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Efetividade da Avaliação de Impacto Ambiental na previsão e mitigação de impactos à fauna em empreendimentos hidrelétricos em operação no Brasil

Natalia de Alencar Monteiro

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Natalia de Alencar Monteiro

Orientador: Dr. Murilo Sversut Dias

Projeto de Dissertação de Mestrado apresentado ao Programa de Pós- Graduação em Ecologia, do Instituto de Ciências Biológicas da Universidade de Brasília, como requisito para a obtenção do título de Mestre.

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“Toda mulher parece uma árvore. Nas camadas mais profundas de sua alma ela abriga raízes vitais que puxam a energia das profundezas para cima, para nutrir suas folhas, flores e frutos. Ninguém compreende de onde uma mulher retira tanta força, tanta esperança, tanta vida. Mesmo quando são cortadas, tolhidas, retalhadas, de suas raízes ainda nascem brotos que vão trazer tudo de volta à vida outra vez. Elas têm um pacto com essa fonte misteriosa que é a Natureza!”

(Clarissa Pinkola Estés)

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SUMMARY

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Efetividade da Avaliação de Impacto Ambiental na previsão e mitigação de impactos à fauna em empreendimentos hidrelétricos em operação no Brasil.

RESUMO

Devido ao potencial de causar degradação ambiental, projetos hidrelétricos no Brasil são submetidos ao Licenciamento Ambiental e a Avaliação de Impacto Ambiental para análise de sua viabilidade e para mitigar impactos na biodiversidade. Aferir se esses instrumentos estão melhorando ao longo do tempo e se estão promovendo o desenvolvimento enquanto mitigam os impactos é fundamental para orientar ações de conservação. Avaliamos os processos de licenciamento ambiental de oito usinas hidrelétricas para testar se a predição e identificação dos impactos na fauna e a implementação de medidas de mitigação melhorou em usinas mais recentes. Também avaliamos se características das usinas são indutoras de maior número e magnitude de impactos. Usando modelos lineares, nossos resultados mostraram que a predição e identificação de impactos aumentou ao longo do tempo, mas que os impactos ainda são subestimados na análise de viabilidade ambiental dessas obras. Também descobrimos que reservatórios maiores e barragens mais altas estão associados a alterações ecológicos de maior magnitude. Por fim, identificamos que, em média, 24% das medidas propostas não são implementadas. Nossas descobertas apontam a necessidade de melhorias na Avaliação de Impacto Ambiental e no Licenciamento Ambiental, especialmente na etapa de acompanhamento da execução de medidas mitigadoras, para que esses instrumentos sejam mais eficazes na redução dos impactos adversos das usinas hidrelétricas sobre a biodiversidade.

Palavras-chave: licenciamento ambiental, impacto ambiental, monitoramento de fauna, mitigação, usina hidrelétrica.

Effectiveness of Environmental Impact Assessment in predicting and mitigating fauna impacts in hydropower plants operating in Brazil.

ABSTRACT

Due to the potential to cause environmental degradation, hydroelectric projects in Brazil are submitted to Environmental Licensing and Environmental Impact Assessment to analyze their feasibility and to mitigate impacts on biodiversity. Assessing whether these instruments are improving over time and promoting development while mitigating impacts is essential to guide conservation actions. We evaluated the environmental licensing processes of eight hydropower plants to test whether the prediction and identification of impacts on fauna and the implementation of mitigation measures has improved in more recent plants. We also evaluated whether the characteristics of the plants are inducing a greater number and magnitude of impacts. Using linear models, our results showed that the prediction and identification of impacts has increased over time, but that impacts are still underestimated in the analysis of the environmental feasibility of these plants. We have also found that larger reservoirs and higher dams are associated with ecological changes of greater magnitude. Finally, we identified that, on average, 24% of the proposed measures are not implemented. Our findings point to the need for improvement in the Environmental Impact Assessment and the Environmental Licensing, especially in the stage of monitoring the implementation of mitigation measures, so that these instruments can be more effective in reducing the adverse impacts of power plants on biodiversity.

Key-words: environmental licensing, environmental impact, fauna monitoring, mitigation, hydroelectric plant.

INTRODUÇÃO

A hidroeletricidade é a principal fonte de energia renovável do mundo, contribuindo com 1/5 de toda a produção elétrica mundial (REN21, 2020). Em resposta à crescente demanda por energia, a construção de mais de 3.700 novas usinas hidrelétricas está prevista para os próximos 30 anos (Zarfl et al., 2015). Embora seja uma fonte de energia renovável, a hidroeletricidade é acompanhada por significativas alterações ambientais decorrentes, principalmente, da regularização de vazão, inundação de áreas para formação de reservatórios e implantação de barreira artificial, que têm múltiplos efeitos na diversidade aquática e terrestre associada (Antonio et al., 2007; Rahel, 2007; Agostinho et al., 2008; Esguicero e Arcifa, 2010; Benchimol e Peres, 2015; Latrubesse et al., 2017; Norris et al., 2018; Oliveira et al., 2018). A Avaliação de Impacto Ambiental (AIA) é uma ferramenta importante para evitar ou minimizar esses efeitos sobre a biodiversidade.

A definição clássica de AIA se refere à necessidade de identificar e prever custos ambientais e impactos na saúde e bem-estar da população humana em grandes projetos de desenvolvimento (Munn, 1975). Assim, a AIA visa garantir que os impactos ambientais sejam considerados no processo de tomada de decisão dos projetos propostos, além de possibilitar a revisão dessas atividades para mitigar os impactos resultantes (Sanchez, 1995; Jay et al., 2007; Glasson et al., 2013; Ritter et al., 2017). Considerando a relevância deste instrumento, avaliar como a AIA está atuando ao longo do tempo e se está promovendo o desenvolvimento ao mesmo tempo em que mitiga os impactos é fundamental para orientar as melhores práticas de conservação.

