Indications that fishers perceive socio-environmental problems related to hydroelectric plants in the Tocantins river, Brazil

Indicativos de que pescadores percebem problemas socioambientais relacionados a usinas hidrelétricas no rio Tocantins, Brasil

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ABSTRACT
Hydroelectric dams (HEDs) cause significant socio-environmental damage such as reduced fish diversity, population displacement and health problems. The fishers have extensive local ecological knowledge that can be used to improve understanding of the impacts of HEDs. Therefore, the objective of this study was to verify and evaluate the perceptions of fishers about the impacts caused by the HEDs in the Tocantins River. For this, 25 fishers were interviewed using a questionnaire with 22 questions. Data analyses were performed considering descriptive analysis of the responses. There was convergence in the responses of fishers who perceived the decrease in fish diversity after the construction of the HEDs, including fish of commercial interest, which is linked to a decrease in income and decreased food security for these families. In addition, the fishers noted symptoms that may be a consequence of mercury contamination, and diarrhea as a possible consequence of decreased water quality. Despite all these socio-environmental losses, the fishers report a lack of prior consultation, and low representativeness and transparency in the decision-making process that preceded the construction of HEDs. In general, the fishers perceived themselves as being strongly affected from the socio-environmental point of view and do not cite any benefits offered to the community from these projects.

Keywords: fish diversity, ecological knowledge, health issues, food security, transparency.

RESUMO
As hidrelétricas (HEDs) causam diversos prejuízos socioambientais como redução da diversidade de peixes, deslocamento populacional e problemas de saúde. Os pescadores possuem amplo conhecimento ecológico local que pode ser usado para melhorar a compreensão dos impactos das HEDs. Portanto, o objetivo deste estudo foi verificar e avaliar as percepções dos pescadores sobre os impactos causados pelas HEDs no rio Tocantins. Para isso, foram entrevistados 25 pescadores por meio de um questionário com 22 questões. A análise dos dados foi realizada considerando a análise descritiva das respostas. Houve convergência nas respostas dos pescadores que perceberam a diminuição da diversidade de peixes após a construção dos HEDs, incluindo peixes de interesse comercial, o que está atrelado à diminuição da renda e ao aumento da insegurança alimentar dessas famílias. Além disso, os pescadores notaram aumento de sintomas que podem ser consequência de contaminação por mercúrio e de diarreias como possível consequência da diminuição da qualidade da água. Apesar de todos esses prejuízos socioambientais, os pescadores relatam falta de consulta prévia, de representatividade e de transparência no processo das tomadas de decisões que antecederam as construções das HEDs. Em geral, os pescadores se percebem fortemente afetados do ponto de vista socioambiental e não citam nenhum benefício oferecido à comunidade com esses projetos.

Palavras-chave: diversidade de peixes, conhecimento ecológico, problemas de saúde, segurança alimentar, transparência.

1 INTRODUCTION

In addition to being the current leading source of low-carbon electricity, hydropower is set to become the leading provider of grid flexibility – it will be the backbone of reliable, safe and decarbonised energy systems (IHA, 2023). This energy source can contribute to meeting targets for reducing fossil fuel emissions and for building sustainable communities with diverse

sources of energy (Moran *et al.*, 2018). Reducing fossil fuel emissions is imperative in the face of the growing threats of global warming and the continued depletion of fossil fuels themselves (Chala, Guangul and Sharma, 2019; Marques, Fuinhas and Pereira, 2018).

The potential of the Brazilian Amazon for hydroelectric power generation is high due to the very high volume of water that flows in the rivers of the region and the relevant topographic falls in the tributaries of the Amazon River, via the descent of these tributaries from the Brazilian shield (to the south of the region) or the Guiana shield (to the north) (Fearnside, 2019a; Finer and Jenkins, 2012; Forsberg *et al*., 2017). Given this, the number of dams planned for hydroelectric progress in the Amazon is enormous; 79 dams, a number that despite delays remains unchanged (Brasil MME, 1987; Fearnside, 2019a; Finer and Jenkins, 2012).

Although hydroelectric dams (HEDs) have enabled ecological advances when compared to energy sources generated from fossil fuels, energy generated by dams in the Amazon often does little to improve the lives of people living near the projects (Fearnside, 2019a). As in other locations around the world, the construction of HEDs in the Brazilian Amazon region causes significant social, environmental and health impacts (Fearnside, 2019a; WCD, 2000).

The construction of dams is considered one of the anthropogenic activities that has the greatest potential to threaten aquatic biodiversity, especially in regions that have high levels of biodiversity and endemism (Fitzgerald *et al.*, 2018). As such, this directly harms the way of life of the affected communities (Ansar *et al.*, 2014; Winemiller *et al.*, 2016). In addition, historically, the construction of HEDs in the Amazon are associated with strong signs of irregularities (Fearnside, 2016; Fearnside, 2019a; Pinto, 2012). In this scenario, it is necessary to question which social groups are harmed as a result of the construction of dams and understand how these groups perceive such impacts, as well as which groups benefit from these ventures.

