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PERSPECTIVE

The invisibility of fisheries in the process of hydropower development across the Amazon

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Abstract We analyze the invisibility of fisheries and inadequacy of fishers' participation in the process of hydropower development in the Amazon, focusing on gaps between legally mandated and actual outcomes. Using Ostrom's institutional design principles for assessing common-pool resource management, we selected five case studies from Brazilian Amazonian watersheds to conduct an exploratory comparative case-study analysis. We identify similar problems across basins, including deficiencies in the dam licensing process; critical data gaps; inadequate stakeholder participation; violation of human rights; neglect of fishers' knowledge; lack of organization and representation by fishers' groups; and lack of governmental structure and capacity to manage dam construction activities or support fishers after dam construction. Fishers have generally been marginalized or excluded from decision-making regarding planning, construction, mitigation, compensation, and monitoring of the social–ecological impacts of hydroelectric dams. Addressing these deficiencies will require concerted investments and efforts by dam developers, government agencies and civil society, and the promotion of inter-sectorial dialogue and cross-scale participatory planning and decision-making that includes fishers and their associations.

Keywords Amazon · Dams · Environmental policy · Fishers · Freshwater fisheries · Governance · Hydropower · Inland tropical fisheries · Licensing

INTRODUCTION

Inland fisheries in the tropics support local, regional, and national socio-economic activity and help to sustain traditional livelihoods. Despite their large contribution (> 40%) to global fish production, protein consumption, and economic output (Isaac et al. 2015; Cooke et al. 2016; Lynch et al. 2016), these fisheries have been largely "undervalued and overlooked" (Cooke et al. 2016) in policies and management programs. Their sustainability is threatened by overfishing (Petrere et al. 2004), climate change (Freitas et al. 2013), and the implementation of large infrastructural development projects (e.g., roads, piers, hydroways, mining, oil extraction, and hydroelectric dams) (Castello and Macedo 2016; Winemiller et al. 2016). The association between ineffective inland fisheries management and subsequent fisheries vulnerability is exemplified in the Amazon basin, which accounts for ~ 20% of the world's freshwater fish diversity (13 000 species) (Lévêque et al. 2008). The Brazilian Amazon also supports ~ 330 000 artisanal fishers (MAPA 2016), whose livelihoods and well-being are closely tied to fisheries systems, biodiversity, and to the environmental services provided by Amazonian ecosystems (Alho et al. 2012; Isaac et al. 2016). However, current and planned infrastructural projects are causing irreversible transformations to the region's freshwater ecosystems and associated fisheries systems (Alho et al. 2015; Castello and Macedo 2016).

Among infrastructural projects, the construction of hydroelectric dams has widely recognized impacts on riverine geomorphology, thermal regime, flow regime, and other physical–chemical and biological characteristics that shape local habitat and drive fish diversity, composition, distribution, and abundance (Agostinho et al. 2008). Globally, the "boom" in tropical hydropower expansion threatens one-third of the world's freshwater fish species due to projected diversity losses in the megadiverse Amazon, Congo, and Mekong basins alone (Winemiller et al. 2016). Beyond species extinctions and extirpations,

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dam implementation impacts fishers' livelihoods and well-being through geographical and occupational displacement, decreases in income and lack of alternative employment, threats to food security and food quality, and changes in the physical access to fisheries resources or market demand (WCD 2000; Marmulla 2001). The spatial and temporal scales of these changes can lead to significant cross-scale socio-economic impacts related to changes in fisheries-derived income and social reorganization (Marmulla 2001).

In Brazil, the Amazon region has become the last hydroelectric frontier due to the exhaustion of hydropower potential in other regions. There are currently 154 large hydroelectric dams (> 30 Megawatt, MW) in operation in the Amazon basin, with 14 under construction and 221 planned to be completed in coming decades (Castello and Macedo 2016). While some social–ecological impacts of dams represent unavoidable trade-offs, many impacts are exacerbated by gaps or inconsistencies in the governance and decision-making process. For example, a lack of adequate pre-dam information to support planning and decision-making, along with poor participation and feedback from stakeholders in the licensing process, limits a full understanding of the trade-offs by impacted parties (Athayde et al. 2016; Kirchherr et al. 2016). Another critical gap is the lack of reliable datasets to perform fisheries stock assessments and provide a baseline for management and governance strategies (Isaac et al. 1998; Batista et al. 2012). Finally, management strategies for Amazonian fisheries have largely ignored local and indigenous fishers' knowledge, which may be an important component of the assessment and management of fisheries, especially in data-poor tropical fisheries (Doria et al. 2014; Villas-Bôas et al. 2015). While there are many national[1] and international policies and laws requiring the participation of affected communities in the environmental licensing process (ILO 1989, WCD 2000; Marmulla 2001), in general, these policies have been ignored, leaving local communities disempowered in the decision-making process (Rezende 2009; Jaichand and Sampaio 2013; Athayde 2014).

Fisheries are common-property resource systems regulated by formal and informal rules across a variety of actors and scales (Basurto et al. 2013). Amazonian fisheries management is governed by both fishers' informal community rules as well as those designated by government authorities. Based on empirical work with a series of common-property resource systems (e.g., water, fisheries, and communally managed forests), Ostrom (1990, 2002) identified a set of design principles that characterize the configuration of rules used by actors to collectively use and/or manage the resource. Design principles are defined as an element or condition "that helps to account for the success of these organizations in sustaining the [common-pool resource] and gaining the compliance of generation after generation of appropriators to the rules in use" (Ostrom 2002). Application of Ostrom's (1990) eight design principles to Amazonian fisheries would include the following: 1. Clearly defined fisheries systems boundaries; 2. Congruence, which includes cost–benefit effectiveness and appropriation rules restricting time, place, technology, and/or quantity of fish resources based on local conditions; 3. Collective-choice arrangements that ensure that a majority of individuals affected by fisheries operational rules (i.e., subsistence fishers and indigenous groups) can participate in modifying them; 4. Monitoring methods and systems that ensure accountability of monitors and availability of data to the appropriators or resource users; 5. Graduated sanctions for appropriators who violate operational rules (from other users, government organizations, or both); 6. Access to low-cost, local conflict-resolution mechanisms; 7. Recognition of the rights of appropriators to organize and devise their own organizations, which are not challenged by governmental authorities; and 8. Nested organization of fisheries governance activities (e.g., local vs. state vs. federal; governmental vs. collective vs. private enterprises).