Apesar da importância do tema, são poucos os grupos de pesquisa sistemática da AIA no Brasil (Montaño e De Souza, 2015). Pesquisas anteriores analisaram os procedimentos do AIA (Glasson e Salvador, 2000), a contribuição da AIA para a decisão sobre a viabilidade ambiental de usinas (Andrade e dos Santos, 2015), estudos de caso de usinas (Fearnside, 2014), (Fearnside, 2015) e impactos ecológicos em grupos taxonômicos específicos (Silve e Pompeu, 2008; Benchimol e Peres, 2015; Pelicice et al., 2015; Norris et al., 2018; Abreu et al., 2020). Outros autores se concentraram em identificar falhas no licenciamento ambiental e apontaram problemas relacionados à falta de conexão entre diagnóstico ambiental, análises e propostas para mitigar os impactos (Fearnside, 2013; Hofmann, 2015). No entanto, desconhecemos estudos que avaliaram a previsibilidade dos impactos à fauna em empreendimentos hidrelétricos ou que propuseram o uso de atributos das usinas como preditores de impacto. A predição de impactos é fundamental para que a tomada de decisão quanto à viabilidade ambiental de um determinado empreendimento seja feita considerando a magnitude de seus efeitos adversos. Ela permite ainda que projetos sejam aprimorados e medidas de prevenção ou redução de impactos sejam planejadas e executadas durante a instalação e operação dos empreendimentos. Assim, a predição de impactos pode ser utilizada como um parâmetro de efetividade da AIA.

A expansão global da hidroeletricidade está concentrada, principalmente, em países de economia emergente localizados em áreas ecologicamente sensíveis (Winemiller et al., 2016; Couto e Olden, 2018). O Brasil, com cerca de 85% de sua eletricidade proveniente de projetos hidrelétricos (Prado et al., 2016), se insere nesse contexto como um caso ímpar. Com 13% da biodiversidade terrestre (Lewinsohn e Prado, 2005), o país também pretende expandir o uso de seu potencial hidráulico com mais quinze grandes usinas na próxima década (Brasil, 2017). Devido ao seu potencial de causar degradação ambiental, projetos de usinas hidrelétricas no Brasil estão sujeitos ao Licenciamento Ambiental (Brasil, 1997). Esse instrumento foi associado a AIA com base na exigência de entrega do estudo prévio de impacto ambiental e seu respectivo relatório

(EIA/RIMA) para subsidiar a análise de viabilidade ambiental de empreendimentos hidrelétricos. No âmbito do EIA/RIMA, devem ser apresentados o diagnóstico ambiental da área onde se pretende instalar a usina, o prognóstico dos impactos potenciais, as medidas mitigadoras dos impactos adversos e os parâmetros a serem monitorados (Brasil, 1986).

O licenciamento ambiental no Brasil é subdividido em três fases distintas. A primeira corresponde à etapa de planejamento do empreendimento, na qual a aprovação da localização e concepção do projeto atestam a viabilidade ambiental da obra, que culmina na emissão da Licença Prévia (LP). A LP, por sua vez, estabelece os requisitos básicos e condicionantes a serem atendidas até a etapa seguinte. A segunda fase corresponde à etapa de instalação do empreendimento, na qual a aprovação de planos, programas e projetos (incluindo medidas de controle ambiental e demais condicionantes) resultam na emissão da Licença de Instalação (LI), que autoriza o início das obras. A terceira e última etapa corresponde à fase de operação, na qual a verificação do efetivo cumprimento das condicionantes das licenças anteriores resulta na emissão da Licença de Operação (LO) – que autoriza, no caso de usinas hidrelétricas, o enchimento do reservatório e o comissionamento das turbinas (Brasil, 1997).

A falta de dados compilados sobre os benefícios da AIA e do licenciamento ambiental resulta na falta de clareza do retorno socioambiental desses instrumentos, fragilizando seus papéis em um período de constantes ameaças à legislação ambiental no país. Nesse sentido, novas abordagens para avaliar a eficácia da AIA são necessárias a fim de subsidiar melhorias no licenciamento ambiental e, consequentemente, no planejamento do setor hidroenergético brasileiro (por exemplo, priorização de alternativas com menor custo socioambiental). Especialmente no que diz respeito à capacidade da AIA em prever e mitigar impactos, e de contribuir para ações concretas de proteção ambiental e desenvolvimento sustentável.

Nesse trabalho, sistematizamos informações sobre o licenciamento ambiental federal de grandes usinas hidrelétricas (> 50MW) no Brasil para testar se os impactos são preditos na AIA, se essa predição está melhorando ao longo do tempo e se pode estar relacionada aos atributos das usinas. Também testamos se o número de impactos totais e de alta magnitude estão mudando ao longo do tempo e se podem estar relacionados aos atributos das usinas. Por fim, quantificamos a proporção de medidas de mitigação implementadas a fim de avaliar sua eficácia em previnir, reduzir ou compensar impactos na biodiversidade, e se houve aprimoramento na execução dessas medidas ao longo do tempo. Ao avaliar as diferentes etapas da AIA, esperamos quantificar a precisão e eficácia desse processo em dimensionar e mitigar os impactos ambientais relacionados à construção e operação de grandes usinas hidrelétricas no Brasil.

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Capítulo 1

Efetividade da Avaliação de Impacto Ambiental na previsão e mitigação de impactos à fauna em empreendimentos hidrelétricos em operação no Brasil.

