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RESEARCH ARTICLE

Damming Amazon Rivers: Environmental impacts of hydroelectric dams on Brazil's Madeira River according to local fishers' perception

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Abstract This study aimed to investigate the environmental impacts generated by the hydroelectric complex in the Madeira River, Brazilian Amazon, based on the perceptions of local fishers and fishery database, it focus attention on three main impacts: (i) on local fishery stocks; (ii) in fish fauna and (iii) on the aquatic ecosystems. The local fishers were selected through the "snowball" approach for the application of semi-structured interviews. All the local fishers confirmed having perceived a decline in fishery productivity following the impounding of the Madeira River. Changes in the condition of the fish were also perceived by the local fishers, including exophthalmia (82%), a reduction in the weight or length of the fish (25%), and irregular breeding patterns (14%). In the case of impacts on the river, changes in the hydrological cycle were the process remembered most frequently (75%). The results elucidated a range of environmental impacts caused by the hydroelectric dams of the Madeira River.

Keywords Anthropogenic disturbance · Artisanal fishers · Ethnobiology · Human ecology · Reservoirs · Riverside communities

INTRODUCTION

The number of hydroelectric dams operating in the Brazilian Amazon region has grown at an increasingly rapid rate in recent years (Lees et al. 2016). Including small-scale projects, the number of dams planned for the whole Amazon Basin may reach 277 (Castello and Macedo 2015). In Brazil alone, the 2017–2026 Decadal Energy Expansion Plan foresees the construction of six new hydroelectric power stations in Amazonian ecosystems by 2026 (Brasil 2017). This proliferation of hydroelectric projects, together with the facilitation of the environmental licensing process required for the construction of dams in the Amazon Basin, indicates that the environmental impacts being generated by these schemes may be underestimated (Pelicice et al. 2017).

Despite being considered a source of clean energy, hydroelectric power stations have profound negative impacts on the fundamental ecological processes that sustain the biological diversity of aquatic ecosystems (Athayde et al. 2019). One of the principal impacts caused by these hydroelectric projects is the modification of the hydrological cycle of the river (Timpe and Kaplan 2017). Dams may also reduce the availability of nutrients in the floodplain (Zahar et al. 2008), alter the physicochemical characteristics of the water, and modify the morphology of river channels (Lobato et al. 2015).

Another type of impact resulting from the construction of hydroelectric dams is the blocking of fish migration routes. Dams may create insurmountable barriers to the movement of these organisms along fluvial corridors, affecting their reproduction patterns, and changing their whole life cycle (Nunes et al. 2015; Winemiller et al. 2016). The interruption of migration routes may also affect the composition, abundance and functional attributes of the local fish assemblages (Agostinho et al. 1999; Pinto et al. 2019). This process is especially preoccupying in the Amazon Basin, where many commercially important fish species, such as the catfishes (*Brachyplatystoma* spp. and *Pseudoplatystoma* spp.) undertake systematic long-distance migrations over the course of their life cycle (Barthem et al. 2017; Anderson et al. 2018).

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In addition to their negative impacts on fish populations, hydroelectric dams also affect the human populations that depend on fishery resources (Alho et al. 2015). Approximately, 40.3 million people, worldwide, depend on artisanal fisheries for their livelihood, and this activity provides high-quality food for many of the planet's most vulnerable populations, thus combatting poverty, hunger, malnutrition, and inequality (FAO 2018). In the Amazon region alone, fisheries generate input of US$200 million per annum and support a workforce of 200 000 fishers (Tundisi et al. 2014). In addition, the per capita fish consumption of Amazonian populations is among the highest in the world and is considered to be both the main source of protein and income for many local communities (Doria et al. 2016).

The Basin of the Madeira River is one of the Amazonian ecosystems that has most suffered from the implantation of hydroelectric dams (Latrubesse et al. 2017). As one of the principal tributaries of the Amazon River, the Madeira River play a fundamentally important role in the region's fisheries, with more than 1000 species recorded up to now (Ohara et al. 2015), including a large number of recently described taxa (Bifi et al. 2019). At least 57 of the fish species recorded in the Madeira Basin are commercially important for the region's fishing communities (Doria et al. 2012). Six major fishing ports are located on the Brazilian stretch of the Madeira River, and more than 40 local communities practice traditional fishing activities (Doria and Lima 2015). It seems likely that most, if not all these communities will suffer irreversible, long-term impacts from the hydroelectric dams.

Given this, the identification and evaluation of the impacts provoked by the hydroelectric complex of the Madeira River will be fundamental to the management of the region's fisheries and its aquatic ecosystems. The analysis of the perceptions of local human populations is an important practical tool for this type of evaluation (Hanazaki et al. 2013). Throughout history, humans have congregated at the margins of watercourses, which have provided them with important ecosystem services (Moulton and Souza 2006). This relationship has resulted in the accumulation of knowledge on environmental processes, and the impacts suffered by aquatic ecosystems over the years (Silvano and Begossi 2009). This knowledge can be of enormous relevance to the environmental management of these ecosystems (Collier et al. 2015).

The present study used the knowledge of local fishers to evaluate the impacts of the Madeira River hydroelectric complex. The local fishers' knowledge has been an inestimable and extremely useful source of data on the biology and ecology of the local fish species, the fluctuations in the abundance of commercial stocks, and environmental impacts (Silvano et al. 2008). From this perspective, the present study aimed to investigate the environmental impacts generated by the hydroelectric complex in the Madeira River based on the perceptions of local fishers and fishery database, focusing attention on three main impacts: (i) on local fishery stocks; (ii) in fish fauna and (iii) on the aquatic ecosystems. It is expected that the results of this study may contribute to the management of aquatic ecosystems by mitigating or preventing similar impacts in other hydrographic basins affected by hydroelectric dams.

MATERIALS AND METHODS

Study area

The study focused on the municipality of Humaitá, located in the southern extreme of the Brazilian state of Amazonas, approximately 675 km southwest of the state capital, Manaus (Fig. 1). The municipality of Humaitá has an area of 34 430 km^2, located on the margin of the Madeira River, with an estimated population of 54 000 inhabitants (IBGE 2010).

The source of the Madeira River is located in the Bolivian Andes, where it is formed by the confluence of the Beni and Mamoré rivers (Goulding et al. 2003). The Madeira River has a total length of 3240 km, of which, 1425 km are within Brazil, where the river runs through the states of Rondônia and Amazonas before discharging into the Amazon River near the town of Itacoatiara (Costa 1998). The local climate is classified as A (tropical rainy) and Am (monsoon rains) in the Köppen system, with a short dry season, annual precipitation of 2250–2750 mm, and mean annual temperatures of between 24 and 26 °C.

The Santo Antônio hydroelectric dam (08° 48′ S, 63° 56′ W) is 175 km upstream from Humaitá city and 7 km upstream from Porto Velho city, the capital of Rondônia State. The Jirau hydroelectric dam (09° 15′ S, 64° 38′ W) is further upstream, 263 km from Humaitá and 100 km from Porto Velho (Fig. 1).

Humaitá fishing colony

Under Brazilian federal legislation (Law 1699 of July 13th, 2008), fishing colonies are recognized as professional class entities for artisanal fishers, that is, for individuals that make their livelihood predominantly from fishing. The statute of the Humaitá colony (colony Z-31) was established on January 15th, 2002. The catches of the members of this colony are landed on a floating pier on the left margin of the Madeira River. The catches are then sold in the municipal market of the town of Humaitá or to middlemen. Approximately, 1655 fishers are currently affiliated with the Humaitá fishing colony (Santos et al. 2018).

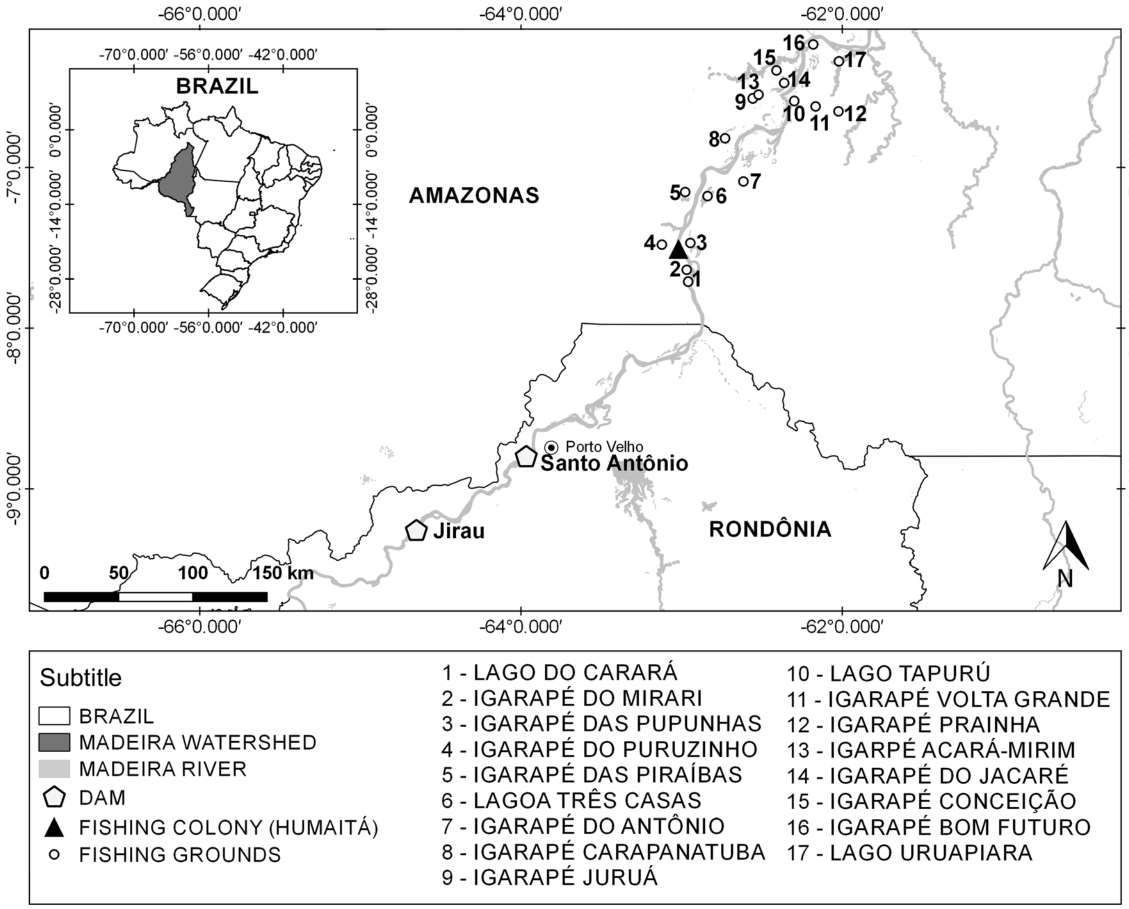

Fig. 1 Fishing grounds of the Z-31 (Dr. Renato Pereira Gonçalves) fishing colony, which operates out of the municipality of Humaitá, in Amazonas State, Brazil, and the location of the Santo Antônio and Jirau dams on the Madeira River in Rondônia State. The catches landed by this fishing colony were obtained at 17 fishing grounds located downstream from the dams