In this paper, we address the invisibility of fisheries and inadequacy of fishers' participation in the hydropower development process in the Amazon, focusing on gaps between legally mandated and actual outcomes. We adopt Ostrom's design principles to analyze how rule setting and compliance, as well as power relations among fishermen, dam developers, and government agencies, affect decision-making around data collection, negotiation, mitigation, and compensation procedures during the different phases of hydroelectric dam construction in the Amazon (Ostrom 1990; McCormick 2007; Martínez and Castillo 2016). We selected five case studies across major Amazonian watersheds where hydroelectric dams have been built from the 1970s to the present, and for which relevant data were available. For each case study, we collected information from governmental agencies, official environmental licensing reports, and other publications, and we use this information to describe fisheries-relevant aspects of each dam's implementation. Next, we discuss common problems related to fisheries governance across case studies and throughout the dam project cycle. We conclude with lessons learned, insights, and recommendations to improve public policies and the overall decision-making process.

[1] Brazilian bills and resolutions: Instrução Normativa IBAMA N°146, 2007; Portaria IBAMA N°10, 200.

Different dams, same problems: Case studies from Amazonian watersheds

Our methodological approach is based on comparative case-study qualitative analysis (Yin 2009). We selected five case studies across diverse Amazonian watersheds, based on the following criteria: (a) authors' research experience; (b) temporal diversity (i.e., a chronological series) to understand if and how decision-making processes and fishers' participation have changed over time; (c) spatial diversity (i.e., across watersheds) to identify context-specific processes versus overall patterns; and (d) available information. We analyzed each case study based on our own experience and published information when available. We identified both unique and common elements across case studies in relation to Ostrom's design principles for successful governance of common-property resources (Ostrom 2002). Finally, we organized the results to illustrate the explanation-building approach proposed by Yin (2009), in which each case adds additional insight to the main topics considered in this synthesis.

We present case studies from dams built on the Jamari, Uatumã, Tocantins, Madeira, and Xingu Rivers from 1988 to 2016 (Fig. 1). Table 1 summarizes available information for each case study. While these case studies span nearly three decades of ostensible technological, environmental, and social advancement, we found that they share consistent shortcomings in regard to understanding, regulating, protecting, and mitigating damages to fisheries systems.

The Samuel dam in the Jamari River was built during the Brazilian military dictatorship, prior to the implementation of policies regulating environmental licensing in Brazil.[2] The reservoir was closed in 1988, flooding 560 km^2. The dam changed the flow of the Jamari River by reducing its connectivity with the Madeira River floodplain, resulting in decreased fisheries productivity, impacts on indigenous and traditional livelihoods, and other socio-economic impacts (Santos 1995). About 650 riverine families were relocated and have yet to be financially compensated.[3] Fish monitoring programs were short-lived (< 2 years) and focused only on direct impacts in the reservoir area, resulting in the loss of information on the impacts on both the fish resources and the socio-economic variables qualifying fishers' livelihoods, that could otherwise have provided important input for future projects (Santos 1995).

The Balbina dam, built on the Uatumã river in 1989, has been considered an environmental disaster because of its low-energy generation potential relative to its enormous flooded area (Kahn et al. 2014) and impact to hydrologic regime (Timpe and Kaplan 2017). Before impoundment of the Uatumã river, human settlements and riverine activities were dominated by the Waimiri-Atroari indigenous group, who practiced subsistence fishing. After dam construction, a local commercial fishery developed, stimulated by an increase in the abundance of the peacock bass (*Cichla* spp.), a species well adapted to the new environmental conditions (Santos and Oliveira 1999). Consequently, commercial and recreational fishers from other parts of the basin migrated to the Balbina reservoir, competing with local subsistence fishers and indigenous groups and creating conflicts, which were neglected by federal and state management agencies (Freitas et al. 2006).

The Lajeado dam was built on the Tocantins River in 2001, displacing 6483 inhabitants according to official records (THEMAG 1996). Approximately 175 fishers and more than 1500 residents of indigenous areas were not formally acknowledged in the environmental impact assessment (EIA) required in the licensing process (Lima et al. 2015). These fishers were therefore not eligible for compensation, despite substantial dam-related impacts to their livelihoods (THEMAG 1996).

The construction of the Santo Antônio dam in the Madeira River was completed in 2011, leading to the resettlement of more than 1600 people (LEME 2005). When the environmental impact assessment was conducted, no commercial fishers were considered to be impacted by the project, despite the fact that 1925 commercial fishers lived in the nearby city of Porto Velho at that time (Doria et al. 2012). Five years after the construction, the number of self-claimed "fishers" doubled, and currently ~ 6000 fishers have filed lawsuits to obtain compensation for dam-induced losses (president of the Porto Velho Fishermen Association, pers. comm.). This number likely includes riverine communities who were not included in the group of fishers and who, despite being highly dependent on fish, were not originally considered to be impacted by the dams. It is estimated that about 5000 riverine families and 3000 indigenous people and inhabitants of protected areas were impacted by the Santo Antônio dam[4] but were "forgotten" in the process of mitigation and compensation.

Finally, the construction of the Belo Monte dam in the Xingu River was finalized in 2016, resettling more than 27 100 people.[5] Belo Monte is an emblematic case due to its size, the biodiversity and vulnerability of the freshwater system, and the diversity of social groups whose livelihoods depend on the river. Impact assessment studies

[2] Brazilian bill: CONAMA n° 1, de 23 de janeiro de 1986. Pages 2548–2549.

[3] http://www.mabnacional.org.br/category/tema/samuel.

[4] http://www.mabnacional.org.br/amazonia/santo_antonio_e_jirau/sobre_a_barragem_santo-antonio.

[5] Data from Brazilian National Institute for the Environment—IBAMA's website and technical reports related to the Belo Monte dam licensing process—http://www.licenciamento.ibama.gov.br/hidreletricas/Belomonte/.

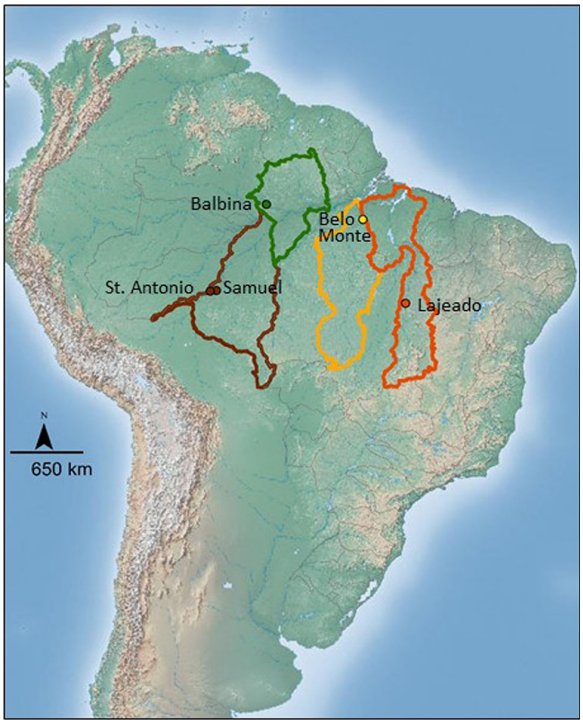

Fig. 1 Map of the Amazon basin, with the locations of the Madeira (*brown*), Uatuma (*green*), Xingu (*yellow*) and Tocantins (*orange*) watersheds, and showing the case studies discussed in this paper

developed through the licensing process were considered to be insufficient regarding potential social–environmental impacts (Hernández and Magalhães 2011). Despite the existence of approximately 3000 fishers and an average fish production of 1000 tons/year (Isaac et al. 2015), collected data were not sufficient to quantify social and economic impacts on fishers' livelihoods. The socio-economic component of the EIA, which was not integrated with the data on fisheries landings, focused only on fishers living around the area to be flooded by the reservoir, ignoring more than half of registered fishers (Villas-Bôas et al. 2015).

