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Stakeholder Perceptions on the Governance of Fisheries Systems Transformed by Hydroelectric Dam Development in the Madeira River, Brazil

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Hydroelectric dams often have significant impacts on freshwater fisheries. Major impacts are known to be driven by changes in river hydrology and fish ecology, but the role of governance arrangements in mitigating or exacerbating fisheries impacts from hydropower development is less understood. This study presents an analysis of stakeholder perceptions about the effects of hydroelectric dam implementation on fisheries governance arrangements in the Madeira River basin, Brazil. Semi-structured interviews were conducted with 50 stakeholders representing the fishers and fish traders, government, non-governmental organizations, and the private sector. Fishers, non-governmental, and private sector agents perceived hydropower development to be the strongest factor driving fisheries decline or change over the past 10 years, while government staff perceived overfishing to be an equally or even more important factor. Most stakeholders affirmed that fisheries governance arrangements have weakened in the face of hydropower development, and that these arrangements have been insufficient to effectively mitigate or compensate for negative impacts on fisheries. Fishers, non-governmental and private sector agents saw lack of opportunities to participate in fisheries governance as a major contributing factor, while government staff emphasized lack of qualified personnel, lack of trust between agencies, and control over the decision-making process held by hydropower companies. Perspectives on other implications of governance arrangements were shared across stakeholder groups. These included increased conflicts; lack of interaction and coordination between agencies; the fragility of fishers' social organization; lack of trust and reciprocity between organizations; and power imbalances between stakeholders. The results show that hydropower development impairs and changes relationships between diverse players involved in fisheries governance, which can exacerbate existing weaknesses and negatively affect fishery sustainability. Drawing from the perspectives and comments of the various stakeholders

who participated in the study, we provide recommendations to improve freshwater fisheries governance in the Madeira River basin and in the Brazilian Amazon.

Keywords: mitigation, inland fisheries, institutional arrangements, hydroelectric dams, social-ecological impacts, freshwater fisheries, Amazon, fisheries governance

INTRODUCTION

Hydropower development is an electric energy supply strategy adopted by many Asian, Latin American, and African countries (Soares-Filho et al., 2006). Government leaders have pursued the implementation of these projects to meet their countries' growing electricity demand. They often highlight positive aspects of hydropower, including energy security, low carbon emissions, increased employment, and economic development (Prado et al., 2016; MME/EPE, 2017). The negative aspects of these projects on social, environmental, and economic dimensions are frequently underestimated or ignored by developers and decision-makers worldwide (Araújo and Moret, 2016; Siciliano et al., 2016; Moran et al., 2018; Athayde et al., 2019).

Construction of large hydroelectric projects triggers significant modifications in the physical-chemical dynamics of aquatic ecosystems and in the composition and abundance of the local ichthyofauna (Castello and Macedo, 2016; Winemiller et al., 2016). These changes in turn lead to significant socioeconomic impacts for riverine communities, where fishing represents an important source of animal protein and income (Agostinho et al., 1997; Fearnside, 2014; Doria et al., 2018b). Biophysical impacts of hydroelectric dams on fisheries can be mitigated by improving governance arrangements for managing fisheries, by improving the design and operation of hydropower dams, and by developing or strengthening broader public policies such as resettlement or welfare programs (WCD, 2000). Mitigation measures could include, for example, restrictions on fishing in the vicinity of fish passage facilities, requirements to maintain environmental flows, and compensation payments for lost income from fishing (WCD, 2000). Conversely, failure of governance arrangements to mitigate dam impacts on fisheries, or worse, deterioration of existing fisheries governance arrangements in the face of dam construction, can exacerbate the overall impact on fisheries. Therefore, it is essential to consider both the social and ecological dimensions of the fisheries system when assessing or planning to identify and mitigate the impact of dam projects (Lorenzen et al., 2007).

Previous studies have addressed the impacts of dams on fisheries resources, on fishing activities, and on riverine communities (Lima et al., 2012; Castello and Macedo, 2016; Winemiller et al., 2016; Arantes et al., 2019). However, there is a lack of research on potential social impacts of dams, integrating the perceptions of key stakeholders such as local fishers, private sector (Doria et al., 2018b), dam-builders, and other stakeholders interested in dam developments (Kircherr et al., 2016).

Fisheries system (FS) can be considered a type of social-ecological system (SSE) that includes the natural resources used, its users, the governance and management systems and how these interact and affect the SSE and its components (Ostrom, 2009). Diverse authors have studied SSEs in different settings and common property resources, with a focus on fishing resources (e.g., Imperial and Yandle, 2005; Lorenzen, 2008; Burns and Stöhr, 2011; Basurto et al., 2013; London et al., 2017; Yatim et al., 2018; Doria et al., 2020). A central challenge for understanding fisheries systems is to elucidate how governance arrangements might influence fishery resources and the sustainability of the system as a whole (Ostrom, 1990; Lorenzen, 2008; Burns and Stöhr, 2011). Here, we define fisheries governance as the public and/or private coordinating steering regulatory processes based on different stakeholders' behavior and formal and informal institutional arrangements (Burns and Stohr, 2011).

According to Ostrom (1990) and Berkes and Ross (2013), specific characteristics of governance systems may be typically associated with SSEs resilience and sustainability, such as the design and implementation of rules adapted to local needs and conditions. Where this is the case, stakeholders are able to participate in rule design and modification or have the right to formulate their own rules. Other characteristics of sustainable governance systems include diversified and innovative engaged governance (involving collaborative organizations); equity of participation and power among group's members; the affected group's social capital related to past experiences of cooperation; as well as strong leadership, which allows community action in response to internal and external influences and pressures on the fisheries system (Ostrom 1990; Berkes and Ross 2013).