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ABSTRACT

Due to the potential to cause environmental degradation, hydroelectric projects in Brazil are submitted to Environmental Licensing and Environmental Impact Assessment to analyze their feasibility and to mitigate impacts on biodiversity. Assessing whether these instruments are improving over time and promoting development while mitigating impacts is essential to guide conservation actions. We evaluated the environmental licensing processes of eight hydropower plants to test whether the prediction and identification of impacts on fauna and the implementation of mitigation measures has improved in more recent plants. We also evaluated whether the characteristics of the plants are inducing a greater number and magnitude of impacts. Using linear models, our results showed that the prediction and identification of impacts has increased over time, but that impacts are still underestimated in the analysis of the environmental feasibility of these plants. We have also found that larger reservoirs and higher dams are associated with ecological changes of greater magnitude. Finally, we identified that, on average, 24% of the proposed measures are not implemented. Our findings point to the need for improvement in the Environmental Impact Assessment and the Environmental Licensing, especially in the stage of monitoring the implementation of mitigation measures, so that these instruments can be more effective in reducing the adverse impacts of power plants on biodiversity.

Key-words: environmental licensing, environmental impact, fauna monitoring, mitigation, hydroelectric plant.

INTRODUCTION

The hydroelectricity is the main source of renewable energy in the world, contributing with 1/5 of the world's electrical production (REN21, 2020). In response to the growing demand for energy, the construction of more than 3.700 new hydropower plants is expected for the next 30 years (Zarfl et al., 2015). Although it is a renewable energy source, the hydroelectricity is followed by significant environmental changes resulting mainly of flow regularization, flooding of areas to form reservoirs and implantation of artificial barriers, which have multiple effects on the associated aquatic and terrestrial diversity (Antonio et al., 2007; Rahel, 2007; Agostinho et al., 2008; Esguicero and Arcifa, 2010; Benchimol and Peres, 2015; Latrubesse et al., 2017; Norris et al., 2018; Oliveira et al., 2018). Environmental Impact Assessment (EIA) is an important tool to prevent or minimize such effects on biodiversity.

The classical definition of EIA refers to the need to identify and predict environmental costs and impacts on the health and well-being of the human population in major development projects (Munn, 1975). Thus, the EIA aims to ensure that environmental impacts are considered in the decision-making process of proposed projects, besides enabling the review of these activities to mitigate the resulting impacts (Sanchez, 1995; Jay et al., 2007; Glasson et al., 2013; Ritter et al., 2017). Considering the relevance of this instrument, assessing how the EIA is acting over time and promoting development while mitigating impacts is essential to guide best conservation practices.

Despite the importance of the theme, there are few EIA systematic research groups in Brazil (Montaño and De Souza, 2015). Previous researches have analyzed the EIA’s procedures (Glasson and Salvador, 2000), the EIA's contribution to the decision on the environmental viability of hydropower plants (Andrade and dos Santos, 2015), case studies of hydropower plants (Fearnside, 2014; Fearnside, 2015) and ecological impacts on specific taxonomic groups (Silve and Pompeu, 2008; Benchimol and Peres, 2015; Pelicice et al., 2015; Norris et al., 2018; Abreu et al., 2020). Other authors focused on identifying environmental licensing failures and pointed out problems related to the lack of connection between environmental diagnosis, analysis and proposals to mitigate the impacts (Fearnside, 2013; Hofmann, 2015). However, we are unaware of studies that evaluated the predictability of impacts on fauna in hydroelectric projects or that proposed the use of plant's attributes as predictors of impact. The prediction of impacts is fundamental so that the decision-making regarding the environmental feasibility of a given project is made considering the magnitude of its adverse effects. It also allows projects to be improved and measures to prevent or reduce impacts to be planned and executed during the installation and operation of the projects. Thus, the impact prediction can be used as an EIA effectiveness parameter.

The global expansion of hydroelectricity is concentrated mainly in emerging economy countries located in ecologically sensitive areas (Winemiller et al., 2016; Couto and Olden, 2018). Brazil, with about 85% of its electricity from hydroelectric projects (Prado et al., 2016), fits into this context as a unique case. Containing 13% of Earth biodiversity (Lewinsohn and Prado, 2005), the country also intends to expand the use of its hydraulic potential with fifteen more large plants in the next decade (Brasil, 2017). Due to their potential to cause environmental degradation, hydroelectric plants projects in Brazil are subject to Environmental Licensing (Brasil, 1997). This instrument was associated with the Environmental Impact Assessment (EIA) based on the requirement to present the previous environmental impact study and its respective report (EIA/RIMA) to support the environmental feasibility analysis of hydroelectric projects. Within the scope of the EIA/RIMA, it must be presented the environmental diagnosis of the area where the hydropower plant pretend to be installed, the prognosis of potential impacts, the mitigating measures for adverse impacts and parameters to be monitored (Brasil, 1986).

The lack of data compiled on the benefits of EIA and environmental licensing results in a lack of clarity on the socio-environmental return of these instruments, weakening their roles in a period of constant threats to environmental legislation in Brazil. In this sense, new approaches to assess the effectiveness of the EIA are necessary in order to support improvements in environmental licensing and, consequently, in the planning of the Brazilian hydroenergy sector (for example, prioritizing alternatives with lower socio-environmental cost). Especially with regard to the EIA's ability to predict and mitigate impacts, and to contribute to concrete actions for environmental protection and sustainable development.

In this work, we systematized information on the federal environmental licensing of large hydroelectric plants (> 50MW) in Brazil to test whether impacts are predicted in the EIA, whether this prediction is improving over time and whether it can be related to the attributes of the hydropower plants. We also tested whether the number of total and high-magnitude impacts are changing over time and whether they can be related to the plant's attributes. Finally, we quantified the proportion of mitigation measures implemented in order to assess their effectiveness in preventing, reducing or compensating impacts on biodiversity, and whether there has been an improvement in the execution of these measures over time. By evaluating the different stages of the EIA, we hope to quantify the accuracy and effectiveness of this process in dimensioning and mitigating the environmental impacts related to the construction and operation of large hydropower plants in Brazil.