Deficiencies in fisheries governance during the implementation of hydroelectric dams

Brazil has extensive legislation and institutional arrangements that regulate evaluation and monitoring of the social–environmental impacts of large infrastructure projects (Fiori 2005; Ferraz 2012). Environmental licensing mechanisms, which have been formulated as tools for conflict mediation, seek to guide a consistent and documented dialogue between sectoral organizations and civil society (Fiori 2005). In practice, however, these mechanisms often exist only on paper and are considered no more than a bureaucratic burden. Many of the shortcomings in the environmental licensing process stem from insufficient dialogue between stakeholders, excessive bureaucracy in the exchange of information, ideological and disparate interpretations of the study results, and widespread corruption (Fearnside 2016). Unfortunately, energy planning and execution in Brazil have often been controlled by political interests or power structures, which do not necessarily abide to existing guidelines, legal frameworks, and policies, severely reducing government agencies' management capacity (Fonseca 2014).

Since 2007, policies for environmental licensing of large hydroelectric plants in Brazil (> 30 MW) require three stages of technical evaluation: (1) the "Previous License" stage, which includes evaluation of project feasibility and the execution of the EIA (required for approval by the

Table 1 Compilation of existing data on fish species and estimated number of resource users affected by selected hydropower plants in five watersheds in the Brazilian Amazon

Basin	Hydroelectric dam	Year closed	Fish species	Number of displaced people (official)	Number of people in indigenous and protected areas	Number of people in riverine communities	Number of fishers
Uatumã	Balbina	1989	216[a]	1	1939[a]	3000	120
Jamari	Samuel	1988	122[b]	1290[c]	*NA*	*NA*	*NA*
Tocantins	Lajeado	2002	343[d]	6483[e]	3017[f]	131 316[e]	175 [g]
Madeira	Santo Antônio	2011	1057[h]	1645[c]	3009	50 563	1354[i]
Xingu	Belo Monte	2016	408[j]	27 100[j]	19 692[j]	320 145 [l]	2500[j]

NA Not available

Sources We used the best information available for these cases. Additional references on these and other dammed Amazonian systems can be found in the Amazon Dams Network website on: www.amazondamsnetwork.org

[a] Programa Waimiri-Atroari (http://www.waimiriatroari.org.br); [b] Santos (1995); [c] Observatório de Barragens (www.observabarragem.ippur.ufrj.br); [d] Lucinda et al. (2007); [e] THEMAG (1996); [f] FUNASA (2010); [g] Lima et al. (2015); [h] Ohara et al. (2015); [i] Doria et al. (2012); [j] IBAMA report http://www.licenciamento.ibama.gov.br/hidreletricas/Belomonte/; [l] Villas-Bôas (2015)

designated governmental agencies); (2) the "Installation License" stage, which allows construction to begin, pending descriptions of mitigation and compensation procedures and conditions (including details of a monitoring plan for social and environmental impacts, which are synthesized in a "Basic Environmental Plan" document, known as PBA); and (3) the "Operation License," which allows the project to begin and must be renewed every 3–5 years. Several inventories and environmental impact monitoring studies, including actions for mitigation and/or compensation of impacts are carried out during these three stages, guided by a "Terms of Reference" document issued by the designated government agencies.

Critically, Brazilian policies for licensing hydropower dams and other infrastructure projects are threatened by constitutional amendments currently under consideration by the Senate. The main constitutional amendment proposing this legislative reform institutes a "fast-track" process for the approval of mining, hydroelectric. and other projects, bypassing the mandatory public hearings and current three-step licensing process (Athayde et al. 2016; Fearnside 2016). If approved, these policies have the potential to increase the risk of environmental disasters, intensify the violation of the rights of affected populations, exacerbate social and environmental conflicts, and add to legal uncertainty. Within this policy context, and based on Ostrom's design principles and on the case studies described above, we identified five core deficiencies in fisheries governance and management related to hydroelectric dam construction in Brazil.

LACK OF TRANSPARENCY AND INDEPENDENCE FOR CONTRACTING AND CONDUCTING ENVIRONMENTAL IMPACT STUDIES

The first criticism of the current licensing system is that all actions that comprise the three licensing steps described above are financed and executed by the companies who will manage the hydroelectric plant or its contractors. For all the case studies, the research teams that work to collect baseline monitoring data are selected by dam-building consortia based on lowest cost calculation, with little control by regulating agencies. This situation leads to conflicts of interest, since it is in the financial interest of the consortia to employ their considerable economic and political power to make whatever arrangements are necessary to obtain the licenses as quickly as possible. Another deficiency relates to transparency in the process of making reliable information and data available to interested parties and to society. Since data and information are controlled by dam consortia, they can be easily manipulated or hidden (Fearnside 2016), limiting outside parties' ability to understand impacts and risks and precluding informed participation of affected social groups in decision-making. In relation to Ostrom's (1990) design principles, a lack of independent assessment and monitoring of fisheries systems fails to meet principles 1 and 2; without transparent and accessible data, it is not clear whether fisheries' boundaries reflect local users' geographical patterns of resource use, consider important cross-scale social–ecological interactions, or sufficiently take into account appropriation rules and context-specific conditions.

DATA GAPS

Basin-wide freshwater fish conservation requires reliable data and proper monitoring of fish stocks, ecosystem dynamics, and social–environmental parameters (Lorenzen et al. 2016). Globally, the lack of fish data and the absence of fisheries monitoring programs have harmed inland fisheries sustainability and often resulted in management strategies based on non-existent (or incomplete) scientific data (Beard et al. 2011). In the case of hydropower projects, lack of sufficient and reliable data on fisheries, coupled with limited stakeholder participation and interinstitutional coordination, has led to errors in estimates of social–ecological impacts. This problem is amplified in biodiversity hotspots such as the Amazon basin, where fisheries data are scarce or unavailable to support decision-making processes. Critically, among the estimated 2500 fish species described for this region, only a small number have been studied, and information on species' biological and ecological characteristics are severely lacking (Junk and Soares 2001).