This study aims to evaluate, from a stakeholder perspective (fishers, researchers, dam-builders, and government), how the implementation of hydroelectric dams may affect tropical fisheries systems through effects on their governance arrangements, and how these arrangements may influence the overall system sustainability. We present a case-study analysis of the Madeira fisheries system, where two large hydroelectric plants were built in 2011, contrasting our findings with other contexts and experiences, in Brazil and internationally.

Conceptual Framework

The current study was guided by a theoretical framework for analyzing fisheries systems governance (**Table 1**). This framework was developed based on the architecture of governance elements proposed by Burns and Stöhr, (2011): Social organizational configuration and cognitive-normative configuration. The social organizational configuration includes descriptors of the main stakeholders (actors) (D1) and their interactions (authority and responsibility; expertise and knowledge) (D2), their perceptions of dialogue among stakeholders (D3), and procedures for legitimate decision making (D4). The cognitive-normative configuration related to informal constraints (norms of behavior, conventions, and self-imposed codes of conduct) includes descriptors of the

TABLE 1 | Theoretical framework used to describe the Governance architecture of the Fisheries System and their sustainability, modified from Agrawal and Ostrom (2001), Burns and Stöhr (2011) and Berkers and Ross (2013).

	Descriptor	Sustainability indicator
Social organizational configuration	Main stakeholders (D.1) Interactions among the entities (D.2) Organizations have the: - Authority and responsibility (D.2.1) - Expertise and knowledge required over the problem (D.2.2) Actor's perception about Dialogue among the stakeholders (D.3) Procedures for legitimate decision-making (formal and informal) (D.4)	Social capital (e.g., experiences of cooperation) (SI.1) Existence of strong leadership (SI.2) Engaged governance (involving collaborative organizations; sharing information about the system or the process) (SI.3) Trust and reciprocity between the stakeholders (SI.4) Equity of participation and power (SI.5) Rules adapted to local rules; fishing rules have not changed or changed in an adaptive manner after the dam (SI.6)
Cognitive-normative configuration	Conceptualization of the situation: Key driver in the system (D.5) Goals and priorities which are expected to be applied in the policy-making and governing processes (D.6) Conflicts occurrence (D.7) Suggestions over the problem or to improve the fisheries systems and future perspectives (D.8)	Stakeholders able to participate (SI.7)

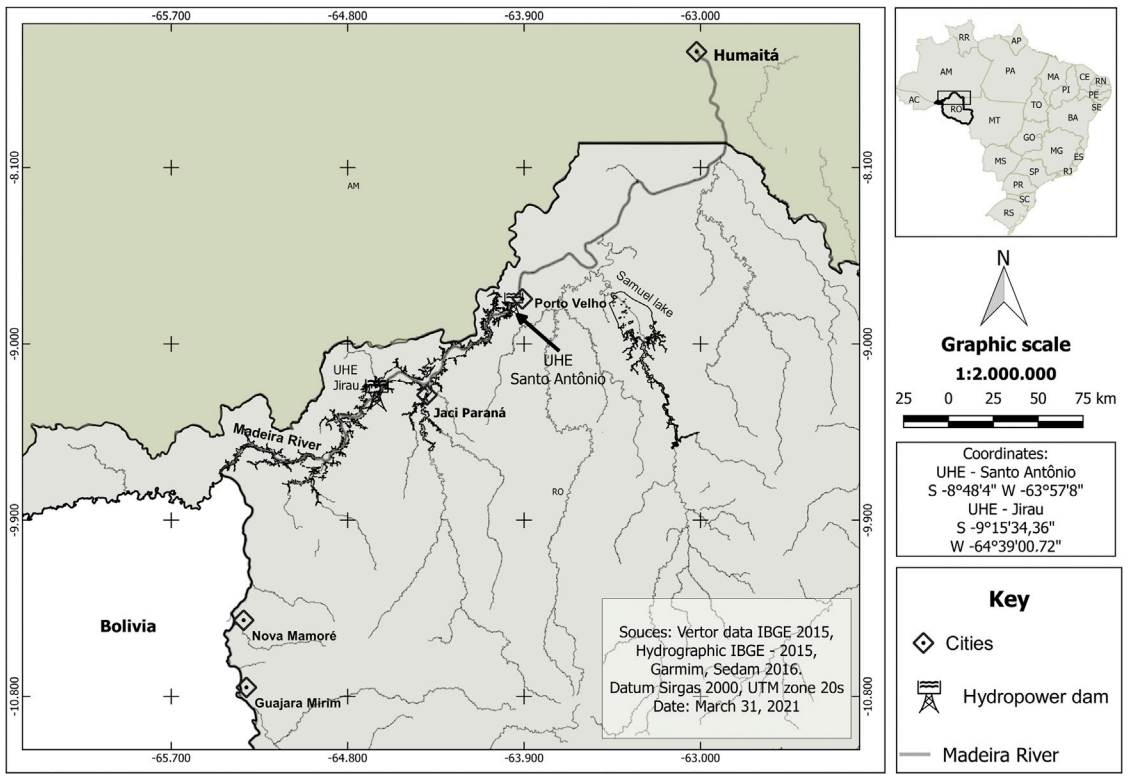

FIGURE 1 | Geographic location of the study area, showing the Madeira River crossing Rondônia State (Brazil), and the Jirau and Santo Antônio dams.

conceptualization of the situation and the main drivers (D5), the goals or priorities expected to be applied in the decision-making process (D6), the occurrence of conflicts (D7) and suggestions for addressing the problem (D8). Descriptors in the social-organizational configuration are related to a set of governance sustainability indicators: characteristics that have been shown in many studies to indicate the capacity of the stakeholders and institutions to respond to change and to maintain the systems' socioeconomic and environmental sustainability (Agrawal and Ostrom, 2001; Berkers and Ross 2013). We use these sustainability indicators to discuss whether changes in the social-organizational configuration identified in our study are likely to enhance or reduce the overall sustainability of the fisheries system.

