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MULTIDISCIPLINARY APPROACH TO IDENTIFICATION OF FISHERY SYSTEMS IN AMAZONIAN RESERVOIR: CASE STUDY IN TUCURUÍ DAM

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ABSTRACT

Dams cause profound changes in the structure of environments and local fishing practices. One example of these impacts is the Tucuruí dam, in the southeast of the state of Pará, in northern Brazil. The changes were gradual, but eventually established unique fishery systems and capture techniques that were consolidated over time. The present study used a rapid analysis technique based on the *Métier* principle to identify 14 fishing systems with distinct characteristics, although a more holistic approach (dimensions: economic, social, technological, and management), supported the identification of four clearly distinguishable groups. From the management perspective, studies of this type are important because they permit the establishment of more effective practices based on the deficiencies found in the different systems or their respective groups.

Keywords: rapfish method; dams; Amazon rivers.

ABORDAGEM MULTIDISCIPLINAR PARA A IDENTIFICAÇÃO DOS SISTEMAS PESQUEIROS EM UM RESERVATÓRIO AMAZÔNICO: ESTUDO DE CASO NA HIDRELÉTRICA DE TUCURUÍ

RESUMO

As barragens causam profundas mudanças na estrutura dos ambientes e nas práticas de pesca das áreas sob sua influência. Um exemplo dessas mudanças ocorreu na barragem de Tucuruí, no sudeste do Pará, Brasil. As mudanças foram tipologias de pesca graduais e estabelecidas como formas únicas de captura que foram consolidadas ao longo do tempo. Neste documento, usando uma técnica de análise rápida baseada no princípio de *métier*, foram identificados 14 sistemas de pesca com características particulares, mas, com base em uma observação mais holística (dimensões ecológica, econômica, social, tecnológica e de gestão), quatro grupos de sistemas pesqueiros foram claramente definidos. Do ponto de vista do gerenciamento, estudos dessa natureza são importantes, pois permitem o estabelecimento de práticas de gerenciamento mais criativas, baseadas nas deficiências encontradas nos sistemas ou grupo de sistemas.

Palavras-chave: método rapfish; hidrelétricas; rios amazônicos.

INTRODUCTION

Given the importance of fisheries in the Amazon region, the impacts of hydroelectric dams on fish stocks have profound socio-cultural and economic implications for local communities. Fishing was practiced in the Amazon well before European colonization, and fish is an essential component of the diet of its riverside and indigenous peoples (Cintra et al., 2011). In the present day, fish continues to be an essential resource for human communities throughout the region, where it is one of the principal sources of both animal protein and income (Cerdeira et al., 1997).

A reliable and systematic evaluation of these impacts is fundamentally important for an adequate decision-making process in fishery management. Unfortunately, in most cases, no satisfactory evaluation is available. One of the most important approaches for the evaluation of impacts is the observation and measurement of changes in fishing practices, in particular, the manners in which the different environments are exploited by local and traditional populations.

The construction of a network of major hydroelectric power plants in the Amazon basin began in the 1970s, when commercial fisheries operated by professional fishers began to target the reservoirs formed by these impoundments. The catches of these fisheries are marketed locally but may also be traded in other regions of Brazil (Santos and Santos, 2005). The fisheries that operate on reservoirs in tropical regions around the world have a number of characteristics in common, in particular, the small scale of most systems, which are artisanal, and constitute the primary source of employment, income, and the production of protein for the riverside populations (Agostinho et al., 2007).

A number of ichthyological studies have been conducted in the area of the Tucuruí reservoir since the impoundment of the Tocantins River. These studies include the inventories of Santos et al. (1984) and Santos and Santos (2005), the identification of the principal target species (Cintra et al., 2007), the analysis of fisheries and vessels (Cintra et al., 2009) and artisanal fishers (Cintra et al., 2011), as well as the study of Mérona et al. (2010), which provided an overview of the local fish and fisheries 20 years after the impoundment of the Tocantins River.