The local fishers use a variety of vessels, including rowboats, motorized canoes, and fishing boats of up to 13 m in length (Lima et al. 2016). Gillnets and cast-nets are the principal types of equipment used to fishing, although some fishers also use hook and line, trawls or dragnets, harpoons, and arrows. More than half (54%) of the interviewees reported living in the periphery of the town of Humaitá, while the other 46% live in the rural zone. All interviewees consider themselves to be artisanal fishers and approximately 65% of them use the fish both for commercialization and for own consumption. The gain from the fish commercialization represents between 50 and 100% of family income in the riverside communities of the Madeira River (Doria and Lima 2015).

Ethnobiological data

Local fishers were accessed using a non-probabilistic "snowball" approach, which consists of the identification of the local "experts" on the topic under investigation. In this approach, each informant identifies one or more experts until no additional individuals are indicated, thus completed the sample within the target group (Patton 2001). Once all the local fishers had been identified, the objectives of the study were explained, and each local fishers was asked to sign a free and informed consent form. This authorized legally their participation in the study, based on the recommendations of Resolution 466/12 of the Brazilian National Health Council (Brasil 2012). The participants' names are not provided here, to protect their identities. This study was approved by the Research Ethics Committee of the Federal University of Minas Gerais (UFMG), under process number CAAE: 80160217.8.0000.5149.

Semi-structured interviews were applied in July 2017 to 28 local fishers (22 men and six women) of the Z-31 colony, also known as the Dr. Renato Pereira Gonçalves fishing colony (Appendix S1). At the time of the study, the interviewees were between 35 and 61 years old, with an average age of 52 years. The basic selection criterion was having lived in the study area since before the construction of the Santo Antônio and Jirau dams, with at least 20 years of fishery experience. The questions presented in the interview were intended to decipher the perceptions of the local fishers with regard to the impacts caused by the dams, focusing on three principal impacts: (i) on local fishery stocks; (ii) in fish fauna and (iii) on the aquatic ecosystems. To facilitate the interviews and the data analysis, the local fishers were asked to refer only to the changes perceived by them over the past 20 years (1997–2017).

To decipher the perceptions of the local fishers on the impacts caused by the impoundment of the Madeira River, the interviewees were asked whether, in the past 20 years, they had perceived: (i) unusual changes (i.e., an increase or decrease) in fishery production, (ii) changes in the characteristics (e.g., their appearance, biology or behavior) of the fish, and (iii) unusual changes in the characteristics of the aquatic ecosystems (tributaries, lakes, margins, etc.) of the Madeira River. Whenever the answer was positive, the interviewee was asked to define "in which year" or "from which year onward" the change was noticed, and what the "possible cause" of these changes may have been. When the interviewee referred to one or more fish, the interviewer asked "which species" were involved. Finally, the interviewee was asked to describe in detail the situation regarding the fishery, fish or river in the periods before and after the impoundment.

The fish species cited in the interviews and recorded in the database were identified taxonomically using a checklist (Medeiros et al. 2014). For this, the interviewees were shown a catalog of photographs of the fish species found in the Madeira River and asked to list the species they knew and their local names. This catalog contained 202 photographs of fish species published in the regional inventories of Queiroz et al. (2013). These photographs were shown to the local fishers in a random order (with the same order being used in all cases).

Fishery data

To evaluate and confirm the perceptions of the local fishers on the impacts of the hydroelectric complex of the Madeira River on its fish and fisheries, the results of the interviews were compared with the local fishery data. These data were obtained from the database available at the Z-31 colony in Humaitá. All catches landed at the colony from 17 fishing grounds located downstream of the dams have been recorded between January 2002 and September 2017 (Fig. 1). The data were recorded daily, and include information on the date of each fishing trip, the type of fish caught, and the catch volume (kg).

Data analysis

The information compiled in the interviews was analyzed using a collective subject technique (Lefevre 2005), which involves the identification of key expressions, that are used to group common themes and the central idea of the "collective discourse". Following the semi-structured interviews, the impacts perceived by the local fishers following the construction of the Madeira River hydroelectric complex were tabulated and allocated to categories. Impacts on fisheries were divided into two categories: (i) decline in fishery productivity and (ii) "peak" in fishery production in the flood season of 2014. The impacts perceived on the fish were assigned into three categories: (i) exophthalmia (lesions in the eyes), (ii) reduction in the size (length/weight) of the fish, and (iii) fish containing mature ova outside the normal breeding season. Impacts on the river were also divided into three categories: (i) irregular flood pulse; (ii) muddy water, and (iii) erosion on the river margins. The relative and absolute frequencies of the different categories were quantified for analysis. Only the perceptions mentioned by at least 10% of the interviewees were considered for analysis.

To compare the perceptions of the local fishers with the fishery data, the information on the catches landed at the Humaitá colony was divided into "Before" and "After" categories, based on the first complete impoundment of the Madeira River (Santo Antônio Dam) in July 2011. All the fishery data collected between January 2002 and July 2011 were thus allocated to the "Before" category, while those collected between August 2011 and September 2017 (except 2013) were assigned to the "After" category. In 2013, the floating pier of the fishing colony was removed from the Madeira River to make way for the construction of flood prevention works by the Humaitá town council. This led to the suspension of data collection between January and October 2013, so the data from 2013 were excluded from the analyses. The sluice gates of the Jirau Dam were shut off completely in October 2012.

All the fish species referred to by the interviewees were included in the comparative analysis of the fishers' perceptions and the data on the catches landed at the Humaitá colony. This analysis included all the species mentioned by the interviewees, as well as the species that were not mentioned but were among the 20 most abundant species in the fishery data. In this case, only one fish, the babão (*Brachyplatystoma platynemum*) was among the 20 species most landed by the fishers of the Humaitá colony but was not cited in the interviews.

RESULTS AND DISCUSSION

Fish most caught

A total of 20 ethnospecies were cited by the local fishers as being the most caught at the Z-31 colony (Table 1). This relatively large number of commercial species indicates that the local fishery production is multispecific, that is, the targeting of an ample diversity of species to supply both the community and the local markets (Ruffino et al. 1998). Multispecies fisheries are typical of tropical environments (Hallwass et al. 2011), given its diversity of habitats and high species richness.

The pacu (*Mylossoma* spp.) and the curimatã (*Prochilodus nigrican*s) were considered to be the most productive fish by the local fishers, each being cited in 79% of the interviews (Table 1). This was corroborated by the fishery data, with the highest production being recorded for the pacu, followed by the curimatã, in all the periods analyzed (Table 1). This is consistent with the findings of fishery studies in the Amazon Basin, where the bulk of the production is provided by migratory characiforms (Gonçalves and da Batista 2008). These findings are thus as expected, given that these species (pacu and curimatã) are not only extremely important fishery resources, but are also widely appreciated and consumed by the riverside populations of the Amazon region (Soares et al. 2007). Souza et al. (2015) recorded a similar pattern in the municipality of Iranduba, in the Brazilian state of Amazonas, where the pacu (*Mylossoma* spp., M*yleus* spp., M*etynnis* sp.) and the curimatã (*P. nigricans*) were considered to be the fish most landed by local fishers.

Impacts of the hydroelectric dams on local fisheries

Decline in catches

All the local fishers confirmed having perceived a decline in fishery productivity following the damming of the Madeira River (Fig. 2a). One of the local fishers reported that in areas in which 200–300 kg of fish were caught typically prior to the impoundment, no more than 50 kg is caught in the present day, representing a decline in productivity of approximately 75–83% (Table 2). One other local fisher, responsible for recording catches at the fishing colony, reported that the number of landings has declined noticeably since the construction of the dams. Additionally, the informants noticed that even during months that were historically the most productive, there are days that the pier remains empty, with no fish being landed (Fig. 3a, Table 2). Fearnside (2014) recorded a similar scenario at a number of communities in the Madeira River, where fish disappeared following the impoundment of the river. Rainey and Rainey (2016) also found a similar situation in the community of Vila São Sebastião, in the municipality of Porto Velho, where residents reported a reduction in catches in areas adjacent to the community.

Based on the perceptions of the local fishers, the production of 15 ethnospecies declined following the impoundment (Table 1). Many studies have shown that impoundments for hydroelectric projects may provoke a reduction in fish populations due to a number of different types of impact, such as the blocking of migration routes (Perkin and Gido 2012; Mahlum et al. 2014), injuries to the fish in the turbines (McKinstry et al. 2007), shifts in the flood pulse (Santos, et al. 2018), changes in the physical–chemical properties of the water (Preece and Jones 2002; Olden and Naiman 2010), and alterations in the trophic structure of the impounded ecosystem (Agostinho et al. 2016; Oliveira et al. 2018). All these factors may have contributed to the decline in fishery production in the Madeira Basin. It is important to note here that the fishery data from the Madeira River reflect the dependence of local fisheries on migratory species, including *Mylossoma* spp.; *P. nigricans*; *Semaprochilodus insignis*; *Pseudoplatystoma* spp., which are among the fish that are most vulnerable to impoundments (Agostinho et al. 2016).