MATERIALS AND METHODS

Study Site: The Madeira Small-Scale Fisheries System

The Madeira River is the main and most important tributary of the right bank of the Amazon River in flow and sediment transport. Its watershed accounts for almost 20% of the Amazon basin across three countries: Brazil, Bolivia, and Peru (Goulding, 1979) (**Figure 1**). The Madeira River basin's ichthyofauna is recognized for its great diversity, with more than 1,057 species described (Ohara et al., 2015). This rich fish fauna is also of great regional socioeconomic importance, generating animal protein and income for subsistence and commercial fishers (Doria et al., 2012).

Driven by the Brazilian National Electric Energy Plan and the government's Accelerated Growth Plans (Fearnside 2014; MME/EPE, 2017), two large hydroelectric dams have been built in the Madeira River basin, which together have an installed capacity of around 7,000 MW: Santo Antônio (operation starting in 2011) and Jirau (operation starting in 2012). The current study focuses on the region of direct and indirect influence of both dams in the municipalities of Guajará Mirim, Nova Mamoré, and Porto Velho (Rondônia State, Brazilian Amazon).

Madeira Fisheries and Fishers' Characteristics

The Madeira River and its tributaries including the Mamoré and Guaporé Rivers, which altogether cover a flooded area of about 2,500 km^2, are the main fishing grounds in the study area (Doria et al., 2017). Prior to the construction of the dams, the three main fish markets of the region had an average production of 619 tons/year for Porto Velho (RO) and 245 tons/year for both Humaitá (AM) and Guajará-Mirim (RO) (Doria and Lima, 2015). Fishing activity is characterized as a small-scale, multi-species artisanal fishery with use of diverse and simple fishing gear, fishing trips of generally short duration and relatively low fisheries yield. The fishing fleet consists mainly of small non-motorized and motorized wooden canoes (~1,000 units, storage capacity of less than 600 kg) and few larger fishing boats (average capacity: 2,500 kg).

The fisheries exploit about 74 different species. Before the construction of the dams, construction, five of these species accounted for 57% of catches: barba-chata (*Pinirampus pirinampu*), pacu-common (*Mylossoma duriventre*), curimatã (*Prochilodus nigricans*), jatuarana (*Brycon amazonicus* and *B. melanopterum*) and Dourada (*Brachyplatystoma rousseauxii*) (Doria and Lima, 2015). Most of these species are migratory, with migrations for reproductive, trophic, or dispersal purposes being strongly influenced by water level and flow (Goulding, 1979; Lima et al., 2017).

Fishing in the Madeira River is an activity of great regional socioeconomic importance, involving about 3,000 commercial fishermen (Doria et al., 2012; Doria and Lima, 2015). Typical local fishing families are composed of two or more fishers. Fishers are typically male, with an average age of 40 years; two-thirds of whom have not completed primary education (Lima et al., 2012). The importance of fishing for these families is emphasized by fish consumption, estimated at 0.5–1.0 kg *per capita* day, and by the average monthly fish landings per family involved in fishing (369 ± 405 kg). Of these landings, 13% is destined to family consumption and 87% for sale. Income obtained from fish sales represents 50–100% of an average riverine family's income (US$ 507 ± 522 in 2009), with the remainder being derived mostly from small-scale agriculture (Doria et al., 2016). Fisheries monitoring data covering two decades prior to dam construction showed relative stability on the catches (Doria et al., 2018a), but catches declined after the Santo Antônio and Jirau dams were built (Lima et al.,2020).

Governance Arrangements

The Madeira fisheries system comprises governmental organizations at different scales (Federal, State, and Municipal); non–governmental organizations; civil society organizations; commercialization chains organizations and consumers; and the private sector (adapted from Doria et al., 2020). In **Table 2** we synthesize the most important organizations and their roles. Artisanal fisheries activity in the Amazonian region is regulated by federal (Ministry of Fisheries and Aquaculture and Ministry of the Environment) and state agencies (State Environmental Agency). These entities are charged with designing and monitoring the implementation of public policies, laws and regulations, as well as with monitoring fishing activity. The Ministry of Fisheries and Aquaculture, along with the Technical Assistance and Rural Extension Company and the Agriculture State Agency state-based agencies, have the mandate to promote fisheries development and sustainability.

The State Environmental Agency (SEDAM) is responsible for overseeing, planning, and managing fisheries. However, this agency works mainly on the supervision and enforcement of fisheries regulations, along with other state environmental policies. Until 2014, issues related to fishing in the State of Rondônia were discussed by the Technical Chamber organized by SEDAM, which was composed of representatives of four entities involved in fishing, and one representative from a fishers colony or association. After this, the Technical Chamber was dissolved. The fishers are organized into local associations (fishers colonies) and syndicates, and at federal scale, into fishers federations. These entities have the mandate to defend fishers' rights (e.g., public policies and legislation compliance, benefits from the government, and compensations) and promote the fishers' class empowerment. Scientific or academic organizations are represented in this study by the Laboratory of Ichthyology and Fisheries of the Federal University of Rondônia (LIP/UNIR), which has been researching fish and fishing dynamics on the Madeira basin since 2000, and which provides information on fishing and fish to fishers colonies and to the government whenever requested.

The licensing and implementation of hydroelectric dams on Brazilian federal rivers is monitored by the Federal Environmental Agency (IBAMA). Santo Antonio and Jirau

TABLE 2 | Organizations by groups of stakeholders and geographic scale (Federal, State, municipal) of the Madeira Fisheries System and their main function.

