.C.; Barros, H.P.; Moraes-Valenti, P.; Bueno, G.W.; Cavalli, R.O. 2021. Aquaculture in Brazil: past, present and future. Aquaculture Reports, 19: 100611. https://doi.org/10.1016/j.aqrep.2021.100611

Vitule, J.R.S.; Skóra, F.; Abilhoa, V. 2011. Homogenization of freshwater fish faunas after the elimination of a natural barrier by a dam in Neotropics. Diversity and Distributions, 18(2): 111-120. https://doi.org/10.1111/j.1472-4642.2011.00821.x

Zambaldi, L.; Pompeu, P.S. 2020. Evaluation of river fragmentation and implications for the conservation of migratory fish in southeastern Brazil. Environmental Management, 65(5): 702-709. https://doi.org/10.1007/s00267-020-01266-9