For the five case studies presented in this analysis, estimation of species richness both before and during the environmental impact assessment (Table 1) was generally based on small sampling efforts. Consequently, differences in documented species richness may be attributed to differences in the intensity of sampling efforts (e.g., Winemiller et al. 2016) and likely underrepresent richness (Alho et al. 2015). It is generally accepted that more intense sampling efforts yield higher estimates of fish richness (for the Madeira basin, see Ohara et al. 2015). Additionally, the composition and abundance of fish stocks, along with the contribution of fisheries to livelihoods and local economies, are thought to be largely underestimated for the Brazilian Amazon (Isaac et al. 1998; Escobar 2015). Given these challenges, data available from EIAs for hydropower projects that should inform decision-making, mitigation, and compensation measures are usually inadequate. Similarly, incorrect estimates on the number of fishers may be caused by deficiencies in the scope of data collection, shortcomings in sampling methods or effort, and data

mismanagement by designated authorities (Ferraz 2012). This context leads to uncertainty and inconsistencies in the definition and monitoring of formal rules (fisheries policies) by government authorities, which fail to achieve Ostrom's principles 2 and 4 (congruence and monitoring).

Unfortunately, reliable data on Amazonian fisheries are currently unavailable or incomplete, both in areas potentially affected by dams as well as in other regions, due to a lack of financial investment to implement research and data management. The most recent basin-wide survey of fisheries production in the Brazilian Amazon was conducted in 2007 (Batista et al. 2012), and the few datasets that are available are outdated or of a limited spatial scale. The responsibility for fish and fisheries data collection is shared across different organizations, including the Ministry of Agriculture and Fisheries, the Brazilian Institute of Geography and Statistics, the Federal Agency for Indigenous Affairs (FUNAI), various federal and state environmental agencies, and even local fishers' social organizations and others listed in Table 1.

Estimates of the human population directly affected by hydropower plants, and thus entitled to receive compensation benefits, generally focuses on those who will be displaced due to reservoir flooding. This approach severely underestimates the population of affected fishers, since it does not include people living in downstream areas, who will have their livelihoods altered by river impoundment and hydrological changes. The contrast between official estimates of dam-displaced people and independent analyses of the number of affected fishers and people living in protected areas, indigenous lands, and riverine communities is highlighted in Table 1. Results from these case studies are in concordance with large differences between official and independent counts of "affected" people found by Martínez and Castillo (2016) in their review of 30 Latin American infrastructure development projects, highlighting a lack of clearly defined boundaries for fisheries system affected by dams, as established by Ostrom's principle 1.

Compiling the few available data on the number and diversity of households and social groups (e.g., riverine communities and indigenous peoples) involved in fisheries affected by hydropower projects in the Amazon remains a challenge. In Brazil, this paucity of reliable data on fishers is worsened by weak and inconsistent governance approaches to fisheries management. While some fishers are neglected in the process of dam implementation, other so-called "fishers" can access government financial compensations inappropriately. A good example is the observed increase in the number of fishers registered to receive financial benefits from the government during the closure season ("defeso"), when fishing is prohibited. Recent reviews have shown a 250% increase in the number of fishers receiving closed season payments from 2003 to 2014 (Campos and Chaves 2014). These authors found discrepancies in the numbers of fishers and closed season insurance beneficiaries, pointing to illegalities and irregularities in the program, which compromises its social and environmental objectives.

Another critical problem weakening the availability and reliability of fisheries data is the lack of research protocols and guidelines to inform data collection and monitoring during the stages of dam implementation. Each term of reference document is different, and the government agencies responsible for approving such terms lack sufficient personnel and technical expertise to critically analyze them. Moreover, sampling and analysis protocols generally are not modified to meet local realities or necessity. For example, developing countries often follow European or North American management models (Marmulla 2001), which are not adequate to address the enormous social and biological diversity of the Amazon basin. While federal guidelines in Brazil prescribe data collection methods for specific target organisms, they are insufficient to inform the goal of biodiversity conservation (Ferraz 2012). Additionally, these guidelines do not include interactions among biological and socio-economic factors to inform integrated management and mitigation procedures. In short, both national and international guidelines need to be better adapted to local realities (Marmulla 2001).

Finally, current systems for data management, data repositories, and data access by the public are deficient and inadequate. In all the studied cases, researchers and consultants involved in the licensing process have generated an impressive number of reports; however, many are of questionable scientific rigor, written in technical language difficult for local fishers to comprehend, and include primary data that are not properly stored or easily accessible to the public. Even if these documents are placed on the internet by environmental agencies, it is unlikely that residents, fishermen, and other interested parties will be able to read this exhaustive material. Summaries presented to the public during public hearings are often written in technical jargon and do not contain the necessary details to allow the population to assess relevant impacts and trade-offs.

STAKEHOLDERS' PARTICIPATION AND CONSIDERATION OF LOCAL KNOWLEDGE

Globally, inland fishers are often excluded from or ignored by regional and global policy discussions about integrated natural resource management and habitat alteration by large projects such as dams (Cooke et al. 2016) (Fig. 2). The exclusion of these actors engenders conflicts between companies, government, and communities, exacerbating

Fig. 2 Artisanal fishery practiced in the Teotônio falls on the Madeira River, Porto Velho, Brazil. These waterfalls were flooded by the Santo Antônio hydroelectric dam in 2011, and this fishery system no longer exists. Courtesy: Gislene Torrente-Vilara, photo taken in 2009

impacts and social discontent (Araújo and Moret 2016; Martínez and Castillo 2016). In Brazil, traditional communities, including artisanal fishers, indigenous peoples, and other riverine communities are recognized as cultural minorities with special rights by national legislation.[6] National and international policies include public and specific consultation processes for evaluation of EIAs and directing mitigation and compensation procedures when necessary. For indigenous peoples, the 169 Convention of the International Labor Organization (ILO), ratified by Brazil, requires free, prior, and informed consent by indigenous communities for projects that affect their well-being (ILO 1989). However, consultation processes are often superficial, cosmetic, or non-existent, resulting in the violation of human rights (Martínez and Castillo 2016). This situation is contrary to Ostrom's principle 7 (minimum recognition of rights to fishers to organize and devise their own organizations); as these organizations may be ignored and/or neglected by dam developers and government organizations during the decision-making process (Ostrom 1990, 2002).