Government		Users	
• **Environmental and fisheries management/enforcement**		**all level**	Fisher, riverine community, indigenous people
Federal	Ministry of fisheries and aquaculture (MPA) -	**all level**	Middlemen
State	State Environmental and development Agency (SEDAM)	**all level**	Consumers
	Environmental Police (BPA)	**Non-government**	
• **Implementation and enforcement of national environmental policies; monitor the dam license process**		• **Representation of professional fishers in issues affecting their interests**	
Federal	Brazilian Institute of environment and Renewable resources (IBAMA)	Federal	Federal Fisher association
• **Promotion of agricultural, fish farming and fishing production**		Municipal	Fisher colony (Colônia de Pescadores Z-1, Z- 2 and Z-13)
State	State Secretary for agriculture, livestock and land regularization (SEAGRI)	• **Support to fishermen/associations; fisheries management**	
	Technical assistance and rural extension company (EMATER)	All level	Non-governmental Organization
Municipal	Municipal Secretariat of agriculture	• **Generate technical subsidies for fisheries management**	
• **Maintain the legal order and safety**		All level	Science
Federal and state	Public Prosecutions (MPF and MPE)	• **Construction and operation of the dam; impact studies, monitoring, mitigation and compensation of the dam impacts**	
Federal	Navy	Public/Private	Hydropower companies

dams, for instance, should comply with the Technical Instruction nº. 060/2008 of the Environmental Licensing Department (IBAMA, 2008), which states that: "*...the impacts caused on fisheries should be mitigated and/or compensated, to guarantee the environmental sustainability and the improvement of the livelihoods of impacted populations.* Additionally, it is recommended that the implementation of a program should be focused*: 1) on the maintenance of the fisheries activities, 2) on the social compensation for the impacted fisheries activities; 3) on the definition of a new technological pattern, including actions for the reorganization of the (fishing) activity, when necessary."*

Interviews with Stakeholders

To understand stakeholder perceptions about the fisheries system, interviews were held with key informants from the main stakeholder groups, including representatives of fishers, and staff from governmental and non-governmental organizations, as well as private dam developers (N = 50) (**Table 3**).

The key informants to be interviewed were selected from among the stakeholder groups using the following: 1) technical reports of the Fisheries Monitoring Program published by dam companies, where it was possible to identify the companies' staff and government officers involved, as well as managers and policy-makers (at different levels) for the fishing sector, from 2009 to 2013; and 2) the database of the LIP/UNIR, which was used to identify the most active community leaders and fishers (greater number of landings by locality) (**Table 3**).

Organizations were officially contacted by an invitation letter or email. In the case of dam building companies, responses to the invitation were negative, and in some cases, there was no response at all. Consequently, we chose to make direct contact with the companies' key informants listed in the reports.

Interviews were conducted from December 2014 to February 2015. Informed consent for participation was obtained from all individuals prior to initiating the interviews. The researcher verbally explained the interview procedures, the participants were given the opportunity to ask questions, and then the participants gave their verbal consent to participate. This research was developed under the Amazon Dams International Research Network support and ethical standards, according to the IRB Protocol number #2014-U- 0490. Each semi-structured interview took 45 min on average. Interviews were carried out in the municipalities of Guajará Mirim and Nova Mamoré (upstream of the Jirau dam); in the community of Cachoeira do Teotônio and in the district of Jaci-Paraná (Santo Antônio reservoir area); and in the communities of São Sebastião and São Carlos (downstream area) (**Figure 1**).

TABLE 3 | Description of the sampled number of interviewees per stakeholder group. The number of agencies interviewed is indicated in parentheses.

Group	Subgroup	Respondents
Users	Fishers	26
	Middlemen	3
	Sub-total	29
Managers or employees		
Government	Federal agencies (2)	3
	State agencies (2)	2
	Municipal agency	1
No government	Fisher's colony (3)	3
	Non-government organization (4)	4
	Hydropower companies (2)	4
	Scientists	4
	Sub-total	21
	Total	50

A semi-structured questionnaire (open and closed questions) was developed to collect information regarding the descriptors and indicators summarized in **Table 1** (*see* **Supplementary Material S1**). The interviews were transcribed and analyzed using the Nvivo 10 software to categorize and code the qualitative data, aiming to compare and contrast the answers and interpretations of each theme. The responses were grouped by stakeholder group: users, government staff, or staff from non-governmental entities. Responses were coded according to themes and subthemes, defined by expected answers from the

FIGURE 2 | Pictorial representation of the Madeira fisheries system used in the stakeholders' interviews and cognitive maps. Each of the insert in the map corresponded to a card, on the bottom the fishes, from left to right, from bottom to top: Fisher; Fishers colony or association; Hydropower Company; Non-governmental organization; Science; Middlemen; Consumers and in the middle the Government.

literature review, and by actual answers. New subthemes were created and coded based on the frequency with which they were cited (over three times). In the end, the codes were reviewed, refined, grouped (when possible) and classified into positive or negative analysis, represented by (+) and (−) in the **Supplementary Material** tables. For each descriptor, we considered the most frequent and relevant answers by group or for all respondents, when they corresponded to 20% or more of the answers.

The governance architecture of the Madeira fisheries system after the dam construction was summarized, highlighting the main results for each descriptor. The results were described considering the descriptors numerical sequence and the sustainability indicators proposed in **Table 1**.

Card Games: Cognitive Map of the Fisheries System

During the interviews, the stakeholders' description of the governance network and its interactions were facilitated through the use of a card game developed to help elicit and visualize the stakeholders' understanding, interaction, and participation, and also to aid the visualization of the fisheries system's structure according to each participant's perception (adapted from Pretty et al., 1995). The game consisted of cards with drawings depicting the main fisheries system's components: fish, fishers, government, researchers, class association, hydropower companies; and consumers (**Figure 2**).