The pacu was the fish most referred in the interviews, appearing in 25% of the cases. A similar pattern was observed in the mean total catch, with the greatest reduction in the biomass landed at the fishing colony (− 2316 kg) was recorded for the pacu. Fishers of the Araguaia Tocantins Basin also reported a decline in the production of the pacu following the impoundment of the Tocantins River (Hallwass et al. 2013). This accentuated reduction in the catches of the pacu may be linked to the fact that the modification of the hydrological cycle of impounded rivers generally leads to a reduction in the survival of the larvae in their spawning areas (Agostinho et al. 2004), a process that may have led to a decline in the abundance of these fish in the Madeira River.

The data indicate that the local fishers of the Humaitá fishing colony have a clear perception of the decline in the production of the pacu, although their perception was less sensitive for other species that suffered an even greater proportional decline in catches, such as the mapará (*Hypophthalmus* spp.) and branquinha, *Potamorhina latir* and *P. altamazonica* (Table 1). In addition, all species that recorded an increase in fish production in the colony's fishery database were not cited in the interviews. This may be related to the fact that local fishers generally provide more details on the most abundant and most exploited species, in particular, those with the highest commercial value (Silvano and Begossi 2002). The pacu, in particular,

Table 1 Perceptions of the local fishers interviewed at the Z-31 fishing colony in Humaitá, northern Brazil, with regard to the impacts on local fish and fisheries, and historical data on the fish catch at the fishery colony. *Af* absolute frequency, *Rf* (%) relative frequency, *Av* absolute variation, *Rv* (%) relative variation. *Fish cited most frequently; [a]Fish most caught; [b]Most accentuated decline in fishery production

Fish				Impact—fishery				Impact—fish						Fish catch				
Common name	Species	Most caught		Decline		"Peak" in production in the flood of 2014		Exophthalmia		Length/ weight		Reproduction		Sum (t)	Monthly mean (kg)		Variation in the monthly mean (kg)	
		Af	Rf (%)	Af	Rf (%)	Af	Rf (%)	Af	Rf (%)	Af	Rf (%)	Af	Rf (%)	Total	Before	After	Av	Rv (%)
Acará	*Astronotus crassipinnis, Aequidens tetramerus, Satanoperca acuticeps*	3	11	0	0	1	4	0	0	0	0	0	0	43	226	300	74	33
Aruanã	*Osteoglossum bicirrhosum*	2	7	1	4	0	0	0	0	0	0	0	0	76	522	294	– 228	– 44
Babão	*Brachyplatystoma platynemum*	0	0	0	0	0	0	0	0	0	0	0	0	27	121	219	98	81
Bodó	*Hypostomus* sp. *Pseudorinelepis genibarbis*	1	4	0	0	0	0	0	0	0	0	1	4	67	415	340	– 75	– 18
Branquinha	*Potamorhina latior, P. altamazonica*	7	25	0	0	0	0	0	0	0	0	1	4	378	2905[a]	914	– 1991[b]	– 69[b]
Curimatã	*Prochilodus nigricans*	22	79*	4	14	2	7	10	36*	3	11*	2	7*	491[a]	3316[a]	2016[a]	– 1300	– 39
Dourada	*Brachyplatystoma rousseauxii*	2	7	2	7	0	0	1	4	0	0	0	0	69	414	377	– 37	– 9
Filhote/ Piraíba	*Brachyplatystoma filamentosum*	1	4	4	14	0	0	0	0	0	0	0	0	33	195	195	0	0
Jaraqui	*Semaprochilodus insignis, S. taeniurus*	5	18	1	4	1	4	0	0	1	4	0	0	392[a]	2749	1420	– 1329	– 48
Jatuarana/ Matrinxã	*Brycon amazonicus, B. melanopterus, B. falcatus*	8	29	4	14	12	43*	0	0	0	0	0	0	304	2331	737	– 1594[b]	– 68[b]
Mandi	*Pimelodus* sp.	0	0	0	0	0	0	3	11	1	4	0	0	2	5	21	16	320
Mapará	*Hypophthalmus* spp.	1	4	1	4	1	4	0	0	0	0	0	0	11	89	12	– 77	– 87[b]
Pacu	*Mylossoma* spp.	22	79*	7	25*	2	7	11	39*	5	18*	2	7*	763[a]	5256[a]	2940[a]	– 2316[b]	– 44
Piau	*Schizodon fasciatus, Leporinus* spp.	5	18	0	0	0	0	7	25*	2	7	0	0	60	342	368	26	7
Pintado/ Surubim	*Pseudoplatystoma* spp.	12	43*	4	14	0	0	0	0	0	0	0	0	214	1175	1369	194	17
Piranha	*Serrasalmus* sp., *Pygocentrus nattereri*	3	11	0	0	0	0	0	0	0	0	0	0	30	147	217	70	47
Pirapitinga	*Piaractus brachypomus*	1	4	2	7	1	4	0	0	0	0	0	0	52	383	150	– 233	– 61
Pirarara	*Phractocephalus hemioliopterus*	3	11	1	4	0	0	0	0	0	0	0	0	70	387	439	52	13
Sardinha	*Triportheus auritus, T. angulatus*	10	36	4	14	0	0	6	21	0	0	2	7*	127	733	747	14	2
Tambaquí	*Colossoma macropomum*	5	18	4	14	3	11*	0	0	0	0	0	0	138	875	673	– 202	– 23
Tamoatá	*Hoplosternum littorale*	2	7	1	4	0	0	0	0	0	0	0	0	78	353	631	278	79
Traíra	*Hoplias malabaricus*	0	0	0	0	1	4	0	0	0	0	0	0	19	114	108	– 6	– 5
Tucunaré	*Cichla* spp.	2	7	1	4	0	0	0	0	0	0	0	0	70	490	253	– 237	– 48

is a prominent fishery target throughout the Amazon Basin (Batista and Petrere 2003), which probably enhanced the perceptions of the local fishers, even though some other species had declined more, in relative terms.

The low frequency of catches of some species may have been the main factor that negatively influenced the perception of local fishers. The mapará, for example, suffered the largest decline in relative frequency in the fishery database but was largely ignored by local fishers in the interviews. While the mean catch of the mapará declined 87%, it represented only 0.31% of the total catch recorded (Table 1). In addition, species that recorded a significant increase in fishery production, such as Mandi (Pimelodus sp.), were not also remembered by local fishers in the interviews. The increase in fishery production observed for Mandi was 320%, however, its capture represents only 0.06% of all fishery production in Humaitá Colony (Table 1). This pattern can also be observed for the other species that have registered increased fishery production. These results indicate that the low frequency of the capture of landed species may have influenced the perception of local fishers regarding the hierarchy of species that were more or less impacted.

Such minor inconsistencies between the perception of the local fishers and the biological data do not necessarily detract from the value of the semi-structured interviews, given that the relationship formed between the researchers and the traditional communities provides an opportunity for the accumulation of knowledge and the collection of new data (Silvano and Valbo-Jørgensen 2008; Daw et al. 2011). In the present study, for example, while the hierarchy of the species most impacted was not defined exactly, it was possible to confirm the negative influence of the impoundment on the fishery stocks (i.e., decline in stocks), as well as identifying the taxonomic groups potentially most affected.

The decline in fishery production reported by the local fishers and confirmed by the fishery data from Humaitá can have a negative impact on the economy of the local communities. In the Amazon region, fisheries are an important source of income and employment and supply both national and international markets (Almeida et al. 2004). Santos et al. (2018), for example, estimated that the hydroelectric complex of the Madeira River represents a loss of approximately US$342 000 per annum for fishing activity in Humaitá. In addition to economic losses, the decline of fisheries on the Madeira River may affect the subsistence of local families. The per capita consumption of fish in the Amazon is among the highest in the world, reaching 440 g/day in some regions (Cerdeira et al. 1997; Doria et al. 2016). This implies that the impact of the dams will also modify the diets of local riverside populations that depend on fish as a source of animal protein.

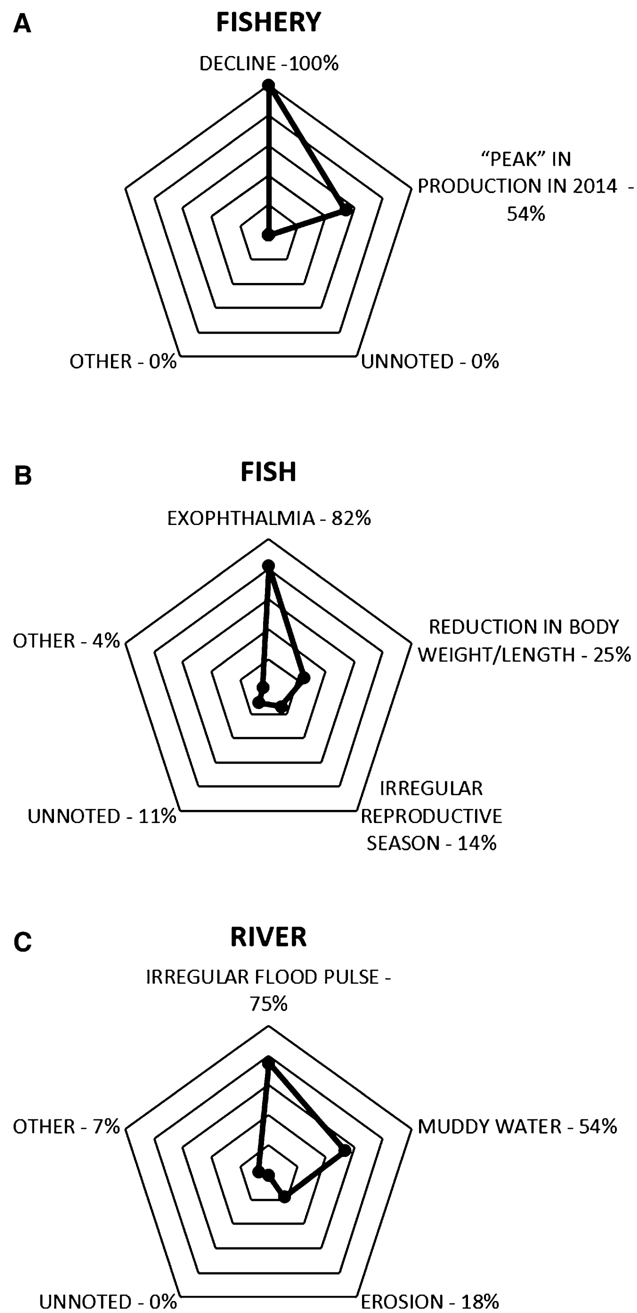

Fig. 2 Relative frequency of citations of the different environmental impacts perceived by the local fishers from the Z-31 fishing colony in Humaitá following the construction of the Madeira River hydroelectric complex: **a** impacts perceived in fisheries; **b** impacts perceived on the fish, and **c** impacts perceived on the river