For example, public consultations organized for the Madeira and Xingu river dams did not reach their objectives, which in theory should have considered affected peoples' needs and demands. In reality, these meetings became political forums with weak stakeholder participation (Hernández and Magalhães 2011). To optimize costs, the meetings included a vast number of people, limiting effective and complete public participation. Fishermen and other local social groups who have difficulties understanding technical jargon and publicly expressing their opinion, shared the stage with local politicians, who were seeking popularity and voters' approval. Often, these meetings were raucous and unproductive, lacked in-depth analyses of project viability, and failed to address mitigation and compensation procedures and alternatives.

Another critical gap in the planning, construction, and monitoring stages of dam implementation is the neglect of fishers' knowledge, which can be used to improve fisheries management (Berkes and Folke 2002; Doria et al. 2014). Indigenous and artisanal fishers hold experiential knowledge of species occurrences and associated ecological parameters, natural uses of native flora and fauna, sustainable harvest levels, ecological interactions, and ecosystem dynamics (Berkes and Folke 2002). The incorporation of this

[6] Presidential Decree 6040 (Brasil 2007).

information into EIAs and monitoring programs can inform mitigation and management procedures to enhance fishermen's ability to adapt to the new natural conditions imposed by river impoundment. Local knowledge is often not considered in EIAs and PBAs, which focus primarily on socio-economic parameters. For instance, indigenous knowledge was not considered in the development of mitigation plans for the loss of fish diversity for the Belo Monte dam in the Xingu River, despite the long-term experiential knowledge that these fishers have about fish diversity, ecology, and geographic distribution in relation to hydrologic regime and flow variation (Villas-Bôas et al. 2015). In many regions, traditional knowledge held by fishers and traditional people can help to fill crucial knowledge gaps needed to foster biodiversity conservation, but this source of information is rarely incorporated into environmental assessments or management (Doria et al. 2014).

DEFICIENCIES IN FISHERS' ORGANIZATION AND REPRESENTATION

The task of establishing procedures for fisheries management falls under State jurisdiction; however, there are other non-governmental actors who hold a key role in the success or failure of these measures. Working with these stakeholders is a prerequisite for effectively planning and managing fisheries in ways that are compatible with the socio-cultural and environmental requirements of the Amazonian region (Ruffino 2005). In Brazil, fishermen are frequently subject to relations of dependence and clientelism with diverse organizations such as the market, the fishers' associations, and even with some governmental agencies that fail to promote effective participation (Haimovici et al. 2014). While fishers' federations, colonies, and associations represent a large number of workers, they are largely disorganized and have little influence in the formulation and implementation of policies, contradicting Ostrom's principle 3 describing robust collective-choice arrangements. Instead of joining forces to strengthen their role, these organizations are becoming increasingly divided and diffuse due to internal disputes and conflicts of interests (Ruffino 2005). For example, in the area of influence of the Santo Antônio dam, some fishermen are represented by the leadership of the fishing association, others by the fishermen's union (sindicato), others by the fishermen's federation, others by community leaders, and still others do not feel represented by any of these groups. Moreover, fishers groups are sometimes represented by leaders who lack legitimacy, or by non-governmental organizations whose interests do not necessarily align with theirs (Ramalho 2014).

The absence of strong, legitimate organizations representing fishermen in the Amazon complicates the dialogue between organizations and those affected by the projects (Ruffino 2005). This problem is reflected in the loose accounting (by fishers' associations) of those involved in fishing and other routine operations linked to fishing (e.g., fish processing plants and sales). On the other hand, past experiences show that a good articulation of the fishermen's social movement forced the Tucuruí dam company to promote social and environmental compensatory actions and technical assistance to strengthen cooperative networks and community associations (Cardoso et al. 2005); improved planning and fisheries management in other basins affected by dams will require an equally strong performance of fishers' organizations.

Despite the general feeling of "failures" captured by the stories compiled here, we recognize important advances in public participation and power negotiation in the decision-making around Amazonian dams, including the strengthening of social movements, the development of coalitions across groups of social actors (such as the "Xingu alive forever movement"), the role played by the public prosecutors, and the Brazilian Public Ministry in defense of the rights of social minorities (MPF), as well as the articulation of strategic alliances and partnerships between local groups, national society, and even international forums (especially in the case of Belo Monte) (Forline and Assis 2004; McCormick 2006). Regarding indigenous social movements, the role of local and extra-regional alliances in promoting enhanced negotiation, compensation, and mitigation processes cannot be ignored. In the case of the Belo Monte dam, for instance, resources and knowledge provided by alliances with NGOs, universities and participation in local, regional, and international forums have equipped the Juruna people to develop their own consultation protocol, and to better negotiate and dispute inadequate compensation projects (Laufer et al. 2017; Povo Juruna da TI Paquiçamba 2017). By engaging with these cross-scalar processes and networks, communities have been better prepared to self-organize and negotiate compensation and mitigation plans, including, in the case of the Apinajé people of the Tocantins watershed, having their local association being responsible for executing the Basic Environmental Plan (PBA), which encompasses diverse compensation and mitigation sub-programs (Laufer et al. 2017).

LACK OF GOVERNMENTAL STRUCTURE AND CAPACITY TO MANAGE DAM CONSTRUCTION ACTIVITIES AND SUPPORT FISHERS AFTER DAM CONSTRUCTION

Agencies that manage the dam licensing process are not adequately empowered to inspect, monitor, and demand compliance from dam-building consortia. Lack of

Table 2 Core issues and recommendations for improvement of fisheries governance affected by hydropower implementation across the Amazonian region