The Tocantins River is among the rivers in Brazil that have most been affected by dams and is certainly the most dammed river in the Amazon (Akama, 2017). Constructions of HEDs are among the activities that pose the most threat to the aquatic ecosystem, especially when they are installed in areas with high biodiversity and endemic species (Fitzgerald *et al.*, 2018). They cause hydrological alterations, loss of connectivity, habitat degradation, species invasions, destruction of riparian biosystems, biotic homogenization and alterations in the land-water interface with increased deforestation in riparian areas downstream of the dams (Ferraz *et al*., 2021; Pelicice *et al*., 2021; Swanson and Bohlman, 2021).

The high biodiversity of the Amazon region requires greater prudence in the investigation of the impacts that dams can cause in this biome. In these environments, the disturbances can have much larger proportions compared to temperate climate zones. However, even important actors in this scenario such as fishers of rivers have generally been marginalized or excluded from decision-making on planning, construction, mitigation, compensation and monitoring of the socio-ecological impacts of hydropower (Doria *et al.*, 2018).

In addition to the problems related to loss of biodiversity, historically, the construction of HEDs has shown signs of corruption in the Brazilian Amazon. In the 80s, while Brazil was under military rule, the lack of transparency during the construction of the Tucuruí dam (state of Pará) on the Tocantins River raised suspicions of possible irregularities. A problem that was repeated in the case of the Belo Monte dam in the past decade under the governments of the Workers' Party (Partido dos Trabalhadores - PT) (do Amaral, 2016; Fearnside, 2016; Fearnside, 2019b; Pinto, 2012). Thus, in addition to the electricity that is generated and supplies the population, historically, the construction of HEDs seems to benefit mainly public officials, who receive money from the corruption involved.

Fishers have extensive local ecological knowledge (LEK) (Berkes, 2021), which is built from community experiences and is considered an important alternative for collecting information about local socio-ecological problems, conflicts and biodiversity conservation (Silvano *et al*., 2009; Sousa, de, Zacardi and Vieira, 2022; Thompson, Lantz and Ban, 2020). In this sense, the integration of local fishers and riverine populations in planning and decision-making can result in better resolutions to environmental problems, better conflict mediation strategies, and improved fisheries management (Olsson, Folke and Berkes, 2004; Reed, 2008).

Studies that aim to analyze the perception and/or LEK of fishers on the problem of hydroelectric dams are fundamental not only to contribute to the development of mitigation strategies for socio-environmental problems, but also to warn about threats that may negatively impact the economic situation of the riverine population and aquatic biodiversity. For example, fishers have indicated that dams planned upstream of the Tapajós River pose a threat to migratory fish, as well as to artisanal fisheries and local food security (Nunes, Hallwass and Silvano, 2019; Runde, Hallwass and Silvano, 2020). The absence of studies such as these, both before, during or after the various constructions of dams on the Tocantins River, represents a major knowledge gap.

According to neuroscience, perception can be understood as the human ability to associate sensory information with memory and cognition in order to build concepts about the world and about ourselves and guide our behavior (Lent, 2010). Thus, people's perception

directly influences social factors and processes, which are essential for the environment, management and conservation (Bennett *et al.*, 2017; Christie *et al.*, 2017).

Therefore, the objective of this study was to evaluate the perception of fishers about the impacts of the hydroelectric dams in the Tocantins River in order to verify the social, environmental and community health impacts caused by the HEDs along the middle and lower Tocantins River and thus be able to answer the following questions: How do fishers perceive the consequences of the implementation of HEDs? How does the perception of the fishers relate to expectations from the scientific literature? What factors may explain the differences among the perceptions of individual fishers?

2 MATERIALS AND METHODS

2.1 ETHICAL CONSIDERATIONS

The research is in accordance with Brazilian legislation with licenses authorized by the Research Ethics Committee (REC) at the National Institute for Amazonian Research (INPA) under the following codes: CEP (5.066.051) and CAAE (44565721.0.0000.0006).

2.2 SAMPLING

The research was conducted with fishers from the Tocantins River. This river is 2,500 km long (Mérona *et al.*, 2010) and runs through the states of Goiás, Tocantins, Maranhão and Pará (Brasil MMA, 2006). Throughout its course, there are eight HEDs, of which two are in the studied municipalities: the Estreito hydroelectric dam in the state of Maranhão and the Tucuruí hydroelectric dam in the state of Pará (ANEEL, 2022; Moraes *et al.*, 2022).