MATERIAL AND METHODS

1. Collection of data

We used the database of the Environmental Licensing System (SISLIC) and the Electronic Information System of IBAMA (SEI) to consult environmental licensing processes of federal competence and elaborate a general list of hydropower plants. We have consulted the environmental studies, licenses and reports of fauna monitoring of power plants that corresponded to the following criteria: (i) digitalized and available processes for consultation; (ii) installed power exceeding 50 MW; (iii) presence of the three environmental licenses according the federal Brazilian laws (Preliminary License, Installation License and Operating License); (iv) presence of previous environmental impact study and Environmental Impact Report - EIA/RIMA; and (v) existence of fauna monitoring program started at least one year before the beginning of reservoir filling, and in progress or finalized at least one year after the start of the operation. The exclusion of projects with power below than 50MW is justified by differences in the environmental licensing process of smaller hydroelectric projects, which may be subjected to simplified procedure. Obtaining the three environmental licenses ensures that the projects screened have gone through all the stages of three-phase licensing: planning, installation, and operation. The requirement to present EIA/RIMA ensures that potential impacts have been presented and indicated mitigation measures as a subsidy to the project's feasibility analysis. Finally, the fauna monitoring initiated before the disturbance and continued during the plant’s operation is an indication that changes in ecological parameters were measured over time, which may corroborate predicted impacts or indicate new impacts.

Of the total of 68 power plants in operation found in the database, five were excluded from our sample for not having a fully digitized process available for consultation, three for having power less than 50MW and 44 for not having the three environmental licenses (projects started before the current environmental legislation, in the process of regularization). Among the remaining 16, all had EIA/RIMA and fauna monitoring program and fit the requirements of our research. For the 16 power plants that met the established criteria, we consulted the technical and procedural documents (EIA/RIMA, reports on compliance with environmental license conditions, reports on monitoring environmental programs, opinions, notes and technical information) to extract the information of the project's name, inclusion of biome, installed power, reservoir area, year of delivery of the EIA/RIMA and the dam's height. Due to the large volume of data in each process (e.g. Belo Monte Plant: 107 volumes at Sislic and 284 volumes at SEI) we had to reduce the sample number so that our research could be done within the time available. In this way, we selected four power plants located in Amazonian biome and four located in the Atlantic forest, with power characteristics, reservoir area, dam's height and year of environmental studies preparation more divergent among themselves.

For these processes, we consult the same technical documents to extract information on impacts to fauna. We consider as impact all the changes that caused loss, reduction, increase or change in ecological parameters. In order to homogenize the nomenclature of the impacts described in each process, we group the impacts into categories. In sequence, we classify the impacts as potential (predicted before the construction of the plant) and observed (occurred and verified from the beginning of the construction). Then, we extract information from the classification of impacts magnitude (high, medium or low) and affected taxonomic group. The magnitude classification of the impacts followed the criteria defined by the teams that prepared the studies in each of the plants. For cases in which there was more than one magnitude rating for the same impact, we adopted the highest level of impact as a conservative criterion. We understand that assigning significance to impacts is challenging. However, considering that magnitude was the attribute of the impact prediction most common among the analyzed projects, we chose to use it in this study as a measure of intensity. Although, we consider that the analysis of the criteria used to classify the magnitude in different projects is a relevant issue to be addressed in future analyzes. Regarding the taxonomic classification, we used the groups of vertebrates in the format most presented in the monitoring reports: birds, mammals, herpetofauna, ichthyofauna and invertabrates.

We have also compiled all measures suggested during the environmental licensing for each impact and group them into categories to homogenize the nomenclatures between the hydropower plants. Then, we check if these measures have been implemented or not. In sequence, they were classified as prevention (used to prevent the occurrence of impact), reduction (seek to minimize impacts that will occur), compensation (compensate residuals impacts), and monitoring (used to complement diagnostics, evaluate pre-established parameters to measure or identify impacts and/or to verify the efficiency of implemented initiatives). The entire search for data and classification was carried out by a single person to avoid classification confusion and standardize the collection of information between the plants.

2. Data analysis

To quantify the EIA`s accuracy in anticipating impacts arising from hydropower plants, we calculated the similarity between potential and observed impacts. For this, we created a table of presence and absence where the lines corresponded to the pre and post installation phases of each project and the columns corresponded to the impacts detected in each of the phases. We consider as a pre-phase all activities and studies presented before any environmental change and as a post-phase, activities and studies presented after the beginning of the installation and during the operation of the plants.

If an impact was predicted in the pre-phase and observed in the post-phase, for example, both lines would have a value of 1 (presence); and if the impact was not recorded in one or none of the phases, it would be represented by the value 0 (absence). We used the Sorensen index to calculate the similarity (i.e., 1-Sorensen) of the impacts between pre and post-stages in each venture individually. Basically, the Sorensen index is a widely used in ecology to summarize similarity of species composition between two pair of assemblages (Koleff et al., 2003) and here measures how similar are both EIA phases regarding the impacts registered in each of them. The resulting values for each hydropower plant vary between 0 (total dissimilarity) and 1 (total similarity). In sequence, we tested the time effect (year of EIA/RIMA's elaboration), of the reservoir area and of the dam's height on the similarity of impacts between phases in a multiple linear regression model.

To quantify the impacts, we calculated the number of total impacts observed in each plant and their respective frequencies of occurrence, by category and taxonomic group affected. Then, we used the reservoir area, the dam's height, and the year of EIA/RIMA's elaboration as predictors of impacts in a multiple linear regression model with Gaussian distribution. As many high magnitude impacts have been registered during the EIA process and these represent major risk to biodiversity, we also refit the model using the same variables to test plant attribute effects, exclusively, on the number of high magnitude impacts. All number of impacts were log-transformed (log(x+1)) previously to improve model assumptions.

To calculate the proportion of mitigation measures implemented, we counted the number of mitigation measures that have been implemented and divided by the total number of proposed measures in each plant. We also calculate the proportion of measures implemented by type (prevention, reduction, compensation, and monitoring) and counted impacts without associated measures. Finally, we tested the time effect and the similarity between impacts (potential and observed) in the proportion of implemented measures.