Issues	Recommendations
1. Lack of transparency and independence for conducting environmental impact assessments (EIAs) and basic environmental plans (PBAs) by dam consortia	Promote government control and independent assessments of strategic studies and data. Dam developers should transfer data and financial resources to build capacity of local academic and research institutions and government to properly manage studies
	Promote the dissemination, publication, and discussion of data produced from EIAs and monitoring programs (developed under PBAs). Synthesize and publicize existing data in different formats, making them available to diverse stakeholders
2. Data gaps	Promote the implementation of independent and participatory monitoring programs of subsistence and commercial fisheries (yield, effort, and ecology and biology of fish) across Amazonian basins by state agencies and research entities prior to dam construction
	Improve research design to map fishers and define actors who depend on the fishery activity and need to be included in consultation, planning, compensation and mitigation processes. Develop databases containing sufficient socio-economic information to support monitoring and mitigation strategies
3. Stakeholder participation	Fishers' organizations should hold the right to be represented in any discussion or decision-making forum related to the fishing activity. The government should guarantee such participation, considering: (i) the "weight" and the size of each of these organizations; (ii) whether the organization legitimately represents the interests of the sector; and (iii) the extent to which the organization reflects the interests of the group it represents (Ruffino 2005)
- Public hearings with little stakeholder participation	Enable and expand the participation of actors in public hearings through the creation of smaller local forums that facilitate empowerment and effective participation of fishers prior to the official hearings
- Lack of discussion forums about the fishing industry, including information on changes and impacts, as well as mitigation procedures and alternatives	Promote fisheries forums for sectorial organization before and after hydropower construction. Implement collaborative and participatory planning and community-based fisheries management. Form multi-stakeholder committees composed of civil society and government representatives, in collaboration with researchers and relevant actors, to propose and implement policies towards improved social learning and decision-making
	Expand the participation of fishers and integration of local and indigenous knowledge throughout the project cycle, from project elaboration to discussion of results
4. Deficiencies in fishers' organization and representation	Develop local policies to strengthen fishers' social organization during the licensing process to ensure their participation in the process.
5. Lack of governmental structure and capacity to manage dam construction activities and support fishers after dam construction	Improve government capacity and public policies directed to manage the process of planning, construction, and operation of dams. Improve existing guidance and criteria to consider local realities
	Strengthen government entities responsible for management of the fisheries sector, guaranteeing support from research institutions as needed, as well as improving technical capacity of management groups or committees
	Implement the existing safeguards and fiscal mechanisms for riverine people or fishermen to mitigate dam impacts on fisheries and strengthen the ability of local governance to do so. Example: Financial Compensation for Utilization of Water Resources for Electric Generation (CF), "Bolsa verde"
- Insufficient or inadequate guidelines to generate effective information to guide managing and mitigation processes	Improve the guidance, criteria, and research design for EIAs and PBAs with consideration of local conditions. Define guidelines for conducting research through the different phases of dam implementation, with clear rules for management and monitoring

personnel (both in numbers and qualifications) results in deficiencies in the analyses of environmental assessment documents during the licensing process. In addition, economic and political pressure to approve large infrastructure projects is strong, compromising the neutrality and independence of the decision-making process (Zhouri and Oliveira 2007; Fearnside 2015). This lack of governmental capacity and coordination translates into a lack of support for stakeholder groups that seek to negotiate with dam-building consortia and hold them accountable to the licensing and mitigation process, thereby undermining Ostrom's design principle 4 (accountability of monitors or monitoring system to appropriators or resource users; Ostrom 1990). The resulting situation is chaotic; agencies are paralyzed to regulate, inspect, and demand compliance from the companies, since they are not empowered in the process and do not have information on the magnitude of social–environmental impacts.

Final considerations and recommendations

Hydropower development adds complexity and vulnerability to the existing problem of fisheries mismanagement that has historically characterized the Brazilian Amazon. In the case studies analyzed, the already weak social–political organization of fishermen prior to the installation of hydropower plants is further complicated by new (and often imposed) resource boundaries (principle 1) and unclear distribution of benefits after dam construction (principle 2). Moreover, the individuals affected by operational rules (i.e., fishers) generally cannot participate in modifying rules (principle 3), while monitoring projects are often developed without their full participation and lack of accountability (principle 4). A lack of governmental capacity to establish and apply sanctions, along with the existence of corruption or clientelist relationships, further clouds the reliability and adherence to environmental policies (principle 5). In general, there are few effective conflict-resolution mechanisms (principle 6), and fishers' rights are not valued or recognized in the process (the "invisibility phenomenon"; principle 7). Finally, the cross-scalar (i.e., nested) arena where management occurs and decisions are made are disconnected, and there often exists confusion over jurisdictional and conflicts of interests among actors and organizations involved in research, decision-making, and compliance assessment of mitigation and compensation procedures (principle 8).

Given limited fisheries data for comprehensive analysis of dam impacts and insufficient guidelines to ensure fishers' rights throughout the licensing process, the same problems are repeated over and over as hydropower expands across Amazonian basins. Similar situations have been described for other parts of Brazil, other Latin American countries, and across the developing world. Across systems, this outcome is driven by a disconnect between energy and environmental policies and social and cultural sectors and is commonly characterized by lack of information and dialogue (Fonseca 2014; Martínez and Castillo 2016). Addressing these deficiencies will require concerted investments and efforts by diverse government agencies, private sector companies and civil society, along with expanded inter-sectorial dialogue and the promotion of local and regional participatory planning and decision-making that includes fishers and their associations (Fonseca 2014). Core issues, deficiencies, and recommendations to improve fisheries governance through the process of dam planning, construction, and operation in the Amazon are summarized in Table 2. These changes will be difficult to implement all at once, but progress may be made in a stepwise fashion. While we do not aim to present conclusive solutions for the multifaceted problem of fisheries invisibility in face of hydropower development in the Brazilian Amazon, we believe that these solutions may come from discussion and a participatory process of dialogue involving multiple stakeholders. This perspective article is a contribution to generate dialogue and reflection on this topic, aiming to support the sustainability of one of the most productive and socio-biodiverse river systems in the world.

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REFERENCES

Agostinho, A.A., F.M. Pelicice, and L.C. Gomes. 2008. Dams and the fish fauna of the Neotropical region: Impacts and management related to diversity and fisheries. *Brazilian journal of biology* 68: 1119–1132.

Alho, C.J.R. 2012. Importance of biodiversity for the human health: an ecological perspective. *Estudos Avançados* 26: 151–165.

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.

Araújo, N.C., and A.S. Moret. 2016. Direitos humanos e hidrelétricas: Uma análise dos impactos socioambientais e econômicos gerados em Rondônia. *Veredas do Direito* 13: 167–194. https://doi.org/10.18623/rvd.v13i26.622.

Athayde, S. 2014. Introduction : Indigenous peoples, dams and resistance in Brazilian Amazonia. *Tipiti: Journal of the Society for the Anthropology of Lowland South America* 12: 80–92.

Athayde, S., P.F. Moreira, and M. Heckenberger. 2016. Public feedback at risk in Brazil. *Science* 353: 1217.

Basurto, X., S. Gelcich, and E. Ostrom. 2013. The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change*. 23: 1366–1380. https://doi.org/10.1016/j.gloenvcha.2013.08.001.

Batista, V.S., V.J. Isaac, N.M. Fabré, O.T. Almeida, J.C.A. Gonzalez, M.L. Ruffino, and C.O. Silva. 2012. O Estado da Pesca na Amazônia. In *Peixes e Pesca Solimões-Amazonas*, ed. V.S. Batista, and V.J. Isaac, 13–29. Brasília: Instituto Brasileiro do Meio.

Beard, T.D., R. Arlinghaus, S.J. Cooke, P.B. McIntyre, S. De Silva, D. Bartley, and I.G. Cowx. 2011. Ecosystem approach to inland fisheries: Research needs and implementation strategies. *Biology letter* 7: 481–483. https://doi.org/10.1098/rsbl.2011.0046.