We interviewed 25 fishers, of which 68% have fishing as their main source of income. A questionnaire was applied to each fisher in March 2021 and April 2023, in the cities of Cametá, Pará (N=11) and in March 2021 in Babaçulândia, Tocantins (N=4), and, in October 2022 and April 2023, in the city of Imperatriz, Maranhão (N=10) (Figure 1). The questionnaires were prepared using the Google Forms platform and later printed out considering the possibility that the interviewees did not have access to the Internet. Each questionnaire contained 13 structured and 9 semi-structured questions (Table 1). For these, alternative responses were suggested (Table 2). The questions were based on the impacts of HEDs highlighted in the literature (Clarkson, 1997; Fearnside, 2019a). Questions L, O and S allowed more than one answer so that the sum of the percentages of the graph that show the answers equated to over 100%.

Table 1 – Questions included in the questionnaire applied to fishers of the Tocantins River.

N	QUESTIONS
A	Where do you live?
B	Which sex are you?
C	How old are you?
D	How long have you been fishing the Tocantins River?
E	Is fishing your main livelihood?
F	How many HEDs did you accompany the construction process of or know that they were being built in the course of the Tocantins River?
G	Do you live or have you lived near a hydroelectric dam? (consider a distance of approximately 5 km).
H	Were you a fisher on this river before the installation of the HED closest to your residence?
I	Before the construction of the nearest HED, were you consulted by the government as to your opinion on this venture? Or do you know someone who was consulted?
J	When you heard about the construction of the nearest HED what feelings did you have?
K	Did the construction of the nearest HED cause a change in the diversity of fish in this region? If so, in what way?
L	If your previous answer was "Yes, it reduced the diversity of fish", name three fish that were found in the region in abundance before the construction of the HED and that today are rare or no longer present.
M	Did you know that consuming fish caught in the vicinity of hydroelectric dams can cause problems with your sight and fetal development problems in pregnant women due to the high mercury content?
N	HEDs are portrayed by the government as a clean energy source with zero or negligible emissions of greenhouse gases that worsen global warming. Do you agree with this?
O	Which of the problems mentioned below began to arise in your region after the construction of the nearest HED?
P	Are you aware that hydroelectric dams contribute to global warming by emitting methane?
Q	Do you know of any cases of resettlement of residents resulting from the flooding caused by the filling of a dam reservoir that was not paid for by the government?
R	Did you have a higher or lower income after the construction of the nearest HED?
S	Are there fish species that you have noticed that have decreased in size over time after the construction of the HED(s)? Which ones?
T	Did the installation of the HED(s) bring any benefit to your community?
U	Have you met anyone in your community who has gotten a job because of the construction of the HED?
V	As a whole, do you consider that the construction of the HED(s) near where you live has brought more harm or more benefits to your community?

Source: survey data.

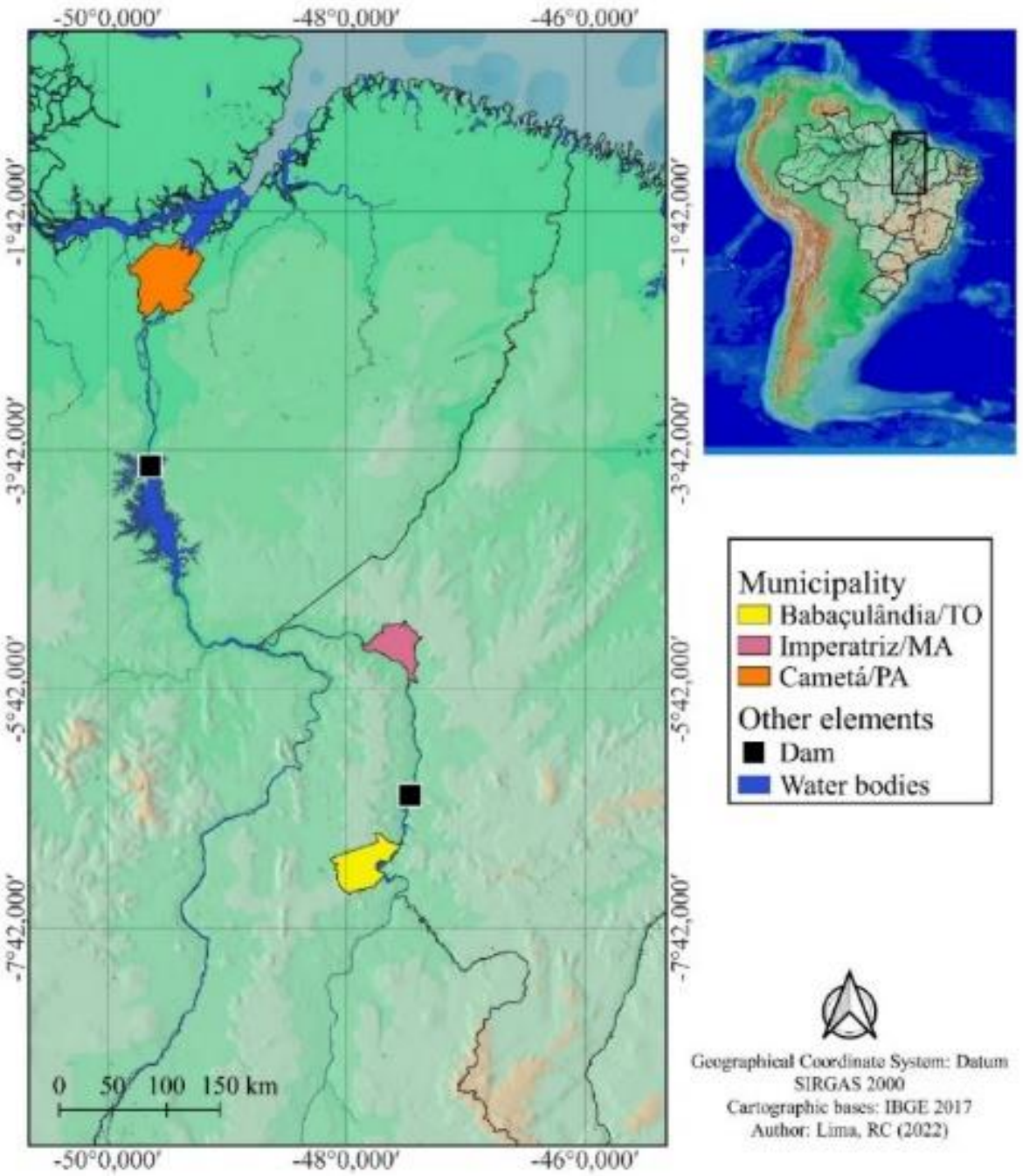
Table 2 – Answer options that were made available to the fishers interviewed using the structured questions presented at Table 1.