We tested the correlation between all independent predictors and overall there were no multicollinearity problems in our multiple regression models. We only identified that the biome variable is correlated with the reservoir area (Pearson correlation, $r = -0.69$; $p = 0.05$) and year of EIA's elaboration ($r = -0.94$; $p < 0.01$). We opted to remove biome from our multiple regressions. However, despite the correlation, we consider it relevant, as a complementary analysis, to use biome to test effects on the number of high magnitude impacts, considering that this variable can indicate characteristics of habitats more susceptible to environmental changes.

We tested the significance of each variable using the *Likelihood Ratio Test* (made with *Fisher's* test) by removing the variables individually and comparing them with the model fit containing all variables (Zuur et al., 2009). All models were implemented with all predictors together, removing the variable with highest *p* value and adjusting the models without the predictor in question, until the definition of a final model (i.e., backward selection) (Zuur et al., 2009). We checked the presence of outliers in all tests by calculating *Cook's* distance and model assumptions using graphical tools (Zuur et al., 2009). All analyses were performed in the R program (R Core Team, 2017).

RESULTS

Similarity between potential and observed impacts over time

Evaluating the similarity over time and against surface area and height of hydropower plants, we found that the average similarity between the potential and observed impacts was 74%, ranging from 54% (*Itapebi*) to 90% (*Barra Grande*). None of the predictors had a significant effect on the degree of similarity of impacts between phases ($F_{3,4}$=1.153; p=0.43 and R2=0.061) and this result remained when we removed from the analysis the *Barra Grande* plant, a potential outlier (*Cook's* distance=1.2) ($F_{3,3}$=1.994; p=0.292, R2=0.332). However, when we used only the variable 'year of EIA's elaboration' in the model without the outlier, we found a strong positive relationship between time and similarity (F_1=9.494, p=0.027, R2=0.586) (Figure 1).

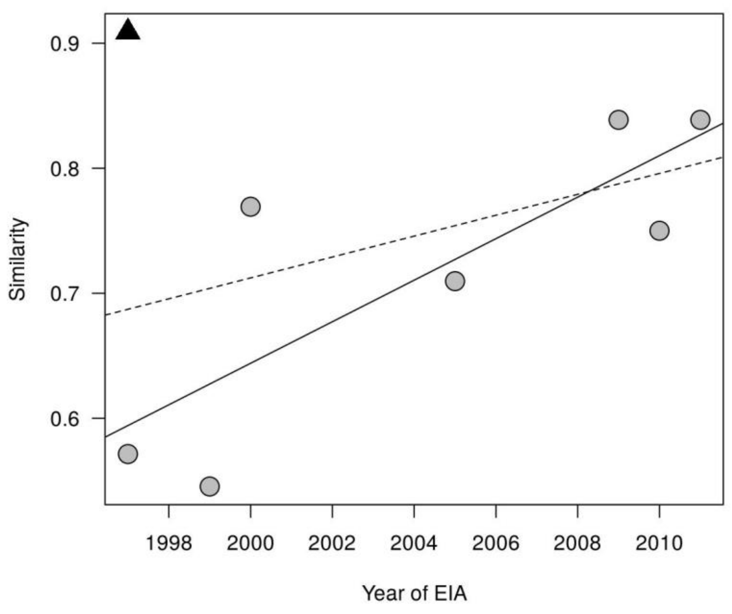

Figure 1. Similarity between potential and observed impacts as a function of the year of elaboration of previous environmental impact studies. Using the whole dataset leads to the non-significant model fit show with dashed line but removing the Barra Grande outlier (black triangle) the trend is highly significant (full black line).

Identification of impacts over time and with plant attributes

In total, we identified 258 impacts (pre=124; post=134) and grouped them into 26 categories. The categories 'change in reproductive activity', 'change in habitat use' and 'change in body size' were not predicted in any of the previous environmental impact studies, but were observed after the entry into operation in four, two and two plants, respectively. From the predicted categories, four were not confirmed in any plant after the implementation and operation of the projects (Table 1).

Table 1. Categories of impacts to fauna, frequency of occurrence and occurrence by type in environmental licensing process of power plants in Brazil.

Impact categories	Type			Frequency of occurrence
	Potential	Observed	New	
alteration of the species distribution area	X			0.39
alteration of population dynamics	X	X		0.78
alteration of population structure	X	X		1.55
alteration in the population of disease vectors	X	X		6.59
alteration of reproductive activity			X	3.49
Alteration of community dynamics	X	X		5.43
alteration of habitat	X	X		3.88
alteration in body size			X	0.78
alteration in species composition	X	X		1.94
alteration in community structure	X	X		3.88
alteration in trophic structure	X	X		2.33
fauna imprisonment	X	X		4.26
attraction and establishment of fauna for anthropic areas	X			0.78
increased anthropic pressure on fauna resources	X	X		6.98
increase in accidents with venomous animals	X			1.16
contamination of the fauna	X	X		1.94
elimination of species locally	X	X		10.08
fragmentation of populations or metapopulations	X	X		7.36
wildlife escape	X	X		4.65
introduction or increase in the population of exotic species	X	X		2.33
death of individuals	X	X		8.91
change in habitat use			X	2.33
habitat loss	X	X		11.63
physiological and behavioral disturbances of fauna	X	X		0.78
population reduction	X	X		5.43
overpopulation of surrounding areas	X			0.39

The category 'habitat loss' was the most frequent and the only one to be confirmed in all plants. The number of impacts observed per plant varied from six in *Aimorés*, *Itapebi* and *Barra Grande* to 17 in *Belo Monte* (average=10.5) (Table 2).

Table 2. Number of impact categories to fauna and similarity between potential and observed impacts per hydroelectric plant.