"Peak" of fishery production during the flood of 2014

More than half (54%) of the local fishers reported that the flood of 2014 resulted in a period of atypically high fishery productivity at Humaitá (Fig. 2a, Table 2). The flood of 2014 was considered to be the greatest ever recorded on the Madeira River, reaching a historic peak of 19.74 m on

Table 2 Selected comments from the local fishers of the Z-31 fishing colony, in the municipality of Humaitá, on the impacts perceived in the fishery, the fish, and the river

Impacts	Comment
Fishery	
Decline	"Since 2012 fishing is more difficult, where we used to catch 200–300 kg of fish per trip, I now catch only 50 kg"
	"After they built the dams, our catches decreased so much, look at this pier, completely empty. I pass my days fixing my nets and selling bananas, to make a little money, because, if I were to depend on fishing, I wouldn't have any money at all"
	"Before they built the dam, I could easily sustain my daughter in the dry season, but now, there are no more fish in the river"
"Peak" in fishery production in the flood of 2014	"During the big flood of 2014, I caught so many fish, that they were beginning to rot"
	"In 2014, I caught so many jatuarana that I had to give them away to my neighbors because no-one wanted to buy them. But afterward, the fish were even more scarce"
	"Our catches had been declining since 2012, but after the peak in 2014, the fish disappeared completely. I never saw some types of fish again"
Fish	
Exophthalmia	"Right after they built the dam, the pacu and the piau got bug-eyed"
	"In 2017, I began catching fish with enormous eyes, full of pus. When they got trapped in the nets, their eyes dropped out!"
	"I've seen some fish, in particular the sardinha and the curimatã, with bug eyes since 2012. It looks like they've got an eye tumor"
Reduction in the body weight/length	"Before the dam, I always caught nice plump pacu, but now, they're all thin"
	"After the dam, the curimatã and the jaraqui are all small"
Irregular reproduction season	"Now (after the dam) we catch fish with roe in July"
	"The fish is coming with roe now. I saw fish with roe in May"
River	
Irregular flood pulse	"In the old days, the river was more predictable, but now, we don't know when the water will rise or fall. It's difficult to fish now, because the dam controls the river"
	"The river is varying a lot, and the fish have disappeared. Last week, there was a strong variation in water ("repiquete") and my catch was so small, the only money I received was just enough to pay my crew, there was nothing left for me. I lost almost all the ice I had bought"
	"When the river level begins to fall, we begin to catch a lot of fish. But then they release water from the dam, and the fish disappear. There is no more dry season for us to fish"
Muddy waters	"When the dam releases water, there is this flood ("repiquete"), and the river water gets all muddy"
	"The water is muddier now, and it is so muddy that people have stopped drinking the river water"
Erosion	"We have been having a lot of landslides since they built the dams"
	"The riverbank is collapsing a lot of now; some parts of the river have even become wider"

March 30th, 2 m higher than the previous record, in 1997 (Brasil 2014). Rainey and Rainey (2016) recorded a similar situation in Porto Velho, where local fishers reported a major increase in the availability of fish in 2014. Some studies have recorded peaks in fishery productivity in years with atypical floods, such as 2014 (as well as 1993 and 1997) on the Madeira River (Doria and Lima 2015; Lima et al. 2017; Ayla et al. 2018). These peaks in fishery productivity recorded during exceptional floods may have been associated primarily with the higher river levels recorded in the preceding years (Lima et al. 2017). Welcomme and Halls (2004) concluded that higher flooding periods lead to an increase in the availability of nutrients, refuges and breeding grounds, which may favor the reproduction of stocks in subsequent years.

However, the more experienced local fishers interviewed in the present study were unanimous in saying that the atypical peak in fishery production during these historic floods is more closely related to the unique features of these events than river levels during the preceding period. In particular, the local fishers explained that the historic floods inundate floodplain lakes that are not normally reached by the rising waters during typical years, enabling large numbers of fish to migrate from these lakes to the river:

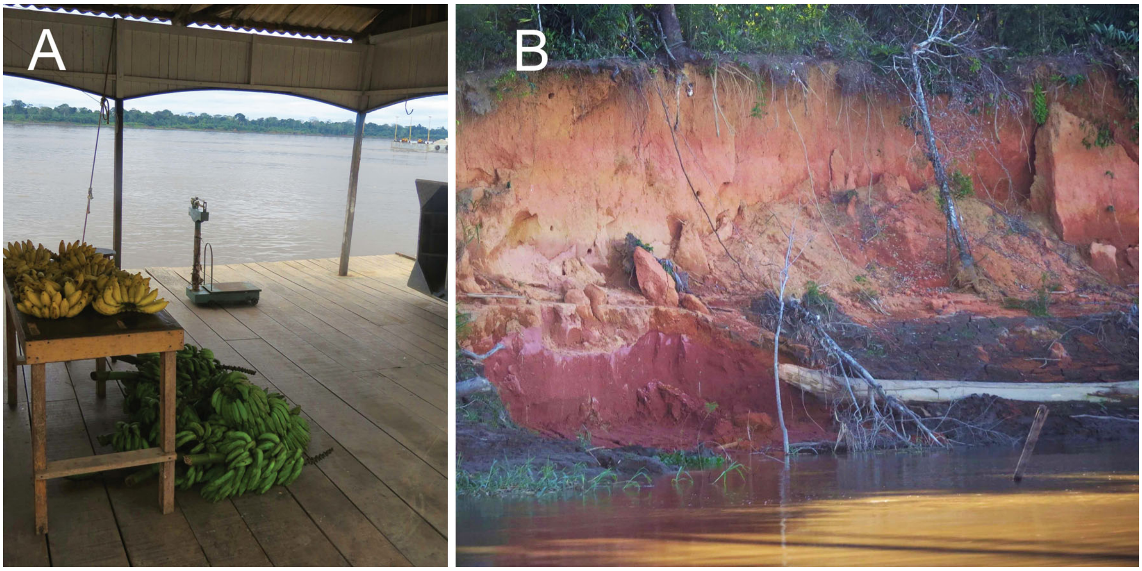

Fig. 3 Environmental impacts generated by the hydroelectric complex in the Madeira River. **a** Floating landing pier at the Z-31 fishing colony in Humaitá at the time of the interviews (July 2017). Note that on this day, in one of the months that is typically among the most productive in this area, the pier is completely empty. It is also possible to observe the sale of bananas by one of the local fishers to minimize the fishery financial losses. **b** Erosion of the left margin of the Madeira River in the municipality of Humaitá at the time of the interviews (July 2017). Note that the soil and some roots are exposed. Photo by Rangel Eduardo Santos

> Fisher: "When the flood is normal, the river is not connected to all of the lakes, so the fish cannot get to the river, and they stay in the lake for about five years. But during big floods, like in 2014, the water fills all this floodplain, and all the lakes and várzea (floodplain). Thus, the fish that have been living in the lakes for a long time, like the jatuarana (Brycon spp.), who live in clean water, can get to the river. This is why we caught so many jatuarana in 2014, because they passed here in front of the town, and we just caught them."

This explanation is supported by other observations from the local fishers, who reported that characiform fish, such as the jatuarana/matrinxã (*Brycon amazonicus, B. melanopterus, B. falcatus*) and the tambaqui (*Colossoma macropomum*), were the most caught during the 2014 flood, with an average citation of 43% and 11% respectively (Table 1). Characiforms are known to dominate the fish faunas of floodplain lakes (Freitas and Garcez 2004), and the increase in their production in 2014 may have been related to the inundation of these lakes, which may not have been reached by the waters of the less intense floods of the previous, more typical years.

Franca et al. (2015) and Marengo and Espinoza (2016) found that the exceptional 2014 flood event was not related directly to the impacts of the hydroelectric complex of the Madeira River, but rather to the exceptional rainfall recorded in central-northern Bolivia and southeastern Peru, where the principal affluents of the Madeira are found.

However, the local fishers did report that the 2014 flood-impacted local fisheries in a manner not observed in the historic floods that occurred prior to the construction of the dams. In particular, the local fishers reported that following other atypical flood events, like that of 1997, the peak in fishery production was followed by a decline in the next year, although stocks recovered during subsequent years. Following the peak in productivity associated with the 2014 flood, however, the local fishers reported that many of the species that declined in the subsequent year were unable to recuperate their stocks (Table 2). This indicates that the impoundment of Amazonian rivers may aggravate the impacts of major flood events on the region's fisheries. It is important to note here that most fish populations found in ecosystems impacted by dams are more than usually vulnerable to environmental changes, due to the blocking of migration routes (Anderson et al. 2018), for example, and the modification of the hydrological cycle (Santos et al. 2018). In other words, the increase in fishery productivity during extreme floods results in the depletion of fish stocks already left vulnerable by the impacts of the impoundment. This may reduce the number of juveniles available for recruitment to the subsequent generations, which places the species at risk of local extinction.