Berkes, F., and C. Folke. 2002. Back to the future: ecosystem dynamics and local knowledge. In *Panarchy. Understanding transformations in human and natural systems*, ed. L.H. Gunderson, and C.S. Holling, 121–146. Washington: Island Press.

Campos, A.G., and J.V. Chaves. 2014. *Seguro defeso: diagnóstico dos problemas enfrentados pelo programa*, 67. Brasília: IPEA.

Cardoso, A.C.D., A.E. Reymão, A.P.V. Bastos, A.J.O. Castro, C.F. Szlafsztein, J.J.F. Lima, M.C.F. Silva, and M.I.T. Côrtes. 2005. Concepção integrada de Planos Diretores Municipais e Plano de Desenvolvimento Regional: o caso do baixo Tocantins/PA. In *XI Encontro Nacional da Associação Nacional de pós-graduação e pesquisa em planejamento urbano e regional—ANPUR.*, 21. Salvador, Bahia.

Castello, L., and M.N. Macedo. 2016. Large-scale degradation of Amazonian freshwater ecosystems. *Global Change Biology*. https://doi.org/10.1111/gcb.13173.

Cooke, S.J., E.H. Allison, T.D. Beard, Jr., R. Arlinghaus, A.H. Arthington, D.M. Bartley, I.G. Cowx, C. Fuentevilla, et al. 2016. On the sustainability of inland fisheries: Finding a future for the forgotten. *Ambio* 45: 753–764. https://doi.org/10.1007/s13280-016-0787-4.

Doria, C.R.D.C., M.L. Ruffino, N.C. Hijazi, and R.L. Da Cruz. 2012. A pesca comercial na bacia do rio Madeira no estado de Rondônia, Amazônia brasileira. *Acta Amazonica* 42: 29–40. https://doi.org/10.1590/S0044-59672012000100004.

Doria, C.R.C., M.A.L. Lima, A.R. Santos, S.T.B. Souza, M.O.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. https://doi.org/10.5380/dma.v30i0.34196.

Escobar, H. 2015. Brazil roils waters with moves to protect aquatic life. *Science* 348: 169. https://doi.org/10.1126/science.348.6231.169.

Fearnside, P.M. 2015. Amazon dams and waterways: Brazil's Tapajós Basin plans. *Ambio* 44: 426–439. https://doi.org/10.1007/s13280-015-0642-z.

Fearnside, P.M. 2016. Tropical dams: To build or not to build? *Science* 351: 456–457. https://doi.org/10.1126/science.351.6272.456-b.

Ferraz, G. 2012. Twelve guidelines for biological sampling in environmental licensing studies. *Natureza a Conservacao* 10: 20–26. https://doi.org/10.4322/natcon.2012.004.

Fiori, A.M. 2005. *Licenciamento ambiental: Um desafio que exige apenas o velho e necessário bom senso*.

Fonseca, I.F. 2014. Capacidades estatais e políticas ambientais: Uma análise comprada dos processos de coordenação intragovernamental para o licenciamento ambiental de grandes de grandes barragens (Brasil, China, Índia). In *Capacidades Estatais em Países Emergentes: o Brasil em perspectiva comparada*. Brasília: IPEA.

Forline, L., and E. Assis. 2004. Dams and social movements in Brazil: Quiet victories on the Xingu. *Practicing Anthropology* 26: 15–21.

Freitas, C.E.C., A.A.F. Rivas, F.A. Nascimento, F.K. Siqueira-Souza, and I.L.A. Santos. 2006. The effects of sport fishing growth on behavior of commercial fishermen in Balbina reservoir, Amazon, Brazil. *Environment, Development and Sustainability* 10: 157–165. https://doi.org/10.1007/s10668-006-9043-6.

Freitas, C.E.C., F.K. Siqueira-Souza, R. Humston, and L.E. Hurd. 2013. An initial assessment of drought sensitivity in Amazonian fish communities. *Hydrobiologia* 705: 159–171. https://doi.org/10.1007/s10750-012-1394-4.

FUNASA. Fundação Nacional de Saúde. 2010. *Relatório de Gestão*. Superintendência de Tocantins. 139 p.

Haimovici, M., J.M. Andriguetto Filho, P.S. Sunye, and A.S. Martins. 2014. Padrões das dinâmicas de transformação em pescarias marinhas e estuarinas do Brasil (1960–2010). In *A pesca marinha e estuarina no Brasil: Estudos de caso multidisciplinares*, ed. M. Haimovici, J.M. Andriguetto Filho, and P.S. Sunye, 181–191. Rio Grande: FURG.

Hernández, F.M., and S.B. Magalhães. 2011. Ciência, cientistas e democracia desfigurada: O caso Belo Monte. *Novos Cadernos NAEA* 14: 79–96.

International Labour Organization (ILO). 1989. *Indigenous and tribal peoples convention 169*.

Isaac, V.J., M.L. Ruffino, and D. McGrath. 1998. In search of a new approach to fisheries management in the middle Amazon region. *Fishery Stock Assessment Models*. https://doi.org/10.4027/fsam.1998.49.

Isaac, V.J., M.C. Almeida, T. Giarrizzo, C.P. Deus, R. Vale, G. Klein, and A. Begossi. 2015. Food consumption as an indicator of the conservation of natural resources in riverine communities of the Brazilian Amazon. *Anais da Academia Brasileira de Ciencias* 87: 2229–2242. https://doi.org/10.1590/0001-3765201520140250.

Isaac, V.J., L. Castello, P.R.B. Santos, and M.L. Ruffino. 2016. Seasonal and interannual dynamics of river-floodplain multispecies fisheries in relation to flood pulses in the Lower Amazon. *Fisheries Research*. https://doi.org/10.1016/j.fishres.2016.06.017.

Jaichand, V., and A.A. Sampaio. 2013. Dam and be damned: The adverse impacts of belo monte on indigenous peoples in Brazil. *Human Rights Quarterly* 35: 408–447. https://doi.org/10.1353/hrq.2013.0023.

Junk, W.J., and M.G.M. Soares. 2001. Freshwater fish habitats in Amazonia: State of knowledge, management, and protection. *Aquatic Ecosystem Health & Management* 4: 437–451.

Kahn, J.R., C.E. Freitas, and M. Petrere. 2014. False shades of green: The case of Brazilian Amazonian hydropower. *Energies* 7: 6063–6082. https://doi.org/10.3390/en7096063.

Kirchherr, J., H. Pohlner, and K.J. Charles. 2016. Cleaning up the big muddy: A meta-synthesis of the research on the social impact of dams. *Environmental Impact Assessment Review* 60: 115–125. https://doi.org/10.1016/j.eiar.2016.02.007.