N	ANSWER OPTIONS
G	a) Yes b) No
H	a) Yes b) No
I	a) I was not and do not know anyone who was consulted b) I was not consulted, but I know someone who was consulted c) I was consulted
J	a) Sadness b) Joy c) Fear d) Indifferent
K	a) Yes, fish diversity was reduced b) Yes, fish diversity increased c) It did not change at all, the same diversity exists now.
M	a) No b) Yes
N	a) No b) Yes
O	a) Displacement of the population b) Flooding of the forest c) Decrease in the water level (the river has become lower or dried up) d) Deforestation e) Decrease in fishing for fish of commercial interest f) Plagues of mosquitoes g) Increase in cases of malaria h) Mercury contamination i) Displacement and disruption of indigenous groups j) None
P	a) No b) Yes
Q	a) No b) Yes
R	a) Lower b) Higher
T	a) No b) Yes
U	a) No b) Yes, but it was only during construction and then they stopped working c) Yes, they continued to work for many years even after the opening of HED d) Yes, they continue to work to the present day

V	a) Harm b) Benefits

Source: survey data.

Figure 1 – Location of the three municipalities in which interviews were conducted with fishers of the Tocantins River (map prepared using the software QGIS 3.22.10).



Source: Lima, 2022.

3 RESULTS

3.1 PROFILE OF THE INTERVIEWEES

The age of the interviewees ranged from 37 to 75 years old, with a mean of 52.52 ± 12.32 years of age, and all had between 10 and 65 years of fishing experience, with a mean of

34.88 ± 13.01 years. It was also observed that 68% live exclusively off fishing. Most of the fishers (92%) accompanied or knew about the construction/existence of only one hydroelectric dam. A great majority (92%) of the interviewees lived at a distance of over 5 km from a HED and they were fishers on the Tocantins River before the construction of the nearest hydroelectric dam (88%) to where they live or of which they are aware.

3.2 DESCRIPTIVE ANALYSIS OF THE RESPONSES

The answer to question K was unanimous, and was as follows: all reported that the construction of HEDs reduced the diversity of fish in the region. Most (84%) of the interviewees were not consulted by, or even know someone who had been consulted by the respective public authorities at the time of the construction of the HED in order to hear their opinions about the construction of the HED closest to their home.

The most frequently reported feeling among fishers in relation to the news that a dam would be built in the course of the Tocantins River was sadness (48%) since, according to the interviewee, they had been deceived with the promise of progress for the region. In the responses that expressed sadness and fear, there were the comments “concern about the dam possibly bursting”, “I knew everything was going to end” and “If it went back to being the river again, it would be great, I could fish again and would return to live in my spot”.

The fish species most reported by fishers as suffering from a decreased abundance was curimatá (*Prochilodus* spp. - 40%), followed by pacu (*Myleus* spp. and *Myloplus* spp. - 32%), surubim (*Pseudoplatystoma punctifer* (Castelnau, 1855) - 28%), piabanha (*Brycon insignis* Steindachner, 1877 - 24%) and matrinxã (*Brycon cephalus* (Günther, 1869) - 24%), mandi (*Megalonema* spp., *Pimelodina flavipinnis* Steindachner, 1876, *Pimelodus* spp. and *Propimelodus eigenmanni* (Van der Stigchel, 1946) - 20%), and jaraqui (*Semaprochilodus insignis* (Jardine, 1841)) and sardine (*Pellona* spp.) with 12% each. Most (76%) did not know that consuming fish caught in the vicinity of dams can cause sight problems and fetal development problems in pregnant women due to the high mercury content (Clarkson, 1997).