From this perspective, the environmental impacts of the impoundments, together with natural stochastic events, may result in an increase in the vulnerability of many Amazonian fish species. This may, in part, account for the accentuated decline in the production of some fish, such as the jatuarana/matrinxã (68%), which was the species reported in the interviews as the most productive during the historic flood (Table 1). Overall, this evidence indicates that the local fish fauna has yet to adapt to the environmental changes imposed by the hydroelectric dams.

Impacts of the hydroelectric dams on the fish

Exophthalmia

The appearance of abnormalities in the eyes (exophthalmia) was the change in the fish most cited (82%) in the interviews (Fig. 2b; Table 2). In fish, exophthalmia has been recorded in ecosystems impacted by hydroelectric dams and is generally associated with the passage of the fish through the hydraulic turbines, which may cause physical trauma related to the variation in the pressure in the fish's body, a process known as barotrauma (Stephenson et al. 2010; Brown et al. 2014). This occurs when the fish pass through the turbines and suffer rapid decompression, for less than one second, before returning to the surface pressure (Brown et al. 2012). In addition to exophthalmia, the passage through the turbines may cause other types of barotrauma, such as the rupture of the swim bladder, emboli and hemorrhaging (Colotelo et al. 2012).

Exophthalmia in fish may also be associated with parasitic infections (bacteria, fungi, viruses and worms), which may damage the eyes and cause necrotic material to be exuded through the ulcerated cornea (Eiras et al. 2010). However, it seems unlikely that the lesions observed in the fish from the Madeira River are caused by parasitosis, given that infection-related exophthalmia is more typical in farmed fish kept at high densities and water of low quality. By confining fish stocks together at high densities, fish farming may provoke chronic stress, making the fish more vulnerable to infection (Jerônimo et al. 2010). In their natural environment, by contrast, fish are often infected by a number of different parasites, but typically do not present any obvious symptoms (Pavanelli et al. 2002).

While ocular lesions have been observed by local fishers ever since the inauguration of the hydroelectric dams, there has not yet been any specific study of the appearance of exophthalmia in the fish from the Madeira River. The first fish with this condition were caught by the local fishers in 2012, soon after the impoundment of the river (Table 2). The local fishers reported that fish with this condition have been caught continuously since this time, up until the date of the interviews (July 2017). This appears to support the hypothesis that the exophthalmia observed in the fish is in fact associated with their passage through the turbines (i.e., barotrauma), and indicates that some species may be impeded from to access the fish ladders adequately, being attracted instead to the area of the turbines. Fearnside (2014) discusses this possibility and concluded that the reduced volume of water in the fish ladder at the Santo Antônio Dam is insufficient to attract fish toward its entrance, leaving them to follow the principal flow of the river.

Fish ladders have long been used for migratory species, such as salmon, but due to the enormous diversity of Amazonian fish, systematic studies of the most effective types of transposition mechanisms have not conducted for the majority of the species (Fearnside 2014). This may account for the apparent ineffectiveness of the fish ladders for some characiform species, such as the pacu, curimatã, and the piau (*Schizodon fasciatus, Leporinus* spp.), which were the main species observed with exophthalmia by the local fishers (Table 1). The occurrence of these lesions in the fish may also explain to the decline in catches reported by the local fishers and recorded in the fishery database (Table 1), given that barotrauma typically results in the eventual mortality of the animal (McKinstry et al. 2007).

Reduction in the weight/length of the fish

Some of the local fishers (25%) reported that, following the construction of the dams, "scrawny" or "small" fish were caught frequently (Fig. 2b, Table 2). The growth and weight gain of an individual organism are determined by a complex of environmental factors, in particular, the quantity and quality of the nutrients available in the environment (Dourado and Benedito-Cecilio 2005). In the Madeira Basin, the quality and availability of nutrients on the floodplain is related directly to the hydrochemical characteristics of its waters, which contain high concentrations of suspended solids and nutrients derived from its Andean drainage (Barthem and Fabré 2004). This favors the primary production of the floodplain, which supports a complex trophic network (Bayley 1989).

However, by regulating the flow of the river and retaining nutrients within the reservoir, hydroelectric dams may limit the input of organic matter downstream from the impoundment, restricting the diversity and abundance of feeding resources, and the primary productivity of the floodplain environment (Hahn and Fugi 2009). Alterations in the timing of the seasonal flood pulse in impounded ecosystems may also provoke behavioral shifts and the adaptation of the fish's physiology to the availability of nutrients (Vismara et al. 2004). It thus seems likely that the presence of "scrawny" or "small" fish is related directly to the impacts of the Santo Antônio and Jirau dams on the quality and/or availability of feeding resources downstream from this impoundment, as well as to a general reduction in the primary productivity of the floodplain.

This finding is preoccupying in the specific case of the Humaitá fishing colony, given that the species considered by the local fishers to have been the most affected are the pacu and the curimatã, which contributed to the greatest catch volume, according to the fishery data (Table 1). The greater impact observed in the pacu may, in part, be related to their omnivorous feeding behavior, and their dependence on a regular hydrological cycle and the seasonal flooding of the floodplain forests to guarantee access to an adequate diet. Claro et al. (2004), for example, found that the principal source of energy of the pacu is allochthonous items, such as the fruit, seeds, and terrestrial invertebrates typically found in flooded forests.

The reduction in body size and/or weight of the fish will have an important impact on fisheries in the Amazon region. Larger fish are generally considered to be more valuable by fishers and consumers, given that they represent a richer source of nutrients (greater biomass) and comparatively demand less processing time to be consumed (fewer or larger spines), tending to be thus more easily marketed (Begossi et al. 2012). A reduction in body mass is also expected to affect the condition factor of the fish, with negative consequences for the reproduction of the basin's fish fauna (Vazzoler 1996).

Irregular reproductive season

Some of the local fishers (14%) also reported that the construction of the hydroelectric dams on the Madeira River resulted in the capture of females containing mature ova during periods outside the reproductive season (Fig. 2b, Table 2). This unseasonal breeding may be related to changes in the hydrological cycle of the Madeira River following its impoundment. The reproductive migrations of Amazonian fish are closely synchronized with the hydrological cycle of the region's rivers (Arantes et al. 2019), and any alteration of this cycle will obviously have a significant impact on migration patterns and, ultimately, population structure (Agostinho et al. 1999). Santos et al. (2018) observed a 2-month delay in the migration period of the fish of the Madeira River, resulting from the shift in the hydrological cycle, which would be consistent with the delay in the reproductive cycle of some species observed by local fishers.

The principal fishes impacted in this case were pacu, sardinha (*Triportheus auritus*, *T. angulatus*), and curimatã (Table 1). The possible changes in the breeding season observed in these species (females containing mature ova between May and July) reflect a delay in comparison with the legal close season for the Madeira River (Brazilian federal law 11 959 of 2009). This period is timed to prohibit the fishing of certain fish species during the reproduction season, to guarantee the preservation of the species. In Amazonas State, the close season is established by the State Environment Council (CEMAAM) and is normally between November and March. The increase in the numbers of mature females captured by the local fishers 2 to 4 months after the close season (Table 2) may be related to the impoundment of the Madeira River and has negative consequences for fishery management in the Amazon Basin and for maintaining the diversity of local fish.

Impacts of the hydroelectric dams on the river

Irregular hydrological cycle

Changes in the hydrological cycle were the impact on the river most remembered (75%) by the local fishers during the interviews (Fig. 2c, Table 2). The local fishers believe that this change is related primarily to sudden variations in the level of the river, known locally as "repiquetes", which are more frequent and intense than they were prior to the impoundment of the river (Table 2). Some fishers also reported that the river is now constantly flooded and that the low water periods are now less intense than they were prior to the construction of the dams (Table 2).

Agostinho et al. (2004) found that changes in the hydrological patterns of inland aquatic ecosystems are one of the principal impacts caused by the construction of hydroelectric dams, throughout the world, given that major daily variations in the discharge of water are necessary to maximize the generation of electricity. A number of other studies in the Madeira Basin (e.g. Doria et al. 2014; Silva and Paula 2018) have obtained similar results. Santos et al. (2018), for example, found that, following the impoundment of the Madeira River, the level of the river remained high during the ebb period, reaching its lowest levels during what would normally be the rising water periods. According to the study, the river levels also varied more between years, and there was less homogeneity in the fluviometric patterns following damming of the Madeira River. See Table S1 and Fig. S1 for more details about the impacts of hydroelectric dams (Santo Antônio and Jirau) on the hydrological cycle. The fishers from the area of Ponta do Abunã also observed that the regular cycle in the level of the river had changed following the construction of the Jirau Dam and that this change was considered to be the principal cause of the scarcity of fish in the region (Silva and Paula 2018).

In the present study, the local fishers were unanimous on the negative effects of the loss of predictability of river flow, claiming that this affects most fishing trips, given that, when they go to fishing during a period of "low" water, they are surprised by a sudden increase in the level of the river, after which, the fish "disappear" (Table 2). As fishery productivity is closely related to the hydrological cycle in the Amazon Basin, changes in this cycle caused by the impoundment of rivers have been one of the principal factors in the decline in catches across the region (Winemiller et al. 2016; Timpe and Kaplan 2017). Santos et al. (2018), for example, concluded that part of the decline (39%) in catches landed at the Humaitá fishing colony is related to the increase in the mean level of the river following impoundment, based on (i) a reduction in the concentration of fish, which hampers catches and limits fishery efforts (Goulding 1979), and (ii) a reduction in the number of fishing trips during periods of more intense flow, as a means of reducing costs.

In addition to causing a decline in fishery production, the local fishers reported that the increased variability in the level of the river has resulted in other losses. Major fishing trips require the purchase of ice, fuel, provisions, and the contracting of additional personnel. However, the imbalance of the river level often results in investment losses, as catches are almost invariably insufficient to cover costs (Table 2), a similar scenario was also recorded by Santos et al. (2018).

Muddy waters

More than half (54%) of the local fishers reported that, following the impoundment, the water of the Madeira River had become "muddier" than normal (Fig. 2c, Table 2). However, no other study of the perceptions of riverside communities on the Madeira River has recorded any similar response.