Power Plant	Number of impacts	Similarity
Aimorés	6	57,14%
Barra Grande	6	90,9%
Belo Monte	17	83,87%
Foz do Chapecó	8	76,92%
Itapebi	6	54,54%
Santo Antônio	16	70,9%
São Manoel	16	83,87%
Teles Pires	13	75%

Most impacts were classified as medium magnitude (medium=35.5%, high=28.8%, low=21.1%) and, 14.6% had no associated magnitude classification. There was no classification of the magnitude of the impacts observed at any plant, therefore, we consider the same classification given to the potential impacts.

Regarding taxonomic groups, ichthyofauna concentrated the highest number of total and high magnitude impacts (45% and 42%, respectively), followed by mastofauna (12% and 17%), invertebrates (10% and 13%), herpetofauna (9% and 8%) and avifauna (6% and 7%). About 16% of the total and 10% of high magnitude impacts were not associated with a specific group. The full model with the number of total impacts as a response variable identified both positive effect of the year of EIA/RIMA's elaboration (F_1=54.234 p= 0.001) and a positive effect of the reservoir area (F_1=13.362, p=0.021) as determinants of the total number of impacts (R2=0.947), but the *São Manoel* plant was identified as outlier (*Cook's* distance = 2). With the removal of this point, the dam's height also had a positive effect on the number of total impacts (F_1=33.72; p= 0.01) and the significance of the other variables decreased (year: F_1=81.93, p=0.002; area: F_1=113.54, p=0.001; R2=0.99). Considering only the high magnitude impacts, none of the variables had significant effect on the number of impacts in the full model ($F_{3,4}$=2.30, p=0.218,

$R2=0.35$). However, after we removed the *Barra Grande* plant (*Cook's* distance = 2.2), the effect of the three variables was significant (year: $F_1=429.66$, $p<0.001$; area: $F_1=75.47$, $p=0.003$; and height: $F_1=378.9$, p=$p<0.001$; $R2=0.99$). Additionally, when we include only biome (due to high collinearity with other predictors; see *Data analysis*) as a categorical predictor in a simple regression, the model showed a total number ($F_{1,6}=89.59$, $p<0.001$, $R2=0.92$) and number of high-magnitude impacts ($F_{1,6}=14.22$, $p=0.009$, $R2=0.65$) higher in the Amazon than in the Atlantic Forest.

Implementation of Mitigation Measures

We identified 58 categories of measures associated with the impacts. Of this total, 22 proposed categories during the environmental licensing processes were not implemented in any hydropower plant (Table S1). On average, 66% of the measures were implemented, ranging from 45% (*Sao Manoel*) to 82% (*Foz do Chapecó*). Among the proposed categories, reduction measures were the most frequent (55%), followed by monitoring (22.5%), compensation (15%) and prevention (0.5%). Among them, the category 'monitoring' presented the highest implementation rate, while for reduction measures this value was less than 50% (monitoring=86%; compensation=71%; reduction=48%; and prevention=0%). About the impacts without associated measures (7%), the categories 'change in trophic structure', 'body size change' and 'change in habitat use' were the only ones without associated measures in all hydropower plants. The year of environmental studies preparation and the similarity between potential and observed impacts had no effect on the proportion of implementation of mitigation measures ($F_{2,5}=1.43$, $p=0.321$; $R2=0.111$), even after the removal of the *Barra Grande* plant from the model identified as potential outlier (*Cook's* distance = 2.5).

DISCUSSION

Environmental Impact Assessment (EIA) is an important tool to predict and avoid or minimize environmental impacts of development projects. However, the predictability of impacts to fauna in hydroelectric plants has not yet been evaluated. Based on environmental licensing processes of large hydropower plants, we have evaluated the EIA over time and whether we can dimension impacts to fauna from the attributes of these plants. Our results show that the similarity between potential and observed impacts has increased over time. In addition, we note that the age of the hydropower plant, reservoir area and dam's height are determinant in the number and magnitude of impacts. Furthermore, we found that the implementation of mitigation measures was median and did not increase over time and in plants with greater correspondence between predicted and observed impacts.

Despite the existence of previous studies that analyzed EIA's procedures, impacts of dams on specific taxonomic groups or failures in environmental licensing procedures (Glasson and Salvador, 2000; Silve and Pompeu, 2008; Fearnside, 2014; Fearnside, 2015; Andrade and dos Santos, 2015; Benchimol and Peres, 2015; Pelicice et al., 2015; Hofmann, 2015; Norris et al., 2018; Abreu et al., 2020), there are no references from studies that evaluated the predictability of impacts to fauna in hydroelectric projects or that proposed the use of technical attributes of the plants as predictors of impact. In this sense, this research exposes the main environmental impacts of large hydropower plants, identifies characteristics of plants that induce changes of greater magnitude, in addition to highlighting gaps and trends in the environmental licensing process of this typology in Brazil.

Predictability of impacts on EIA

The average similarity between the potential and observed impacts of the analyzed hydropower plants demonstrates high predictability of impacts on environmental licensing. However, we observed a great variation in the similarity of impacts between plants, which indicates that there are factors influencing the accuracy of this prediction. We tested the effect of time and saw that the degree of similarity between impacts is higher in more recent plants, although the analysis with a larger sampling points would decrease the dependence of an outlier (i.e., *Barra Grande*). This positive relationship suggests an improvement in the ability to predict the effects of environmental changes in hydroelectric plants on fauna over time. In addition to time, we tested the effect of the plant's attributes on the degree of similarity, but we did not identify significant relationships. We infer from this result that other factors not addressed in our research, such as the quality of the environmental studies presented, adherence of monitoring programs to the guiding protocols of methods and sampling effort, or even the legal nature of the entrepreneur (public or private), could influence the accuracy of impact prediction.