In addition, most (84%) did not agree that HEDs are sources of clean energy, and 80% did not know that HEDs contribute to global warming by emitting methane (Paucar *et al*., 2018; Pueyo and Fearnside, 2011; Quadra *et al*., 2020), but two respondents reported that “after the dam was built the temperature increased”.

A large proportion (92%) of them recognized that there was a decrease in the capture of fish of commercial interest after the construction of the nearest HED, and 72% understood that population displacement occurred, while 64% indicated a decrease in water levels (“the river

has become lower or dried up") and 44% indicated the emergence of "plagues of mosquitoes". Alarmingly, 38% indicated the appearance of the same symptoms that are related to contamination with high levels of mercury in the food chain (eyesight problems in adults, and problems especially during the early stages of brain development resulting from prenatal exposure, which can cause delayed development and cognitive alterations in children) (Clarkson, 1997), and 32% indicated the deforestation and flooding of the forest.

An increase in malaria cases was indicated by 28% of the fishers, 24% of them cited displacement and disruption of indigenous groups and water pollution to the extent that it has become inappropriate for use, "diarrhea when consuming river water, death of animals (cattle and dogs) that drink the water" was perceived by 20% of interviewees. Increased odor in the fish was perceived by 12% of the interviewees, and 8% of fishers indicated that the following two problems affected the community after the construction of the HEDs: accelerated rotting of fish and decreased flavor of fish. Two impacts were indicated by 4%: the end of tourism ("and consequently of income") in the city, and the disappearance of springs.

The percentage of those who knew of no case of resettlement resulting from the filling of the reservoir of the dam, in which the family was not remunerated by the government, was 64%, while 36% knew people who did not receive money from the government for their losses. A high percentage (92%) considered that their financial income was lower after the construction of the nearest HED.

For 32% of the fishers, there was no change in the size of the fish after the construction of the HEDs. However, for 44%, the mapará (*Hypophthalmus edentatus*) decreased in size; for 16%, all fish decreased in size; for 8%, both the piau (*Leporinus* spp.) and the filhote (*Brachyplathystoma filamentosum*) became smaller, and 24% stated that other fish species have decreased in size. The majority (76%) considered that the HEDs did not bring any type of benefit to the community. Among those who do not perceive any benefit associated with HEDs, it was reported that "tourism decreased, there is no longer a beach, as well as the income of boat owners and beach kiosk owners", "it only brought problems" and "the price of energy did not get cheaper". While 24% state that the construction of dams led to the arrival of electricity.

The majority (76%) did not know of anyone who got a job because of the construction and/or maintenance of the HEDs, while 20% knew of people who were employed only during the construction period. Only a low percentage (4%) knew someone who still works at one of the HEDs. Overall, almost all of the interviewees (92%) considered that the HEDs have brought more harm than good. Interviewees who considered more harm than good had come as a result of the dams also expressed the following discontent: "You didn't have the option to stay in your

house. Many residents were evicted with their belongings being thrown into the street and houses demolished. Before the dam, I had never worried about employment, because fishing offered me everything" and "they knocked down the houses by force, which is revolting".

4 DISCUSSION

4.1 OVERVIEW OF FISHERS' RESPONSES TO THE IMPACTS OF THE HEDS

The present study reveals convergence in the responses of fishers who perceived the decrease in fish diversity after the construction of HEDs, including in regards to fish of commercial interest, which is linked to decreased income and decreased food security for these families. In addition, the fishers noted increased symptoms that may be a consequence of mercury contamination, as well as diarrhea as a possible consequence of decreased water quality. Despite all these socio-environmental problems, the fishers report a lack of prior consultation, and little representativeness and transparency in the decision-making process that preceded the construction of the HEDs.

Sadness and fear were the feelings present in most of the interviewees and these paint the background of the perception of the fishers interviewed in this study. The understanding that the HEDs have brought more harm than good to their reality are the brushstrokes that conclude the picture that exposes the dissatisfaction of fishers in relation to this type of enterprise. This is a reflection of underestimating the impacts of dams and overestimating the benefits (Fearnside, 2014; Fearnside, 2019a; Magalhães Santos and Hernandez, 2009), as well as the lack of a more in-depth discussion with all the actors involved in this scenario.