Given the large number of individuals involved in this activity and the decline of artisanal fisheries around the world (Pauly et al., 2002), including the Brazilian state of Pará (Bentes et al., 2012), a reliable database is essential for the understanding of the dynamics of artisanal fisheries in impacted areas, such as the Tucuruí reservoir. This database will be fundamental to the development of effective measures for the management of the local fisheries, and the protection of the region's species and ecosystems.

A multivariate comparison of fishery production systems highlights the need for differential management measures for different systems. This multivariate approach has become increasingly popular in recent years, leading to the development of packages of statistical tools that have made the management process more cost-effective (Clarke et al., 2008; Gavaris, 2009; Hinz et al., 2009).

The present study identified and described the different fishery modalities found in the Tucuruí reservoir through the application of the concept of production systems, which permitted the definition of the types of fishery that operate in the reservoir and downstream from the dam. This classification should contribute to the development of public policies that guarantee economic growth while also incorporating measures that ensure the conservation of the environment, as well as providing a database for the design and development of future studies in ecology, biology, and fishery yield and effort in the region.

MATERIAL AND METHODS

Study area

The Tucuruí dam (Figure 1) is located on the main channel of the Tocantins River in the Brazilian state of Pará, approximately 7.5 km upstream from the town of Tucuruí and 300 km south of

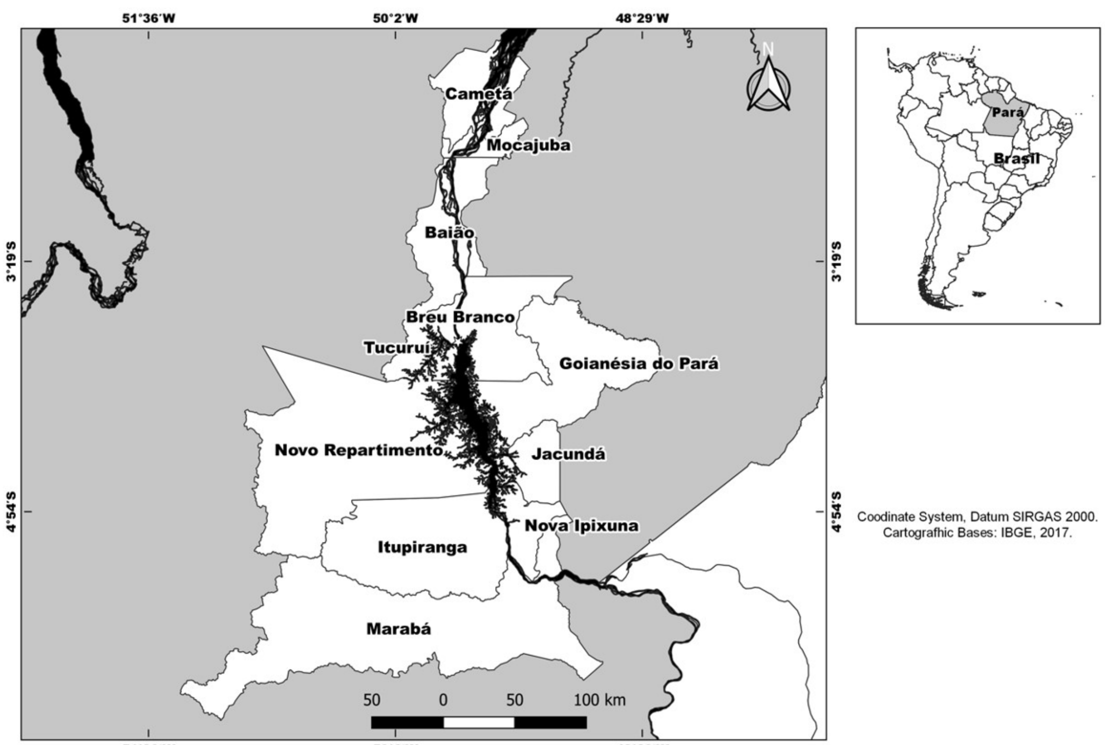

Figure 1. Location of the Tucuruí dam in southeastern Pará, northern Brazil.

the state capital, Belém. Inventories and feasibility studies for the construction of the Tucuruí dam were initiated in 1972, although construction only began in 1976, and the power plant came into operation in 1984. The Tucuruí dam was initially projected to supply power for the local aluminum smelters and to stimulate the industrialization of the eastern Amazon region, as well as to reinforce the national grid (CMB, 2000).