It seems likely that the perception of the local fishers interviewed in the present study was related directly to the increase in the erosion of the margins of the Madeira River following the impoundment, as reported by the local fishers themselves (Table 2). This conclusion was reinforced by the fact that the local fishers reported that the muddy water was observed primarily during periods of "repiquete" when water is discharged by the dam. High levels of river discharge may cause an increase in erosive processes, and lead to an increase in the quantity of particulate matter suspended in the water, and thus, its turbidity, which may have led the local fishers to believe that the water is muddier than normal (Medeiros et al. 2015).

The sediment load may have a negative impact on an aquatic ecosystem, given that the high turbidity caused by suspended solids may hamper the penetration of sunlight, reducing the potential for photosynthesis, and leading to a reduction in the oxygenation of the water and the primary productivity of the river (Wetzel 2001). This may have negative implications for the maintenance of ecological processes and the biological diversity of aquatic ecosystems. Given this, the negative effects of the Jirau and Santo Antônio dams on the quality of the water of the watercourses and lakes of the Madeira Basin entails risks for both local diversity and the management of the region's fishery stocks.

Erosion of the river margins

Some (18%) of the local fishers also mentioned that the number of erosions of the margins of the river had increased following the impoundment (Figs. 2c, 3b, Table 2). Major erosion events have been recorded following the impoundment of the Madeira River, including the damage or destruction of 300 houses by the erosion on the waterfront of the city of Porto Velho in 2012 (Fearnside 2014). At the community of Vila São Sebastião, in the municipality of Porto Velho, local residents confirmed an increase in the number of landslides following the impoundment of the Madeira River, with larger numbers of trees being ripped out of the river margins (Rainey and Rainey 2016).

An increase in erosion downstream from the dams had been predicted by experts prior to the construction of the hydroelectric complex. The environmental impact study required for the approval of the Santo Antônio and Jirau schemes (FURNAS and CNO 2005b) concluded that, prior to the construction of the dams, the sedimentation of the margins, bed, and floodplain of the Madeira River were prevailing over erosive processes. However, Tundisi and Matsumura-Tundisi (2006) predicted that this equilibrium would be annulled by the impoundment of the river, given that the reservoir would favor the deposition of sediments upstream from the dam and would support erosive processes downstream since the deposited sediment load would not be transferred downstream.

Other hydrological alterations of the Madeira River may have contributed to an increase in erosive processes on its margins (Fearnside 2014), given that the channeling of its flow through the spillway altered the currents downstream from the dam, forcing more water toward urban areas. This is confirmed by the residents of the town of Vila São Sebastião, who confirmed that the river is faster-flowing and more turbulent than it was prior to the impoundment and that this turbulence often damages the boats and dugouts canoe moored at the front of their houses (Rainey and Rainey 2016).

CONCLUSIONS

The perceptions of local fishers confirmed that a range of environmental impacts has been generated by the construction of the hydroelectric complex on the Madeira River. It is hoped that these findings will contribute to the development of more effective management strategies for the hydrographic basins affected by hydroelectric dams. As the stocks of some fishery target species are decreasing as a consequence of these impacts, it will be necessary to establish a fish breeding program to ensure the long-term maintenance of their populations. The perceptions of the local fishers on the appearance of exophthalmia in the fish reinforce the need for a more systematic analysis of the efficiency of the transposition systems of the Santo Antônio and Jirau dams. The observation of impacts on the breeding patterns of the local fish fauna also emphasizes the need for the re-evaluation of the timing of the close season for the species most affected by the impoundment, in particular, the migratory characiform species that are targeted by local fisheries.

The perceptions of the local fishers on the aquatic ecosystem and fishery activities no longer reflect the natural processes of the river, but rather, the manner in which the dams control the flood pulse. In addition to modifying the way in which the local fishers perceive and relate to the river, the impacts of the dams on the flood pulse of the Madeira River have had a negative effect on the region's fisheries, which are the principal source of income and subsistence for innumerable local families. In particular, the findings of this study emphasize the need for the implementation of an effective system of management to avoid the enormous oscillations in river levels caused by the operation of the dams, not only seasonally, but also on a daily basis. While this may reduce the output of electricity of the dams, it would result in an important gain in ecosystem services.

Overall, it is clear that the expansion of the hydroelectric network in the Amazon Basin will extend the impacts observed in the present study throughout the basin. Clearly, any reduction in the number of hydroelectric schemes in the region should be seen as a fundamentally important investment to guarantee the future of the region, in economic, social, and ecological terms. Further research will also be essential to minimize the negative impacts of impoundments in the region, as well as developing more sustainable models of power production, that will guarantee a better balance between the region's energy demands and the ecosystem services that support such a large proportion of the population.

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REFERENCES

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

Agostinho, A.A., L.C. Gomes, S. Veríssimo, and E.K. Okada. 2004. Flood regime, dam regulation and fish in the Upper Paraná River: Effects on assemblage attributes, reproduction and recruitment. *Reviews in Fish Biology and Fisheries* 14: 11–19. https://doi.org/10.1007/s11160-004-3551-y.

Agostinho, S.A., L.E. Miranda, L.M. Bini, L.C. Gomes, and S.M. Thomaz. 1999. Patterns of colonization in Neotropical reservoirs and prognosis on aging. In *Theoretical reservoir ecology and its applications*, ed. J.G. Tundisi and M. Straskraba, 227–265. Rio de Janeiro: Backhuys Publisher.

Alho, C.J.R., R.E. Reis, and P.P.U. Aquino. 2015. Amazonian freshwater habitats experiencing environmental and socioeconomic threats affecting subsistence fisheries. *Ambio* 44: 412–425. https://doi.org/10.1007/s13280-014-0610-z.

Almeida, O.T., K. Lorenzen, and D.T. McGrath. 2004. The fisheries sector in the Amazon regional economy. In*: Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries* Volume II. Welcomme R. and T. Petr, Eds., FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2004/17, pp. 15–24.

Anderson, E., C. Jenkins, and S. Heilpern. 2018. Fragmentation of Andes- to- Amazon connectivity by hydropower dams. *Science Advances* 4: eaao1642. https://doi.org/10.1126/sciadv.aao1642.

Arantes, C.C., D.B. Fitzgerald, D.J. Hoeinghaus, and K.O. Winemiller. 2019. Impacts of hydroelectric dams on fishes and fisheries in tropical rivers through the lens of functional traits. *Current Opinion in Environmental Sustainability* 37: 28–40. https://doi.org/10.1016/j.cosust.2019.04.009.

Athayde, S., M. Mathews, S. Bohlman, W. Brasil, C.R. Doria, J. Dutka-Gianelli, P.M. Fearnside, B. Loiselle, et al. 2019. Mapping research on hydropower and sustainability in the Brazilian Amazon: Advances, gaps in knowledge and future directions. *Current Opinion in Environmental Sustainability* 37: 50–69. https://doi.org/10.1016/j.cosust.2019.06.004.

Ayla, D.M., M.A.L. Lima, M. Hauser, and C.R.C. Doria. 2018. Jatuarana fishing dynamics *Brycon amazonicus* (Spix & Agassiz, 1829) of the upper and middle Madeira River Basin. *Acta Scientiarum* 40: 1–11. https://doi.org/10.4025/actascibiolsci.v40i1.34591.

Barthem, R.B., and N.N. Fabré. 2004. Biologia e diversidade dos recursos pesqueiros da Amazônia, p. 17–62. In: Ruffino, M.L. (coord.). A pesca e os recursos pesqueiros na Amazônia brasileira. Ibama/Provárzea, Manaus, Brasil, 268 pp.

Barthem, R.B., M. Goulding, R.G. Leite, C. Cañas, B. Forsberg, E. Venticinque, P. Petry, M.L. de Ribeiro, J. Chictaya, and A. Mercado. 2017. Mercado, Goliath catfish spawning in the far western Amazon confirmed by the distribution of mature adults, drifting larvae and migrating juveniles. *Scientific Reports* 7: 1–13. https://doi.org/10.1038/srep41784.

Batista, V.S., and M. Petrere. 2003. Characterization of the commercial fish production landed at Manaus, Amazonas State, Brazil. *Acta Amazonica* 33: 53–66. https://doi.org/10.1590/1809-4392200331066.

Bayley, P.B. 1989. Aquatic environments in the Amazon Basin, with an analysis of carbon sources, fish production and and yield. *Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences.* 106: 309–408.

Begossi, A., S.V. Salivonchyk, N. Hanazaki, I.V. Martins, and F. Bueloni. 2012. Fishers (Paraty, RJ) and fish manipulation time: A variable associated to the choice for consumption and sale. *Brazilian Journal of Biology* 72: 973–975. https://doi.org/10.1590/S1519-69842012000500030.

Bifi, A.G., R.R. Oliveira, and L.R. Py-Daniel. 2019. A new species of Ancistrus Kner, 1854 (Siluriformes: Loricariidae) from rio Madeira basin, Amazonas State, Brazil. *Neotropical Ichthyology*. https://doi.org/10.1590/1982-0224-20180135.

Brasil. CNS (Conselho Nacional de Saúde). 2012. Resolução CNS 466 de 12 de dezembro de 2012. Ministério da Saúde. Retrieved September 17, 2018, from http://conselho.saude.gov.br/resolucoes/2012/Reso466.pdf.

Brasil. CGU (Controladoria Geral da União). 2014. Secretaria Federal de Controle Interno, Relatório de Fiscalização n° 201408699. Diagnóstico situacional dos efeitos da cheia do Rio Madeira em Porto Velho, Rondônia. Retrieved March 15, 2019, from https://auditoria.cgu.gov.br/download/7129.pdf.

Brasil, MME (Ministério de Minas e Energia). 2017. Plano Decenal de Expansão de Energia 2026. Ministério de Minas e Energia, Empresa de Pesquisa Energética (MME/EPE). Brasília, DF, Brasil. 2 vols. Retrieved March 19, 2019, from http://www.mme.gov.br/documents/10584/0/%20PDE2026.pdf/474c63d5-a6ae-451c-8155-ce2938fbf896.