4.2 PERCEPTION OF CHANGES IN FISH DIVERSITY, FISHERIES AND REGARDING MIGRATORY FISH DECLINES

The association between the construction of the HEDs and the decline in fish diversity in the middle and lower Tocantins River, reported by all fishers interviewed, corroborates what is reported in the literature (Athayde *et al.*, 2019; Farias *et al.*, 2019; Mérona *et al.*, 2010; Santos *et al.*, 2020). Although there is a trend of brief increases in local species richness soon after the river is dammed, which is a recurring pattern in dam construction, this richness usually decreases in subsequent years as fish communities adapt to new conditions (Soares *et al.*, 2009).

Two years after the closure of Tucuruí, fisheries reduced three-fold compared to levels before the dam (Odinetz-Collart, 1987). The ratio between the unit of fishing effort and the landing of caught fish was approximately 60% lower, while the number of fishers fell sharply.

Even after 25 years, fishery production of the Tucuruí reservoir has not reached the levels of that of the undammed river (Cintra *et al.*, 2011).

The barrier to migration is one of the main explanations for the decline in the diversity of migratory fish that need to migrate against the current for long distances in a "piracema" so that they can spawn in the headwaters of rivers (Barthem and Goulding, 1997). When catfish eggs hatch, the larvae drift downstream toward the lower portions of the rivers (Ortiz *et al.*, 2019). Unfortunately, the strategies set up for fish to cross the dams prove ineffective for large catfish populations and, as a result, this fish has largely disappeared in the Madeira River (Fearnside, 2014).

In virtue of the aforementioned facts, the construction of the HEDs has affected ichthyofaunal biodiversity by reducing the richness and relative abundance of several species, such as *Prochilodus* spp., *Myleus* spp., *Myloplus* spp., *Pseudoplatystoma punctifer*; and this is due to the loss of fluvial connectivity and consequent interruption of the migration cycle of these fish. As a direct consequence of this, the riverine fishers had a strong reduction in income, which directly affects the subsistence of these poorer communities.

Given this, it is essential to implement an effective transposition system for migratory fish species so that they can cross this barrier and complete their reproductive cycle as well as offer alternative sources of income to the affected fishers. Without this, rheophilic fish populations will suffer drastic reductions whenever dams are built and this will trigger a cascade of socio-environmental problems.

Another factor that contributes to the loss of fish diversity is the changes in the flood pulse. The changes in the flood pulse observed in Tocantins river must be associated with dams because, in the downstream region, dams tend to decrease the variability of the pulse, by reducing the extent of the floodable area and the volume of water released (Nilsson and Berggren, 2000; Poff and Hart, 2002), while upstream, there is a higher chance of unexpected flooding (Prado Jr. *et al.*, 2016). Changes in pulse amplitude and flooding and duration of droughts are associated with fish mortality events (Pinheiro *et al.*, 2022).

4.3 SOCIOECOLOGICAL IMPLICATIONS (INCOME, FOOD SECURITY)

The answers to some of the questions show that most fishers consider that their income was strongly affected by the construction of the dams. A reduction in fish of commercial interest, especially migratory species, was perceived. The fishers of the Madeira River also noticed this type of damage and impact. Migratory fish species are essential in commercial

fishing and for the subsistence of riverine families in the three countries (Brazil, Bolivia and Peru) that are drained by the Madeira River basin (Doria *et al.*, 2019).

The displacement of the population, indicated by a high percentage of fishers, can cause effects that culminate in a decrease in income. Often the new place of residence does not offer conditions for the practice of fishery activities or restricts it. There are situations in which fishers are led to carry out fishing in places to which access is restricted due to security reasons involving the power plants, such as at the base of the dam. This ends up in the marginalization of fishers (Doria *et al.*, 2019).

Three problems indicated by fishers related to the organoleptic characteristics of fish are highlighted: acceleration of rotting, decrease in taste and increase in bad odor. These last two problems are in accordance with what was reported by indigenous people from the Tuxá village on the São Francisco River (Dávalos, Rodrigues-Filho and Litre, 2021) as a consequence of the Luiz Gonzaga dam, as well as by fishers in China (Rousseau, 2020) where the Nansha and Madushan HEDs were built. These impacts can directly affect the income and livelihoods of riverine populations and need to be investigated in biological and ecological terms.

As a direct consequence of negative impacts on the ichthyofauna, the riverine fishers had a significant reduction in income, which directly affects the subsistence of these poorer communities. In this context, incorporating the fishers' LEK is essential, both before the construction of a hydroelectric dam, in order to seek alternative strategies that avoid such an impact (Nunes, Hallwass and Silvano, 2019; Runde, Hallwass and Silvano, 2020), as well as after construction so as to contribute to the development of mitigation strategies for socio-environmental problems (Olsson, Folke and Berkes, 2004; Reed, 2008; Sousa, de, Zacardi and Vieira, 2022; Thompson, Lantz and Ban, 2020).