We identified observed impacts that were not predicted and the opposite. Impacts that have not been predicted (ie, 'alteration of reproductive activity'; 'alteration in body size' and 'change in habitat use') were identified with medium or long term monitoring, reinforcing the importance of continuous (and long) studies in environmental licensing. The identification of not predicted impacts also demonstrates that both the EIA and the environmental licensing are dynamic and that new impacts can be incorporated as potential in future projects. Among the four predicted impacts that have not been confirmed, two are related to potential conflicts with human populations (i.e., ‘increased accidents with venomous animals’ and ‘attraction and establishment of fauna for anthropic areas’). As they are impacts with effects on public health, the indicated mitigation measures were implemented before the proof of their occurrence. Throughout the environmental licensing processes, we have not identified reports that monitored the effectiveness of these measures in preventing or reducing their related impacts. Therefore, the non-confirmation of these impacts may reflect both the absence of parameters prior to the beginning of the construction (e.g., number of accidents with venomous animals in the municipality) and the absence of gauging the effectiveness of the applied mitigation measures.

Time and plant attributes in identification of impacts on wildlife

The increase in the number of total and high-magnitude impacts in more recent environmental studies suggest an improvement in the effectiveness of the EIA over time, since the existence of a reference of environmental changes resulting from licensed activity reflects in better identification and characterization of impacts. However, the lower number of potential impacts in relation to the observed ones shows that the number of impacts considered in the environmental feasibility analysis (initial phase of environmental licensing) is still underestimated. This result indicates that the decision making regarding the viability of plants is taken without considering the real burden of these projects.

One of the purposes of the EIA is to encourage proponents to design environmentally less aggressive projects and not just judge the acceptability of impacts (Sanchez, 1995). In this sense, the relationship between plants with larger reservoirs and higher dams with a greater number of total impacts and of high magnitude, indicates that the selection of projects with smaller reservoir areas and lower dams may have the potential to cause less effects on the impacted fauna. Large reservoirs imply larger flooded areas, greater loss and alteration of habitat for several groups, while higher dams intensify the effects of fragmentation of the aquatic ecosystem, both of them hindering the fish movement in network system (e.g., Pelicice et al., 2015). However, the attributes of the plants should not be considered in isolation, but with other factors such as the location of the dam in the basin (O'Hanley et al., 2020), presence of endangered species and power, for example. The electricity sector must also use other macro planning instruments (that consider cumulative impacts of multiple dams (Winemiller et al., 2016)), such as strategic environmental assessment and integrated environmental assessment, so that the expansion of hydroelectricity considers, in addition to energy supply, measures of environmental protection, such as the maintenance of river sections free of dams.

Our results also indicate that plants installed in the Amazon biome accumulate a greater number and magnitude of impacts when compared to projects in the Atlantic forest. In general, the plants operating in the Amazon have larger reservoir areas and power. However, if we compare plants with similar power characteristics, reservoir area and dam height, such as *São Manoel* (MT/PA) and *Foz do Chapecó* (SC/RS), we note that the plant located in the Amazon biome has twice as many impacts as the one located in the Atlantic Forest (Table 2). This condition may indicate that local characteristics, such as greater habitat complexity and biodiversity, are more sensitive to changes resulting from the installation and operation of hydropower plants. Still, plants in the Amazon, generally, have greater visibility, which can induce the performance of more comprehensive and robust environmental studies.

In relation to taxonomic groups, our results also demonstrate that aquatic ecosystems are the most affected by hydropower plants, since ichthyofauna concentrates the largest number of total impacts and of high magnitude. Therefore, this group must necessarily be the target of environmental management programs that have long-term monitoring in their scope, as well as the implementation of mitigation measures.

We found that there are common impacts to all plants and others unique ones to each project. According to Agostinho (2016) the intensity and nature of the changes in the structure and dynamics of the fauna are related to the peculiarities of the local biota, morphometric and hydrological characteristics of the reservoir, the operating procedures of the plants and other uses of the hydrographic basin. The variation in the number and types of impacts between plants that we find reinforces the importance of studies that consider the context of each project, in addition to indicating the importance of future research that analyzes the quality of the environmental studies presented. Our results also show that impacts reported with high frequency (i.e., 'habitat loss' and 'death of individuals') may have different causes and occur at different stages of the project. The habitat loss, for example, may result from vegetation suppression, construction site implementation and reservoir filling activities. Thus, the mitigation measures indicated (e.g., ‘fauna scare away and rescue’ and ‘recovery of degraded areas’) and their respective implementation status should be evaluated considering their suitability to the different moments of the project.

Finally, we observed that there is no revision of the classification of the magnitude of the potential impacts that were observed, which probably reflects a difficulty in the methods applied in quantifying the extent of impacts on the fauna, in addition to pointing out an absence of this demand by the licensing agency and society.

Implementation of the Measures to mitigate impacts

Our results demonstrate that 1/4 of all proposed measures are not implemented. This finding support the need for improvements in the accompaniment phase of environmental licensing processes (after the issuance of Operating Licenses). Due to the reduced number of technical staff on the environmental licensing sector (proportionally to demand), it is common for the workforce to be directed to the analysis of new hydropower plants projects (initial licensing phase) that are considered a priority in relation to the plants already in operation. This dynamics hinders the accompaniment and the charge of the implementation of measures. It is also important that improvement actions in the initial phase of environmental licensing are applied, with emphasis on identifying impacts without associated mitigating measures, so that the environmental viability decision of the projects is made considering these non-mitigable impacts. The allocation of financial and human resources for the licensing agency (IBAMA) and the strengthening of supervision and environmental auditing should be a priority for the plant's operation within acceptable environmental criteria, meeting the legal standards and conditions established in environmental licenses.