Brown, R.S., A.H. Colotelo, and B.D. Pflugrath. 2014. Understanding Barotrauma in fish passing hydro structures: A global strategy for sustainable development of water resources. *Fisheries* 39: 108–122. https://doi.org/10.1080/03632415.2014.883570.

Brown, R.S., B.D. Pflugrath, A.H. Colotelo, C.J. Brauner, T.J. Carlson, Z.D. Deng, and A.G. Seaburg. 2012. Pathways of barotrauma in juvenile salmonids exposed to simulated hydro-turbine passage: Boyle's law vs Henry's law. *Fisheries Research* 121: 43–50. https://doi.org/10.1016/j.fishres.2012.01.006.

Castello, L., and M.N. Macedo. 2015. Large-scale degradation of Amazonian freshwater ecosystems. *Global Change Biology* 22: 990–1007. https://doi.org/10.1111/gcb.13173.

Cerdeira, R.G.P., M.L. Ruffino, and V.J. Isaac. 1997. Consumo de pescado e outros alimentos pela população ribeirinha do Lago Grande de Monte Alegre, PA. Brasil. *Acta Amazonica* 27: 213–228. https://doi.org/10.1590/1809-43921997273228.

Claro Jr., L., E. Ferreira, J. Zuanon, and C.R.M. Araujo-Lima. 2004. Effects of flooded forest in the diet of three fish species in floodplain lakes of Central Amazon, Brazil. *Acta Amazonica* 34: 133–137.

Collier, C.A., M.S. de Almeida Neto, G.M.A. Aretakis, R.E. Santos, T.H. de Oliveira, J.S. Mourão, W. Severi, and A.C.A. El-Deir. 2015. Integrated approach to the understanding of the degradation of an urban river: Local perceptions, environmental parameters and geoprocessing. *Journal of Ethnobiology and Ethnomedicine*. https://doi.org/10.1186/s13002-015-0054-y.

Colotelo, A.H., B.D. Pflugrath, R.S. Brown, C.J. Brauner, R.P. Mueller, T.J. Carlson, Z.D. Deng, M.L. Ahmann, et al. 2012. The effect of rapid and sustained decompression on barotrauma in juvenile brook lamprey and Pacific lamprey: Implications for passage at hydroelectric facilities. *Fisheries Research* 129–130: 17–20. https://doi.org/10.1016/j.fishres.2012.06.001.

Costa, L.S.S. 1998. *As hidrovias interiores no Brasil*, 125. Rio de Janeiro: Serviço de Documentaçao da Marinha, Coleção Amigos do Livro Naval.

Daw, T.M., J. Robinson, and N.A.J. Graham. 2011. Perceptions of trends in Seychelles artisanal trap fisheries: Comparing catch monitoring, underwater visual census and fishers' knowledge. *Environmental Conservation* 38: 75–88. https://doi.org/10.1017/S0376892910000901.

Doria, C.R.C., and M.A.L. Lima. 2015. Histórico do projeto e metodologia de obtenção dos dados. In *Rio Madeira: Seus Peixes e sua Pesca*, 1–11 pp. Porto Velho, RO: Rima.

Doria, C.R. da C., M.A.L. Lima, A.R. do Santos, S.T. Brasil de Souza, M.O.D.A.R. Simão, and A. R. Carvalho. 2014. O uso do conhecimento ecológico tradicional de pescadores no diagnóstico dos recursos pesqueiros em áreas de implantação de grandes empreendimentos. *Desenvolvimento e Meio Ambiente* 30: 89–108. 10.5380/dma.v30i0.34196.

Doria, C.R.C., M.L. Ruffino, N.C.H. Hijazi, and R.L.C. Cruz. 2012. A pesca comercial na bacia do rio Madeira no estado de Rondônia, Amazônia brasileira. *Acta Amazonica* 42: 29–40.

Doria, C.R.C., L.F. Machado, S.T. Brasil de Souza, and M.A.L. Lima. 2016. A pesca em comunidades ribeirinhas na região do médio rio Madeira, Rondônia. *Novos Cadernos NAEA* 19: 163–188. https://doi.org/10.5801/ncn.v19i3.2499.

Dourado, E.C.S., and E. Benedito-Cecilio. 2005. *Ecologia energética de peixes: influência de fatores abióticos e bióticos*, 53p. EDUEM: Maringá.

Eiras, J., R., G. Takemoto, E.A.M. Pavanelli. 2010. Clichetec, and undefined. 2010. *Diversidade dos parasitas de peixes de água doce do Brasil*.

FAO. 2018. The State of World Fisheries and Aquaculture 2018—Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO.

Fearnside, P.M. 2014. Impacts of Brazil's Madeira River Dams: Unlearned lessons for hydroelectric development in Amazonia. *Environmental Science & Policy* 38: 164–172. https://doi.org/10.1016/j.envsci.2013.11.004.

Franca, R., E.E.D. Justina, and S.F. Sampaio. 2015. Análise climatológica e hidrológica da cheia do rio Madeira em Porto Velho-Rondônia no ano de 2014. *Terra Plural* 9: 74–90. https://doi.org/10.5212/TerraPlural.v.9i2.0005.

Freitas, C.E.C., and R.C.S. Garcez. 2004. Fish communities of natural channels between floodplain lakes and Solimões-Amazonas River (Amazon-Brazil). *Acta Limnologica Brasiliensia* 16: 273–280.

FURNAS (Furnas Centrais Elétricas S.A.) and CNO (Construtora Noberto Odebrecht S.A.) & Leme Engenharia. 2005b. EIA-Estudo de Impacto Ambiental Aproveitamentos Hidrelétricos Santo Antônio e Jirau, Rio Madeira-RO. 6315-RT-G90-001. FURNAS, CNO & Leme Engenharia, Rio de Janeiro, RJ. 8 Vols.

Gonçalves, C., and S. da Batista. 2008. Avaliação do desembarque pesqueiro efetuado em Manacapuru, Amazonas, Brasil. *Acta Amazonica* 38: 135–144. https://doi.org/10.1590/S0044-59672008000100015.

Goulding, M. 1979. *Ecologia da pesca do rio Madeira*, 172. Manaus: INPA, CNPQ-INPA.

Goulding, M., R. Barthem, and E. Ferreira. 2003. *The Smithsonian Atlas of the Amazon*. London: Smithsonian Books.

Hahn, N.S., and R. Fugi. 2009. Alimentação de peixes em reservatórios brasileiros: Alterações e conseqüências nos estágios iniciais do represamento. *Oecologia Brasiliensis* 11: 469–480. https://doi.org/10.4257/oeco.2007.1104.01.

Hallwass, G., P.F. Lopes, A.A. Juras, and R.A.M. Silvano. 2011. Fishing effort and catch composition of Urban market and rural villages in Brazilian Amazon. *Environmental Management* 47: 188–200. https://doi.org/10.1007/s00267-010-9584-1.

Hallwass, G., P.F. Lopes, A.A. Juras, and R.A.M. Silvano. 2013. Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers. *Ecological Applications* 23: 392–407. https://doi.org/10.1890/12-0429.1.

Hanazaki, N., D.F. Herbst, M.S. Marques, and I. Vandebroek. 2013. Evidence of the shifting baseline syndrome in ethnobotanical research. *Journal of Ethnobiology and Ethnomedicine* 9: 1–11. https://doi.org/10.1186/1746-4269-9-75.

IBGE. 2010. Instituto Brasileiro de Geografia e Estatística. Retrieved 15 August 2018, from https://cidades.ibge.gov.br/brasil/am/humaita/panorama.

Jerônimo, G.T., G.M. Speck, and M.L. Martins. 2010. First report of *Enterogyrus cichlidarum* Paperna 1963 (Monogenoidea: Ancyrocephalidae) on Nile Tilapia *Oreochromis niloticus* cultured in Brazil. *Neotropical Helminthology* 4: 75–80.

Latrubesse, E.M., E.Y. Arima, T. Dunne, E. Park, V.R. Baker, F.M. D'Horta, C. Wight, F. Wittmann, et al. 2017. Damming the rivers of the Amazon basin. *Nature* 546: 363–369. https://doi.org/10.1038/nature22333.

Lees, A.C., C.A. Peres, P.M. Fearnside, M. Schneider, and J.A.S. Zuanon. 2016. Hydropower and the future of Amazonian biodiversity. *Biodiversity and Conservation* 25: 451–466. https://doi.org/10.1007/s10531-016-1072-3.

Lefevre, F., and A.M.C. Lefevre. 2005. Depoimentos e discursos: uma proposta de análise em pesquisa social. *Série Pesquisa* 12. Liber Livro.

Lima, M.A.L., C.E. de Freitas, S.M. de Moraes, and C.R.C. Doria. 2016. Pesca artesanal no município de Humaitá, médio rio Madeira, Amazonas, Brasil. *Boletim do Instituto de Pesca* 42: 924–935. https://doi.org/10.20950/1678-2305.2016v42n4p924.

Lima, M.A.L., D. Kaplan, and C.R.C. Doria. 2017. Hydrological controls of fisheries production in a major Amazonian tributary. *Ecohydrology* 10: 1–19. https://doi.org/10.1002/eco.1899.

Lobato, T., R. Hauser-Davis, T. Oliveira, A. Silveira, H. Silva, M. Tavares, and A.C.F. Saraiva. 2015. Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region. *Journal of Hydrology* 522: 674–683. https://doi.org/10.1016/j.jhydrol.2015.01.021.

Mahlum, S., D. Kehler, D. Cote, Y.F. Wiersma, and L. Stanfield. 2014. Assessing the biological relevance of aquatic connectivity to stream fish communities. *Canadian Journal of Fisheries and Aquatic Sciences* 71: 1852–1863. https://doi.org/10.1139/cjfas-2013-0646.

Marengo, J.A., and J.C. Espinoza. 2016. Extreme seasonal droughts and floods in Amazonia: Causes, trends and impacts. *International Journal of Climatology* 36: 1033–1050. https://doi.org/10.1002/joc.4420.