After a brief explanation of the game's purpose, the interviewees were asked to identify which organizations had worked with or had a relationship with fisheries or fishers in the region. According to the interviewee's responses, the cards representing the stakeholders were organized on the table. From the selected cards, the participants were asked to draw a picture of the fisheries system indicating the quality of the relationships between the organizations. For "strong" relationships, which are positive for maintaining fishing sustainability, continuous lines were used. For "weak" or negative relationships, dashed lines were used (**Figure 3**). The weak and strong responses were added and expressed as percentage of responses related to all answers. The higher values were considered as more important to designate the connection between two given actors. A cognitive map of the Madeira River fisheries system was produced to enable visualization of the system's main stakeholders (cited in more than 5% of the interviews), as well as the strength and quality (weak or strong) of the relationships between stakeholders in the system. Visualization of the cognitive map model representing the frequency of interactions among the stakeholders indicated the intensity of relationships by the line's thickness.

RESULTS

The main results regarding the governance architecture of the Madeira River fisheries system after the dam construction implementation are synthesized in **Table 4**. In general, most stakeholders stated that fisheries-related institutional arrangements had weakened in the face of hydropower development and that the arrangements had been insufficient to effectively mitigate or compensate for fisheries impacts. Fishers, non-governmental and private sector personnel mentioned the lack of opportunities to participate in fisheries governance as a major weakness, government staff emphasized lack of qualified personnel, inter-agency lack of trust, and the decision-making control

FIGURE 3 | Drawing of the perception of actors about the Madeira Fisheries System and a picture of the interview. The continuous blue link here represents the strong relation and the dashed red link represent the weak relation.

TABLE 4 | The governance architecture of the Madeira Fisheries System after the dam implementation.

Social organizational configuration	
Main Stakeholders	Fisher; Fishers associations, hydropower companies, Federal Environmental Agency staff, State Environmental Agency staff, researchers, ONG personnel
Authority and responsibility	Dam licensing process: Federal environmental agency; fishery management on Rondônia State: State environmental agency
Dialogue among the stakeholders	Negative evaluation; got worse
Interactions among the entities	Negative evaluation; got worse
Expertise and knowledge requirements	Federal University of Rondônia: Status and analysis of fish stocks and fisheries dynamics; hydropower companies: fisheries monitoring and impact assessments; government agencies: no data available
Procedures for legitimate decision-making	Decisions on fishing: autocratic Decisions on mitigating the dam impacts: autocratic (the power of the system is concentrated in the government and hydropower companies)
Cognitive-normative configuration	
Key driver	After the dam: declining fish stocks in the Madeira basin, fisheries impact (income and livelihoods)
Goals and priorities	Keep fish healthy fish for sustainable fisheries
Solutions	Interventions to strengthen the policies: 1) qualified participation of Fishers (affected stakeholders) and their institutions in the decision- making process; and 2) guarantee opportunities for communication and follow-up, with those affected, by government agencies responsible for fisheries management and for evaluating/monitoring the projects' impacts on the activity

held by hydropower companies. Perspectives on other factors were shared across stakeholder groups. These included increased conflicts, lack of interaction and coordination between agencies, fragility of fisher's social organization, lack of trust and reciprocity between organizations, and power imbalance between stakeholders. In the following subsections, we detail the findings synthesized on **Table 4**.

Social Organizational Configuration

The interviewees cited 20 entities as participants of the Madeira fisheries system. Twelve were cited by more than four respondents, and the most-cited were the fishers, followed by the fishers' colony or association and the hydropower companies (D.1; **Figure 4**). Fishers were the focal point of the system, where most of the interactions to or from other stakeholders converge.

About the *Interactions among the entities* (D2) a total of 500 relationships were identified using the card game. Of these, 61% were weak relationships and 39% were strong. The fishers generally had weak ties to government agencies responsible for fisheries management and with the fisher's colonies, entities that should work with fishers to guarantee the fishery sustainability, as well as to defend their rights. On the other hand, a stronger relationship was expressed between fishers and science or academic institutions, with the Federal Public Prosecution Service (MPF), and with Non-governmental Organizations. These entities do not have the role of managing the fishing activity. The agency responsible for environmental licensing and supervision of hydroelectric projects (Federal Environmental Agency) and local government appear to have a strong relationship with the hydropower companies and a weak connection with other entities in the system, a situation that is likely to undermine fisheries resilience and sustainability (**Figure 4**).

Based on interviewees' perceptions, the entities that have authority and responsibility (D2.1) over the main problem are the hydropower companies (54% of all interviewees) and the government (24% of the interviewees) (**Supplementary Table S1**).