Regarding the categories of measures, the absence of preventive measures that we found suggests that impacts on fauna with the installation and operation of hydroelectric plants are not preventable (and this burden must also be considered in the decision-making process). The highest implementation rate corresponded to the categorie 'monitoring' (86%) and although reduction measures were the most frequent, half of the measures in this category have not been implemented. Mitigating measures are actions proposed in order to prevent or reduce the magnitude or importance of adverse environmental impacts, or compensate for them. The order of preference for the measures application (mitigation hierarchy) is to avoid the occurrence of impacts, in the impossibility, to minimize them and, if residual impacts still occur, the compensation to the damage must be made (Sanchez, 2013). Therefore, there is a misunderstanding in the pattern that we found, considering that monitoring is not a mitigation measures (despite being a very important part of the EIA), but a way of evaluates, over time, a pre-established parameter (or the effectiveness of a mitigating measure). In this context, our results demonstrate that greater efforts are being directed to measu res that are not efficient in preventing or minimizing impacts, weakening a crucial stage of the EIA. In the environmental licensing process, after attesting to the environmental viability of the project, the proponent must present a management plan containing the executive project of measures to be implemented and the complementary studies indicated, as necessary. Consequently, the implementation of these measures is an important tool for the effective conservation of biodiversity.

Regarding compensatory measures, we observe that the vast majority relate to the legal requirement that entrepreneurs must implement or support full protection conservation unit, in cases of projects with significant environmental impact (Brasil, 2000). The compensation referred in the legislation has an indemnity character and differs from the compensation resulting from the EIA, which aims to replace components or specific ecological functions affected by a project. The importance of the compensation required by law is evident, especially for the management of protected areas in Brazil, however, efforts should also be applied for ecological compensation of environmental damage.

Finally, our results demonstrate that there is no improvement in the implementation of measures over time or with the prior identification of more precise impacts. Other factors not addressed in this research, such as accompaniment environmental licensing processes after issuance of the Operating License, availability and transparency of data, judicialization of measures and or even the legal nature of the entrepreneur, may all influence the implementation status of the measures. In this study, we did not evaluate the effectiveness of the implemented measures, but we consider that this is an important area of knowledge for future research.

CONCLUSION

We analyzed the EIA in environmental licensing processes for large hydropower plants and we identified that despite the accurate prediction of impacts, decision making regarding the environmental viability of these plants is still based on underestimated impacts. We also identified that the dam's height and the reservoir's area are determinant for the number and magnitude of impacts. Furthermore, we note that 1/4 of the proposed mitigating measures are not implemented and that the greatest efforts are concentrated on monitoring fauna, which mistakenly has been considered as mitigation. We hope that the plants' attributes can be considered in the selection and improvement of projects and that the gaps we identified can guide concrete actions in the EIA and environmental licensing so that they can exercise its purpose - which is to ensure environmental protection.

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SUPPLEMENTARY MATERIAL

Table 1. Categories of mitigation measures by type and respective frequency of occurrence and implementation rates.

Categories of measures	Type	Freq. of occurrence	Implementation rate
support for control and public health actions	Compensation	0,34%	100%
creation or support for protected areas	Compensation	10,10%	84,74%
protection of specific environments	Compensation	0,17%	**0%**
scientific rescue	Compensation	2,91%	100%
fauna characterization studies	Monitoring	0,85%	40%
monitoring of fishing activity	Monitoring	0,17%	100%
monitoring the concentration of contaminants	Monitoring	0,34%	100%
monitoring of environmental quality	Monitoring	0,68%	100%
monitoring of fauna	Monitoring	19,00%	100%

monitoring of the reservoir level	Monitoring	0,17%	100%
monitoring of efficiency stp	Monitoring	1,02%	33,33%
epidemiological monitoring	Monitoring	0,17%	100%
limnological monitoring	Monitoring	1,54%	100%
previous elimination of species confined in tanks	Prevention	0,17%	**0%**
conservationist actions	Reduction	0,17%	**0%**
individual and collective protection actions	Reduction	0,68%	100%
surveillance and control actions	Reduction	3,25%	78,94%
fauna scare away	Reduction	0,17%	100%
structural adjustments	Reduction	0,51%	66,66%
adjustments to the work schedule	Reduction	1,36%	**0%**
operational adjustments	Reduction	0,68%	50%
support to fiscalization	Reduction	0,34%	**0%**
aquaculture	Reduction	2,39%	100%
attractive to fauna	Reduction	0,34%	**0%**
restrain the capture of fish at the construction site	Reduction	0,17%	**0%**
lighting control in the reproductive period	Reduction	0,17%	**0%**
control of vessel flow and human presence	Reduction	0,17%	**0%**
control of night lighting	Reduction	0,17%	**0%**
deforestation directed from upstream to downstream	Reduction	2,22%	**0%**
deforestation and cleaning of areas considered critical	Reduction	0,34%	100%
selective deforestation	Reduction	2,05%	**0%**
environmental education	Reduction	9,76%	100%
traffic education	Reduction	0,17%	100%
establishment of public health criteria	Reduction	0,34%	**0%**
fiscalization	Reduction	5,30%	100%
sanitary fiscalization	Reduction	0,34%	**0%**

conflict management related to big cats	Reduction	0,34%	**0%**
ecological hydrograph	Reduction	2,91%	**0%**
encouragement of sustainable fishing	Reduction	2,73%	100%
fauna management	Reduction	0,17%	100%
habitats management	Reduction	1,02%	**0%**
reproductive management	Reduction	0,68%	100%
fishing regulation	Reduction	1,02%	**0%**
fauna passages	Reduction	0,68%	**0%**
recovery of degraded areas	Reduction	5,13%	100%
noise reduction	Reduction	0,34%	**0%**
riparian forest reforestation	Reduction	1,19%	100%
ichthyofauna repopulation	Reduction	1,88%	72,72%
fauna rescue	Reduction	7,02%	100%
signaling and speed reducers	Reduction	1,02%	83,33%
drainage system	Reduction	0,34%	50%
fish transposition system	Reduction	1,54%	55,55%
Selective fish transposition system	Reduction	0,17%	100%
sewage and wastewater treatment	Reduction	0,34%	50%
solid waste treatment	Reduction	0,17%	100%
screens use	Reduction	0,17%	**0%**
use of sodium vapor lamps	Reduction	0,34%	**0%**
socio-environmental zoning of the surroundings	Reduction	1,88%	100%