McKinstry, C., T.J. Carlson, and R.S. Brown. 2007. Derivation of a mortal injury metric for studies of rapid decompression of depth-acclimated physostomous fish. PNNL-17080. Pacific Northwest National Laboratory, Richland, Washington.

Medeiros, P.M., A.L.S. Almeida, R.F.P. Lucena, F.J.B. Souto, and U.P. Albuquerque. 2014. Use of visual stimuli in ethnobiological research. In *Methods and techniques in ethnobiology and ethnoecology*, ed. U.P. Albuquerque, L.V.F.C. Cunha, R.F.P. Lucena, and R.R.N. Alves, 87–98. New York: Springer.

Medeiros, P.R.P., G.H.C. Segundo, and E.M.M. Magalhães. 2015. Comportamento da turbidez e material em suspensão, em um rio com vazão regularizada por sistema de barragens em cascata: Rio São Francisco (NE, Brasil). *Geochimica Brasiliensis* 29: 35–44. https://doi.org/10.5327/Z0102-9800201500010004.

Moulton, T.P., and M.L. Souza. 2006. Conservação com base em bacias hidrográficas. In *Biologia da Conservação*, ed. H.G. Bergallo, C.F.D. Rocha, M.A.S. Alves, and M.V. Sluys, 45–52. Rio de Janeiro: Universidade do Estado do Rio de Janeiro.

Nunes, D.M.F., A.L.B. Magalhães, A.A. Weber, R.Z. Gomes, F.T. Normando, K.B. Santiago, E. Rizzo, and N. Bazzoli. 2015. Influence of a large dam and importance of an undammed tributary on the reproductive ecology of the threatened fish matrinxã Brycon orthotaenia Günther, 1864 (Characiformes: Bryconidae) in southeastern Brazil. *Neotropical Ichthyology* 13: 317–324. https://doi.org/10.1590/1982-0224-20140084.

Ohara, W.M., L.J. de Queiroz, J. Zuanon, G. Torrente-Vilara, F.G. Vieira, and C.D.C. Doria. 2015. Fish collection of the Universidade Federal de Rondônia: its importance to the knowledge of Amazonian fish diversity. *Acta Scientiarum. Biological Sciences* 37: 251–258. https://doi.org/10.4025/actascibiolsci.v37i2.26920.

Olden, J.D., and R.J. Naiman. 2010. Incorporando regimes térmicos em avaliações de fluxos ambientais: modificando operações de barragens para restaurar a integridade do ecossistema de água doce. *Freshwater Biology* 55: 86–107.

Oliveira, A.G., M.T. Baumgartner, L.C. Gomes, R.M. Dias, and A.A. Agostinho. 2018. Long-term effects of flow regulation by dams simplify fish functional diversity. *Freshwater Biology* 63: 293–305. https://doi.org/10.1111/fwb.13064.

Patton, M.Q. 2001. *Qualitative research and evaluation methods*. London: Sage Publications.

Pavanelli, G.C., J.C. Eiras, and R. M. Takemoto. Doenças de peixes: profilaxia, diagnóstico e tratamento. Maringá: Ed. UEM, 2ª Ed., 305p., 2002.

Pelicice, F.M., V.M. Azevedo-Santos, J.R.S. Vitule, M.L. Orsi, D.P. Lima Junior, A.L.B. Magalhães, P.S. Pompeu, M. Petrere, et al. 2017. Neotropical freshwater fishes imperilled by unsustainable policies. *Fish and Fisheries* 18: 1119–1133. https://doi.org/10.1111/faf.12228.

Perkin, J., and K.B. Gido. 2012. Fragmentation alters stream fish community structure in dendritic ecological networks. *Ecological Applications* 22: 2176–2187. https://doi.org/10.1890/12-0318.1.

Pinto, M.D.S., C.R.C. Dória, and E.E. Marques. 2019. Alterações temporais sobre a estrutura funcional das assembleias de peixes durante onze anos de formação de um reservatório do médio rio Tocantins, Brasil. *Biota Amazônia* 9: 17–21. https://doi.org/10.18561/2179-5746/biotaamazonia.v9n1p17-21.

Preece, R.M., and H.A. Jones. 2002. The effect of Keepit Dam on the temperature regime of the Namoi River, Australia. *River Research and Applications* 18: 397–414. https://doi.org/10.1002/rra.686.

Queiroz, L.J., G. Torrente-vilara, W.M. Ohara, T.H.S. Pires, J. Zuanon, and C.R.C. Doria. 2013. Peixes do Rio Madeira, vol. 1,2,3 st ed. 1163 pp. São Paulo, Brazil: Dialeto.

Rainey S.J., and M.C.A. Rainey. 2016. Perspectivas ribeirinha sobre os impactos da construção de usinas hidrelétricas no rio Madeira em Rondônia. *Confins* 29. https://journals.openedition.org/confins/11621.

Ruffino, M., V.J. Isaac, and A. Milstein. 1998. Fisheries ecology in the Lower Amazon: a typical artisanal practice in the tropics. *Ecotropica* 4: 99–114.

Santos, R.E., R.M. Pinto-Coelho, R. Fonseca, N.R. Simões, and F.B. Zanchi. 2018. The decline of fisheries on the Madeira River, Brazil: The high cost of the hydroelectric dams in the Amazon Basin. *Fisheries Management and Ecology* 25: 380–391. https://doi.org/10.1111/fme.12305.

Silva, F.M., and E.A. Paula. 2018. Usinas hidrelétricas sob os véus da "sustentabilidade": o pescador artesanal da Ponta do Abunã e a Usina Hidrelétrica de Jirau, em Rondônia. *Novos Cadernos NAEA* 21: 159–178. https://doi.org/10.5801/ncn.v21i1.3497.

Silvano, R.A.M., and A. Begossi. 2002. Ethnoichthyology and fish conservation in the Piracicaba River (Brazil). *Journal of Ethnobiology* 22: 285–306.

Silvano, R.A.M., and A. Begossi. 2009. What do people think about pollution? Contributions of human ecology to the study of river pollution with a focus on Brazil. In *River pollution research progress*, 1st ed, ed. M.N. Gallo and M.H. Ferrari, 283–296. New York: Nova Publishers Inc.

Silvano, R.A.M., A.L. Silva, M. Ceroni, and A. Begossi. 2008. Contributions of ethnobiology to the conservation of tropical

rivers and streams. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18: 241–260. https://doi.org/10.1002/aqc.825.
Silvano, R.A.M., and J. Valbo-Jørgensen. 2008. Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management. *Environment, Development and Sustainability* 10: 657–675. https://doi.org/10.1007/s10668-008-9149-0.
Soares, M.G.M., E.L. Costa, F.K. Siqueira-Souza, H.D.B. Anjos, K.C. Yamamoto, and C.E. Freitas. 2007. *Peixes de lagos do Médio rio Solimões*, 176. Manaus: EDUA.
Souza, L.A., C. Edwar, D.C. Freitas, and R.G. Costa. 2015. relação entre guildas de peixes, ambientes e petrechos de pesca baseado no conhecimento tradicional de pescadores da Amazônia central. *Boletim do Instituto de Pesca* 41: 633–644.
Stephenson, J.R., A.J. Gingerich, R.S. Brown, B.D. Pflugrath, Z. Deng, T.J. Carlson, M.J. Langeslay, M.L. Ahmann, et al. 2010. Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine passage using a mobile aquatic barotrauma laboratory. *Fisheries Research* 106: 271–278. https://doi.org/10.1016/j.fishres.2010.08.006.
Timpe, K., and D. Kaplan. 2017. The changing hydrology of a dammed Amazon. *Science* 11: 1–13. https://doi.org/10.1126/sciadv.1700611.
Tundisi, J.G., J. Goldemberg, T. Matsumura-Tundisi, and A.C.F. Saraiva. 2014. How many more dams in the Amazon. *Energy Policy* 74: 703–708. https://doi.org/10.1016/j.enpol.2014.07.013.
Tundisi, J.G. and Matsumura-Tundisi, T. (2006). Parecer Técnico sobre Limnologia, Qualidade das Águas e Sedimentologia, Part B. Vol. 1, Parecer 4, In: Pareceres Técnicos dos Especialistas Setoriais—Aspectos Físicos/Bióticos. Relatório de Análise do Conteúdo dos Estudos de Impacto Ambiental (EIA) e do Relatório de Impacto Ambiental (RIMA) dos Aproveitamentos Hidrelétricos de Santo Antônio e Jirau no, Rio Madeira, Estado de Rondônia. 1–50 pp, Porto Velho, Rondônia: Ministério Público do Estado de Rondônia. 2 Vols.
Vazzoler, A.E.A.M. 1996. *Biologia da reprodução de peixes teleósteos: teoria e prática*. Maringá: Eduem.
Vismara, M.R., E. Benedito-Cecilio, A.C. Esper, and A. De Faria. 2004. Efeito da maturação gonadal sobre o conteúdo calórico e condição geral de peixes da planície de inundação do alto rio Paraná. Acta Scientiarum. *Biological Sciences Maringá* 26: 189–199. https://doi.org/10.4025/actascibiolsci.v26i2.1635.
Welcomme, R.L. and Halls, A.S. 2004. Dependence of tropical river fisheries on flow. In: Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries. Volume II. RAP Publication 2004/16, 267–283 pp. Bangkok: Food and Agriculture Organization of the United Nations (FAO).
Wetzel R.G. Limnology. 2001. 3. ed. Philadelphia, W.B. Sandres, 743 p.
Winemiller, K.O., P.B. McIntyre, L. Castello, E. Fluet-Chouinard, T. Giarrizzo, S. Nam, I.G. Baird, W. Darwall, et al. 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science* 351: 128–129. https://doi.org/10.1126/science.aac7082.
Zahar, Y., A. Ghorbel, and J. Albergel. 2008. Impacts of large dams on downstream flow conditions of rivers: Aggradation and reduction of the Medjerda channel capacity downstream of the Sidi Salem dam (Tunisia). *Journal of Hydrology* 351: 318–330. https://doi.org/10.1016/j.jhydrol.2007.12.019.

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