The absence of awareness-raising actions regarding the impacts caused by dams can be part of the HED implementation strategy, since a conscious community could mobilize itself and question the implementation of these projects. In this scenario, the present study gains relevance because it has the potential to be used in pedagogical actions that aim to problematize the socio-environmental damages of the HEDs already built and those that are part of government plans (Brasil MME, 2017).

Most fishers (76%) did not recognize any benefit that dam construction has brought to the community. This can be understood by looking at the discrepancy in the cost/benefit ratio of these enterprises. Who bears the costs and who enjoys the benefits? Local communities commonly suffer the main negative consequences, while urban centers usually benefit from the

rewards through the export of electro-intensive products, such as aluminum, to other countries (Fearnside, 1999, 2001).

Some fishers that were interviewed (24%) associated the arrival of electricity to HEDs. However, it is important to point out that multinational aluminum plants in Pará (ALBRÁSALUNORTE, a consortium of Japanese companies together with Norsk Hydro, from Norway, the majority owner as of 2010) and Maranhão (ALUMAR, of the Alcoa and Vale companies) benefit from the energy subsidized by Tucuruí, an agreement in which the energy is sold for an amount that represents almost a third of the tariff charged to residential consumers in Brazil (Fearnside, 2019a).

The perception that HEDs offer relatively few employment opportunities for the local community can be explained by the fact that each job generated by hydropower comes at an extremely high cost. US$ 8 billion was spent to build the Tucuruí dam, for example (Pinto, 1991), and for each job created by the hydroelectric plant US$2.7 million was spent (Fearnside, 2019a).

4.4 HEALTH ISSUES (MERCURY, DISEASES)

Although most fishers were not aware of the health risks that HEDs could cause at the time of installation, in the present study, there was the assimilation by the interviewees (36%) that the population may be suffering the effects of mercury contamination through the increase in symptoms possibly related to this heavy metal after HED installations. Given this, it is important that work is carried out to verify the possible accumulation of mercury in these communities and that this factor can be considered for monitoring by the relevant authorities in the stages after the construction of the HED.

The perception of the emergence of “plagues of mosquitoes” after the construction of the HEDs, and the increase in malaria cases represents other impacts directly related to the worsening of the health conditions of the riverine communities. This is because the reservoirs provide breeding grounds for mosquito species, especially of the genus *Anopheles*, vector of *Plasmodium*, the protozoan that causes malaria. An increase in mosquitoes caused by the Tucuruí dam was also reported, in this case of the genus *Mansonia*, transmitter of several arboviruses and filaria, a worm that causes elephantiasis (Tadei, Scarpassa and Rodrigues, 1991).

Malaria continues to be a serious public health problem in Brazil, despite a significant drop in the number of cases in the last decade, which went from 600,000 cases in 2005 to 143,000 cases in 2014 (Hildebrando Pereira da Silva and Engracia Gama de Oliveira, 2002;

Oliveira-Ferreira *et al.*, 2010). Between 2014 and 2016, malaria remained relatively stable, but the significant increase in 2017 to 194,000 cases is particularly alarming and highlights the fragility of the malaria control program (Carlos *et al.*, 2019). In this context, those responsible for building dams need to present effective measures to combat malaria in the affected regions.

Reports of the occurrence of diarrhea, and even the death of animals (cattle and dogs) that drink water from the reservoir, may have been perceived as a consequence of the decrease in water quality and/or pollution after the installation of HEDs. This fact has already been mentioned in the literature (Athayde *et al.*, 2019) and corroborates with the understanding of residents in Africa (Gyasi *et al.*, 2018) and China (Rousseau, 2020) after the construction of HEDs. In other countries, studies show that HEDs negatively impact water quality in several parameters both downstream and upstream of the dam (Ling *et al.*, 2016, 2017; Tomczyk *et al.*, 2021) and the same is found in the Tocantins River (Oliveira, de *et al.*, 2020).

4.5 LACK OF CONSULTATION, REPRESENTATION AND TRANSPARENCY

The high percentage (84%) of fishers in the present study who were not consulted by the government indicates that the traditional knowledge of the community was ignored before the construction of HEDs. The riverine community of the Madeira River also suffered from this neglect (Doria *et al.*, 2019). With this, a valuable instrument for mitigating the harmful effects of this type of enterprise is lost, since the integration of the ecological knowledge of the local community in decision-making is understood as a relevant tool to be used in sustainable development, conflict resolution and improvement of fisheries management (Olsson, Folke and Berkes, 2004; Silvano *et al.*, 2009; Sousa, Zacardi and Vieira, 2022; Thompson, Lantz and Ban, 2020). The negligence of the public authorities and the companies responsible for the construction of HEDs in relation to the local population is revealed in the absence of educational actions that expose and clarify the different impacts caused by the dams (Assunção and Teixeira, 2020).