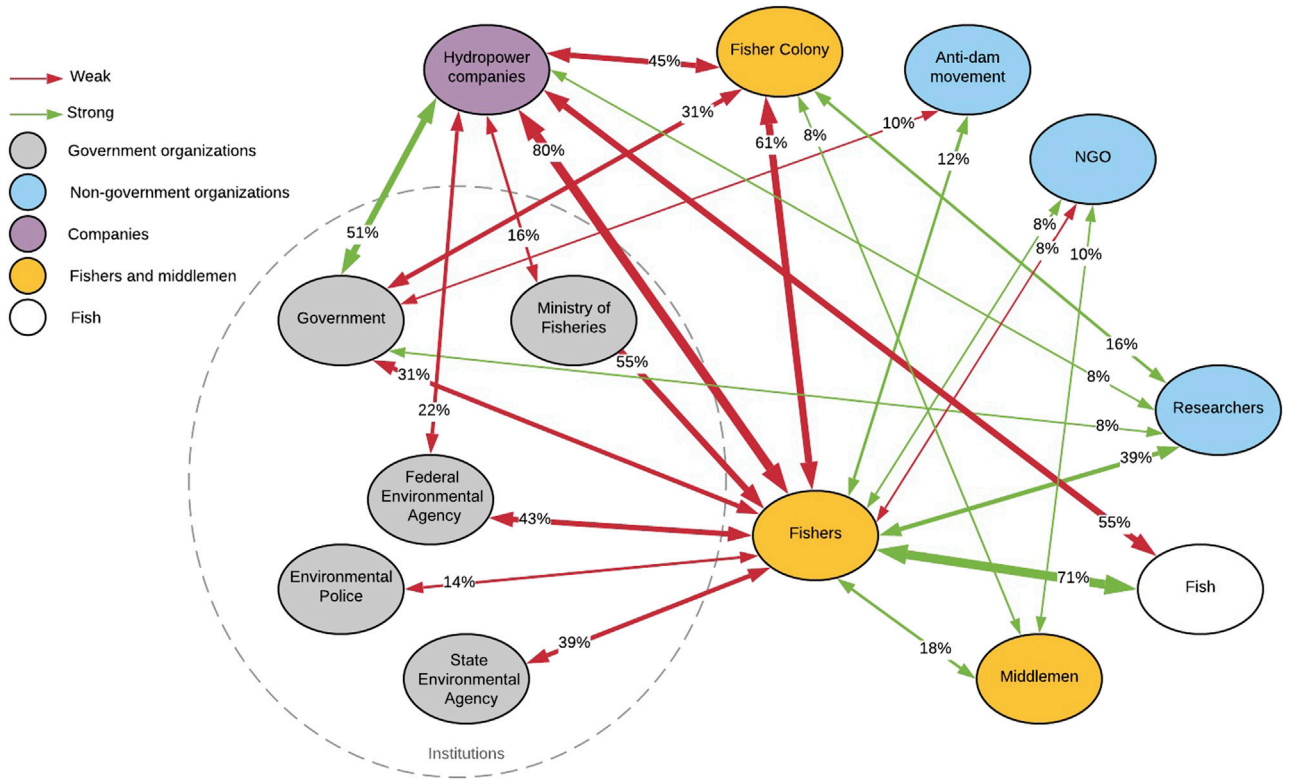

FIGURE 4 | Cognitive map of the Madeira Fisheries System after implementation of the Santo Antônio and Jirau dams. The circles represent the institutions cited by the respondents: the green lines represent strong relationships that contribute to sustainability, while red lines represent weak relationships that do not contribute to the fishing sustainability. Line density represents the percentage of responses related to all answers.

Lack of trust in hydropower companies (92%) stands out among the three stakeholders groups' responses. The same lack of confidence was mentioned in relation to the Ministry of Fisheries and Aquaculture, the Federal Environmental Agency and local government agencies, but with a lower percentage of interviewees (30, 10, and 32% respectively) (Trust and reciprocity between the stakeholders - SI.4). Some testimonies that clearly represent this perspective are:

"[...] there is a very spurious relationship between everybody and the company. The company has a very clear purpose. Because of this, the whole process gets very skewed ... the company keeps insisting and forcing the bar to decrease the cost of it. The discussion of respectability happens at the beginning of the process (e.g.,: Let's do everything and strive) then all of that is lost. After the LO (operating licensing) it gets worse " (Federal Government employee).

"[...] When the turbines get closed, a lot of fish die ... and then they bury everything... Now the fishers will catch a fish if they do not arrest soon.... I have a friend who works there and said it to me. I ask if he can take a photo. He says no because the guy pays his bills - gets fired" (Fisher).

"[...] letting the company hire anyone who wants to do the monitoring or mitigation, is to put the fox to take care of the chicken." (Non-governmental organization member).

In this context, the three groups reported that the hydropower companies own the power or control of the fisheries system at that moment, followed by the local government (50 and 24% of the interviewees, respectively) (**Supplementary Table S1**).

"[...] what exists is an open path to corruption, to neglecting. The fact that the company pays for everything and is the leader of this process only leads to the destruction of the political relations that existed before. The company brings that money and changes all the relationships of interest. It puts money in such a direct way, both in Federal Environmental Agency, in the government and the fishers etc. It ends up being the great dominant. It does it enabled by the money, corrupting the entire system. In the Madeira project, maintaining people's financial conditions and way of life was never considered as a central objective. The main objective is to implement the project. If you can keep the first goal associated with another one, that's okay, if it does not go well, we'll deploy it the same way. " (Federal government employee).

According to the interviewees, the entities that have the required expertise and knowledge over the main problem (D2.2) are the dam-builders (74% of the interviewees) (**Supplementary Table S1**). This is because hydropower companies coordinate fisheries monitoring programs in the affected area, and also control data and information generated by these programs. Respondents argued that this information is not shared by the hydropower companies (SI.4) (84% of the

interviewees) (**Supplementary Table S1**). In this sense, 50% of personnel from non-governmental organizations questioned the effectiveness of monitoring program oversight carried out by the Federal Environmental Agency. This situation suggests a lack of equity in power and participation between the organizations (SI.5).

Theoretically, any technical information, as well as information acquired through monitoring programs should be presented and discussed by the hydropower companies with civil society in public hearings, with the working group on the impacts of fisheries and dams, and with fisheries monitoring program participants. However, respondents demonstrated that they have little knowledge about these discussion spaces (less than 20% of interviewees), especially in the fishers group. It is noteworthy that only 36% of the fishers interviewed knew about the fishery compensation plan, of which they are ostensibly the main beneficiaries (**Supplementary Table S1**).

The dialogue (or lack thereof) among stakeholders (D.3) was viewed as negative after the dams construction by the majority of the interviewees (**Supplementary Table S2**). Below, we share some interviewee testimonies that express this finding:

"[...] *my impression is that there is no dialogue. It was a deaf and mute conversation. No one wanted to see or solve anything in meetings* .... " (Hydropower company employee).

"[...] *it seemed to me that even the environmental agencies did not decide. It depended on the interest of local politicians, it always depended on who was in charge ... there was no local communities' participation in the decisions about fishing.* " (Non-governmental organization).