Laufer, J., S. Athayde, E.E. Marques, S. Setúbal, and L.R. Soares. 2017. Projeto de Pesquisa: Gestão Participativa da

Biodiversidade em Terras Indígenas afetadas por Barragens Hidrelétricas na Amazônia Brasileira. Relatório Técnico n. 4. Universidade Federal do Tocantins e Universidade da Flórida, Palmas e Gainesville, agosto de 2017.

LEME Engenharia S.A., 2005. Estudo de Impacto Ambiental dos Aproveitamentos Hidrelétricos Santo Antônio e Jirau, Rio Madeira—RO. Capítulo IV—Área de Influência Direta dos Aproveitamentos Hidrelétricos de Jirau e Santo Antônio, Tomo B, Volume 5/8, Diagnóstico Ambiental da Área de Influência Direta, Meio Biótico, Ictiofauna e Recursos Pesqueiros. Relatório 6315—RTG90—001. Maio/2005. Páginas IV-755 a IV-916.

Lévêque, C., T. Oberdorff, D. Paugy, M.L.J. Stiassny, and P.A. Tedesco. 2008. Global diversity of fish (Pisces) in freshwater. *Hydrobiologia* 595: 545–567. https://doi.org/10.1007/s10750-007-9034-0.

Lima, A.M.T., E.E. Marques, M.H. Ertzogue, D.T.A.M. Ferreira, and J.D. Lima. 2015. Os Rios Amazônicos Convertidos em Gigawatts: Participação Social no Processo de Implantação de Usinas Hidrelétricas. *Revista de Administração e Negócios da Amazônia* 7: 136–158. https://doi.org/10.18361/2176-8366/rara.v7n2p136-158.

Lorenzen, K., I.G. Cowx, R.E.M. Entsua-Mensah, N.P. Lester, J.D. Koehn, R.G. Randall, N. So, S.A. Bonar, et al. 2016. Stock assessment in inland fisheries: A foundation for sustainable use and conservation. *Reviews in Fish Biology and Fisheries*. https://doi.org/10.1007/s11160-016-9435-0.

Lucinda, P.H., I.S. Freitas, A.B. Soares, E.E. Marques, C.S. Agostinho, R.J. de Oliveira. 2007. Fish, Lajeado reservoir, rio Tocantins drainage, state of Tocantins, Brazil. *Check List* 3: 70–83. https://doi.org/10.15560/3.2.70.

Lynch, A.J., S.J. Cooke, A.M. Deines, S.D. Bower, D.B. Bunnell, I.G. Cowx, V.M. Nguyen, J. Nohner, et al. 2016. The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews* 24: 115–121. https://doi.org/10.1139/er-2015-0064.

MAPA, 2016. Ministério da Agricultura, Pecuária e Abastecimento. http://www.agricultura.gov.br/aquicultura-pesca.

Marmulla, G. 2001. Dams, fish and fisheries: opportunities, challenges and conflict resolution. FAO Fisheries, Technical paper 419, Rome, Italy.

Martínez, V., and O.L. Castillo. 2016. The political ecology of hydropower: Social justice and conflict in Colombian hydroelectricity development. *Energy Research and Social Science* 22: 69–78. https://doi.org/10.1016/j.erss.2016.08.023.

McCormick, S. 2006. The Brazilian anti-dam movement: Knowledge contestation as communicative action. *Organization & Environment* 19: 321–346. https://doi.org/10.1177/1086026606292494.

McCormick, S. 2007. The governance of hydro-electric dams in Brazil. *Journal of Latin American Studies* 39: 227. https://doi.org/10.1017/S0022216X07002374.

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. https://doi.org/10.4025/actascibiolsci.v37i2.26920.

Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action*. New York: Cambridge University Press.

Ostrom, E. 2002. Reformulating the Commons. *Ambiente & Sociedade* 10: 1–21.

Petrere, M., R.B. Barthem, E.A. Córdoba, and B.C. Gómez. 2004. Review of the large catfish fisheries in the upper Amazon and the stock depletion of piraíba (*Brachyplatystoma filamentosum* Lichtenstein). *Reviews in Fish Biology and Fisheries* 14: 403–414. https://doi.org/10.1007/s11160-004-8362-7.

Povo Juruna da TI Paquiçamba. 2017. Protocolo de Consulta Juruna (Yudjá) da Terra Indígena Paquiçamba da Volta Grande do Xingu. Apoio: Rede de Cooperação Amazônica (RCA) e Instituto Socioambiental (ISA). Vitória do Xingu.

Ramalho, C.W.N. 2014. Estado, pescadores e desenvolvimento nacional. *Da Reserva Naval à Aquícola. Ruris* 8: 31–62.

Rezende, R.R. 2009. Navigating the Turbulent Waters of Public Participation in Brazil: A Case Study of the Santo Antônio and Jirau Hydroelectric Dams.

Ruffino, M.L. 2005. *Gestão do uso dos Recursos Pesqueiros na Amazônia*. Edited by IBAMA. Manaus: ProVárzea, 135 p.

Santos, G.M. 1995. Impactos da hidrelétrica Samuel sobre as comunidades de peixes do rio Jamari (Rondônia, Brasil). *Acta Amazonica* 25: 247–280.

Santos, G.M., and A.B. Oliveira. 1999. A pesca no reservatório da hidrelétrica de Balbina (Amazonas, Brasil). *Acta Amazonica* 29: 145–163.

THEMAG, 1996. Engenharia e Gerenciamento Ltda. Usina Hidrelétrica Lajeado: Estudo de Impactos Ambiental—EIA/diagnóstico ambiental—socioeconomia; v.2, tomo c.

Timpe, K., and D. Kaplan. 2017. The changing hydrology of a dammed Amazon. *Science Advances* 3: 1–13. https://doi.org/10.1126/sciadv.1700611.

Villas-Bôas, A., B.R. Garzón, C. Reis, L. Amorim, and L. Leite. 2015. *Belo Monte: Não há condições para a Licença de Operação*. Instituto Socioambiental (ISA): São Paulo.

WCD. 2000. *Dams and development: A new framework for decision-making*. London. https://doi.org/10.1097/GCO.0b013e3283432017.

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 American Association for the Advancement of Science* 351: 128–129. https://doi.org/10.1126/science.aac7082.

Yin, R.K. 2009. *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Zhouri, A., and R. Oliveira. 2007. Desenvolvimento, conflitos sociais e violência no Brasil rural: O caso das usinas hidrelétricas. *Ambiente & Sociedade* 10: 119–135. https://doi.org/10.1590/S1414-753X2007000200008.

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