The favoring of private companies to the detriment of the poorest populations may have as a background a history of irregularities in the dam construction process in the Brazilian Amazon at different times and by different governments. In the Tocantins River itself, in the 80s, still under military dictatorship, the lack of transparency during the construction of the Tucuruí plant in the state of Pará raised suspicions of possible irregularities. A problem that was repeated in the case of the Belo Monte dam in the past decade under the governments of the Workers' Party (Partido dos Trabalhadores - PT) (do Amaral 2016; Fearnside 2016, 2019; Pinto 2012). Thus, in addition to the electricity that is generated and supplies the population,

historically, the construction of HEDs seems to benefit mainly public officials, who receive money from the corruption involved.

The practice of building HEDs in this way goes against what is expected of a modern democratic state, which in theory should serve the real public interest, protect minorities from social violence, protect nature against excessive predation and reconcile real development with respect to human rights and nature. The arguments of economic growth, progress and modernization of the country do not justify violations of the rights of minorities, which are clearly insufficient in the face of economic groups and the state (Andrade and Castro, 1988; Loureiro, 2012).

4.6 SUGGESTIONS FOR ALTERNATIVE POWER GENERATION SYSTEMS

This study was a fundamental starting point for government initiatives to be taken in order to develop effective mitigation strategies for the main impacts mentioned here that were caused by the HEDs built on the Tocantins River, so that the due compensation for such losses is directed both to the fishers and to the conservation of the aquatic ecosystem of this region. It is therefore necessary to rethink the strategies adopted by Brazil for energy generation and for decision makers to consider investing in alternative energy sources for which the suggestions, which consider wind, photovoltaic and biomass energy, for future projects not only in the Brazilian Amazon region, but for all of Brazil are available in the literature.

The promotion of discussions on the reorganization of energy generation systems, especially in the Amazon region, is justified not only in the face of the socio-environmental impacts caused, but also by the underproduction of dams (Faria and Jaramillo, 2017; Moran *et al*., 2018; Sulaeman *et al*., 2021). In addition, the projections generated from climate change predict a reduction in the flow of rivers in the Amazon basin and a consequent reduction in hydroelectric power generation (Almeida *et al.*, 2021).

Given the scenario of increasing inclusion of dams in Brazilian energy planning, especially small hydroelectric dams (HEDs), the informed selection, or portfolios, of new dams must meet Brazil's future energy demands and, at the same time, minimize the resulting loss of river connectivity. In fact, favorable dam portfolios can halve the number of dams compared to less favorable dam portfolios, while delivering the same total power generation capacity, which can substantially decrease river degradation and connectivity, thereby effectively protecting numerous basins that are currently hydropower-free (Couto, Messager and Olden, 2021).

The findings of this study point to the relevance that the traditional knowledge of the local population has for environmental monitoring and conservation programs (Sousa, de,

Zacardi and Vieira, 2022; Thompson, Lantz and Ban, 2020). These findings can be used as a subsidy for the development of future research aimed at verifying some of the perceptions of fishers about the impacts of HEDs in the middle and lower Tocantins River and mark possible conducts with human populations related to ventures of this magnitude.

It is therefore necessary to rethink the strategies adopted by Brazil for energy generation and for decision makers to consider investing in alternative energy sources for which the suggestions, which consider wind, photovoltaic and biomass energy, for future projects not only in the Brazilian Amazon region, but for all of Brazil are available in the literature. They are justified not only in the face of the socio-environmental impacts caused, but also by the underproduction of dams (Faria and Jaramillo, 2017; Moran *et al*., 2018; Sulaeman *et al*., 2021). In addition, the projections generated from climate change predict a reduction in the flow of rivers in the Amazon basin and a consequent reduction in hydroelectric power generation (Almeida *et al*., 2021).

5 CONCLUSION

The perception of the fishers of the middle and lower Tocantins River was predominantly negative in relation to hydroelectric dams and corroborates what has been reported in the literature regarding this theme. In general, they perceived themselves as being strongly affected from the socio-environmental point of view and do not cite any benefits offered to the community from these projects.

The state apparatus at the time was indifferent to the traditional knowledge of these fishers and negligent in elucidating the different impacts that the HEDs would cause. On the other hand, in addition to the energy generated for the general population, civil servants seem to be among the main beneficiaries of the illicit acquisition of public money from corruption in the political procedures related to the construction of HEDs in the Amazon when considering the history of these enterprises since the Brazilian military regime.

The development generated from the installation of the HEDs, therefore, is not in favor of all social groups; the fishing community that resides in the vicinity of these enterprises and that depends on fishing resources for survival is harmed in different ways. Given this, we reinforce the need to reevaluate the policies adopted for electricity generation in Brazil due to all the impacts perceived by the community and that alternative sources, such as wind, photovoltaic and biomass, are considered in the energy planning of the state apparatus aimed at sustainable development. In addition, we encourage the implementation of environmental

education programs that include the problematization of the impacts of hydroelectric dams, especially for riverine populations.

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