"[...] *IBAMA's relationship with the hydropower companies is complex and varied. There were many initiatives, multiple ways of relating both at the technical level and at the political level. At the technical level, we tried to have a close relationship, we actively participated in the conception and we had a huge responsibility in its execution. The relationship worsened after the LO (operating license) was granted, and I don't see the IBAMA relationship with the dam company as good as it was before. It became more bureaucratic and we were not able to open local spaces for conversation, which is very negative.* " (Hydropower company employee).

"[...] *the problem is how the staff (from dam-builder) dialogue with society. The studies are clear about the environmental impacts, there is no doubt. The problem lies in the connections with society, which is willing to participate and also give an opinion. There are provisions for this to be transparent. But there is a lot of resistance in doing this because there is no fertile environment for this discussion. Our councils have become very weak for these discussions and civil society is not prepared. Besides, the companies are not ready to discuss this. They do not see this as important to legitimize the process.* " (Federal government employee).

Most of the reasons cited for this scenario are related to management problems and conflicts of interest between organizations (D.3; **Supplementary Table S2**). The group of government and users highlighted problems with the fisheries monitoring program, as well as political conflicts and interests between organizations. The lack of trained personnel, in governmental entities, to monitor hydropower companies' proposals for compensation and alternative income generation, was cited for all stakeholders. On the other hand, non-governmental organizations personnel emphasized 1) an increase in the number of fishers; 2) management problems within organizations; and 3) political and interest conflicts between organizations.

Some testimonies that voice this result are:

"*... I see that, unfortunately, economic power always overlaps with social interests, especially considering vulnerable social groups such as riverine communities and fishers. I regret the ignorance of the public agencies regarding maintaining a minimum of condition for these people. I see the environmental agency (IBAMA) completely alienated, always connected to the version given by the hydropower companies* (State public prosecutor).

"*... the MPA* (Ministry of Fisheries and Aquaculture) *is an agency that is very accessible to fishers, but it seems that it does not know how to walk. Chico Mendes Institute for Biodiversity Conservation (ICMBIO) lives in poverty, never has financial resources to do anything, so it can't do anything ... only understands that sustainability is forbidding fishing ... can't open up for discussion; IBAMA is an enforcement body qualified to supervise but has no legs for that, lack of resources, sporadic inspections, and Secretary of State for Environmental Development (SEDAM) is the great problem for fishing within the State.* " (Non-governmental organization member).

Most of fishers interviewed (94%) are affiliated with the municipal association or colony, what could express their social capital (SI.1). However, 38% of them reported that they do not have the power or leadership (SI.2) to help them solve fishing problems and few (28%) recognize the colony presidents as leaders.

About the procedures for decision-making (D.4) in the fisheries system, the entity responsible for fishing management is the State Environmental Agency (cited by 56% of the interviewees), that should consult the Technical Chamber of Fisheries (TCF). According to 84% of the interviewees, they have not had the opportunity to attend meetings or discuss fisheries with the TCF (**Supplementary Table S2**). The responses about the TCF are negative, revealing that this chamber is used to legitimize pre-defined government decisions with little stakeholders' participation, which leads one to believe that autocratic management practices were used.

There were changes in the fishing rules after the dam implementation (SI.6) according to 30% of the interviewees (**Supplementary Table S2**). One example is that fishers were banned from fishing in areas where they fished, which required them to adapt to new fishing methods and to where tehy traditonally fish in more distant locations. Most of them (84%) claimed that they have not participated in discussions about changes caused by hydroelectric dams. This result reinforces gaps in stakeholder's participation (SI.7).

Cognitive-Normative Configuration

All three major groups of interviewed stakeholders perceived changes in fisheries over the past 10 years. The majority of interviewees (78%) considered the construction of the dams

to be the most important factor triggering these changes (D.5) (**Supplementary Table S3**). According to three stakeholders groups, dams have caused significant changes in the riverine communities' livelihoods. Many of them are negative and relate to economic losses due to changes in fishing activity, including a decrease in income from fish sales, increased costs of the fishing activity, and a decrease in fish abundance. Changes related to fish and fisheries are also negative. The three groups agreed and reported these changes in decreasing order of importance: decrease in fish abundance, changes in the aquatic system, and changes in fish migration patterns (**Supplementary Table S3**).

As mentioned before, according to Brazilian rules regarding environmental licensing of hydroelectric dams, the goal (D.6) of mitigation/compensation is that: "*the impacts caused on fisheries should be mitigated and/or compensated, to guarantee the environmental sustainability and the improvement of the livelihoods of the impacted populations*" (Technical Instruction n°. 060/2008).

According to 30% of the interviewees, there were no fishing conflicts in the region prior to implementing the dams (D.7; **Supplementary Table S3**). However, 22% reported that there was a conflict between fishers and enforcement agents, and 18% reported conflicts for fishing areas. They mentioned that during the dam implementation, new conflicts appeared, including conflicts between fishers and dam construction companies (34%), increased conflicts between fishers and enforcement agencies (30%), and disagreement related to changing rules regarding fishing areas (42%). The fishers pointed out that they were prohibited from fishing on the rocks near the dam, where they traditionally fished, and that their fishing areas became inaccessible or were damaged by dam construction.

The fragility of the system, especially concerning management, is highlighted by suggestions for improvement (D.8) such as: creating economic alternatives and management of the fishing activity; recognition of fishers' rights; improvement of dialogue between entities; and the implementation of improved and independent monitoring processes (not controlled by the hydropower companies). (**Supplementary Table S3**). A negative perspective for the future of the fisheries system was reported by more than 90% of interviewed people. This perspective is expressed by the following examples: *"[...] fish will not exist in 10 years . . . there won't be any fish in the river, and there won't be anyone to fish in the river* (Fisher).

DISCUSSION

Results from this study strongly suggest that hydroelectric dam construction has caused profound negative effects in the Madeira River region. Impacts extend not only to biophysical elements and processes, but also to social and institutional relationships, fish abundance, and fishers' access to fishing resources. As noted in this and in other studies, these changes have also affected livelihoods and fishing activities, reducing catch and consequently revenue (WCD, 2000; Gutberlet et al., 2007; Santos et al., 2018; Arantes et al., 2019; Figueiredo et al., 2019; Lima et al., 2020). These impacts are attributable in large part to physical, hydrological, and ecological changes, but our results indicate that governance failures have likely contributed to exacerbating some effects (e.g., through changing rules that limit access to traditional fishing areas) and prevented appropriate mitigation or compensation actions. Based on the results presented here, as well as building on previous research, we suggest that analyses of fisheries systems should integrate stakeholders and their interactions, as well as governance processes, in addition to the hydrological and ecological attributes as drivers of dam impacts and mitigation effectiveness (Ostrom 1990; Lorenzen et al., 2007; Lorenzen 2008; Siciliano et al., 2016). In a social-ecological system such as fisheries systems, the governance, including institutional arrangements and their relationships and conflicts, promote understanding of social complexities and how these relationships might affect fisheries sustainability in the long-term (Gutberlet et al., 2007).

Whereas all stakeholders perceived fishers to be at the center of the fisheries system, their relationships with relevant governance agencies were weak even before hydropower development and were further weakened because of it. Weak organization and representation of artisanal fishers are factors Brazil, which contributes to the fisheries sector's invisibility in the context of hydropower development (Doria et al., 2018b). The extent to which local impacts could be mitigated by institutional arrangements and affected communities' ability to withstand impact are partly determined by their social capital and resilience (Siciliano et al., 2016). In this sense, it was observed that although the majority of users (fishers) are members of the Fishers' Associations, these organizations are very fragile, disorganized, and lacking strong leadership. In the case of the Madeira river, organizations are weakened by the abrupt change in the system caused by dam construction. In this already fragile context, organizations are forced to recreate new forms of governance, involving a transformed ecosystem, internal actors and new external actors. The new rules of governance, after dam construction, were not adapted to local fishers' needs and conditions. The affected stakeholders were not able to participate in rule adjustments, there was no governance compromised with the fisheries system sustainability, and no equity of participation and balance of power among group members. Strengthening fishers and their organizations to improve their representation and participation in the decision-making process is therefore crucial, as is the recognition of fishers' rights (Siciliano et al., 2016).

In addition to dialogue, effective impact assessment and mitigation requires understanding and quantifying ecological, fisheries and social impacts, as well as considering trade-offs and synergies. In the Madeira, this was hampered by hydropower companies' control over environmental and fisheries impact studies. There was an evident lack of dialogue and interaction between the agencies responsible for the dam licensing process and for fisheries management. This evident disconnect reinforced negative opinions of the assessments and the feeling of abandonment among fishermen, thus accentuating conflicts between interested parties. Research on dams' social impacts

shows that gaps in knowledge and failures to understanding the trade-offs involved are common in the Americas (Kirchher et al., 2016), Africa, and Asia (Legese et al., 2018; Siciliano et al., 2018). Poor data management and communication is a problem that needs to be addressed to improve the planning and mitigation of hydroelectric dams and to support more transparent assessments and communication of trade-offs involved in dam development decisions (Kirchherr et al., 2016; Athayde et al., 2019).

Also, we found that the governance arrangements of the Madeira fisheries system do not display key characteristics associated with resilience and sustainability (Ostrom, 1990; Agrawal and Ostrom, 2001; Berkers and Ross 2013). In this situation, a participatory process may be initiated to help re-evaluate governance arrangements and support interventions aimed at enhancing resilience and sustainability (Legese et al., 2018).

Finally, to address the main problems mentioned by the stakeholders, which directly affect the fisheries system's governance and sustainability, we offer the following recommendations:

- Strengthening fishers' access to information and institutional organization to improve their participation in the decision-making process by: providing clear information (before, during, and after the project's implementation) on all stages of the process, explaining how potential impacts are monitored and/or mitigated, clarifying how they can participate in discussion spaces, and offering leadership training courses;
- Recognition of fishers' rights by creating spaces for participatory and equitable consultation, discussions and decision-making about fishing and the impacts generated by the dams, and offering, when possible, free legal support for fishers and their associations;
- Creating economic alternatives and management strategies for the fishing activity that target place-based needs and opportunities. This could include technically supporting aquaculture practices, local fishers' input to select potential areas for installation and management of such initiatives, promoting community management of reservoir lakes and natural lakes, and supporting the fish production chain from the affected communities, adding value to managed fish;
- Strengthening of government agencies responsible for fisheries management and for evaluating/monitoring the project's impacts on the activity, with increased financial and human resources training to assess, monitor and manage impacts and fisheries, as well as implementing independent monitoring processes with government control and support from public research entities;
- Improving the dialogue between entities to guarantee opportunities for communication and follow-up with those affected. This could be done through previous training programs, empowerment of fishers and representatives, and regular meetings between the fisheries system stakeholders, with equitable participation in discussions and decision-making on impacts, as well as on the results of monitoring and mitigation initiatives.

Our study provides an in-depth analysis of dam-related changes in the governance system of a tropical river fishery. Results indicate that governance failures can contribute to exacerbating dam impacts, and that these failures have prevented appropriate mitigation and/or compensation efforts. While this study was based on a case study focusing on the Madeira River in the Brazilian Amazon, the results point out to specific governance attributes that are likely to affect many other systems. These insights might help practitioners and scientists to identify, examine, and when necessary, to address such attributes in their focal systems.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. This study is supported and in accordance to the Institutional Review Board Protocol # 2014-U-0490, of the University of Florida, for research conducted in connection to the Amazon Dams International Research Network (ADN).

AUTHOR CONTRIBUTIONS

CD research design, data collection and analysis, article writing. JD-G research design, article writing and review. MP article writing. KL article writing and review. SA research design, article writing and review.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.575514/full#supplementary-material.

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