The Tucuruí reservoir is located on the Tocantins River between latitudes 03°43'S and 05°15'S and longitudes 49°12'W and 50°00'W, as has flooded a total area of 2,430 km^2, based on the analysis of satellite images (Fearnside, 1999), although Fearnside (2015) estimated the area as 2,830 km^2. The reservoir has a perimeter of 6,400 km, a mean width of 14.3 km (reaching a maximum width of 40.0 km), and a mean depth of 17.5 m, increasing to 75.0 m in the vicinity of the dam. The mean water residence time is 51 days, although this period may reach 130 days in marginal areas of the reservoir. The flooding of the reservoir led to the formation of approximately 1,800 islands (CMB, 2000).

The Tucuruí reservoir has a volume of 45.8 billion cubic meters. The maximum height is 74 m, with a normal operating height of 72 m and minimum of 58 m (Fearnside, 2015). The local climate is hot and humid tropical, with a mean annual temperature of 25–29°C, minimum of 18–22°C, and maximum temperatures of 32–36°C (Fearnside, 2015). The prevailing winds in the region are in the northern quadrant, with a mean speed of 14–17 km h^{-1}. The climate of the Tucuruí region has two well-defined seasons, a rainy season from December to May, with intense rains of convective origin reaching 500–600 mm per month, and a dry season (June to November), with a peak drought in August and September, when monthly rainfall is typically around 30 mm. As the region are located in the vicinity of the Equator, temperatures are high throughout the year with monthly means of over 24°C (Fisch et al., 1990).

The principal control mechanism of the volume of water in the reservoir is the operation of the dam. To maintain an ideal level for the generation of electricity, the spillway gates are adjusted constantly to retain or release water, depending on the seasonal rainfall level and river discharge. Prior to the onset of the rainy season, the spillway is opened to drain the reservoir prior to the increased input of water, with the level of the reservoir being lowered to absorb the increased volume of water. At the onset of the dry season, the spillway is closed to avoid a possible decrease in the generation of electricity (Cintra et al., 2011).

Data collect

To classify the local fisheries, information was obtained from fishers, vessel owners, and fishery stakeholders (community leaders, union representatives, and government agents) through interviews conducted at the landing sites. The data were obtained using semi-structured interview forms, which were applied between August and December 2019 in 11 cities showed in the map (Cametá, Mocajuba, Baião, Breu Branco, Tucuruí, Goianésia do Pará, Novo Repartimento, Jacundá, Nova Ipixuna, Itupiranga and Marabá). The interviews were conducted using the non-probabilistic snowball technique (Biernacki and Waldorf, 1981), in which each interviewee indicates the next individual to be interviewed up to a saturation point, at which the respondents have no new information to add to the database. A total of 165 interviews were realized in the cities with about 15 by city. These data were complemented with the specific knowledge and experience of the research team members, and secondary data from the scientific literature, when available, which were incorporated in the database.

Data analysis

The data were tabulated and analyzed in Microsoft Office Excel 2010 spreadsheets. The RAPFISH method (Pitcher and Preikshot, 2001) was applied. This approach is based on the concept of the "Métier", proposed by Mesnil and Shepherd (1990), which divides fishing systems into five categories of analysis: social, ecological, technological, economic, and management (Table 1).

The RAPFISH method is a rapid, simultaneous, and multidisciplinary technique for the assessment of the sustainability of fisheries (Pitcher et al., 1998, 2013). This approach employs simple, easily assessed attributes to provide a rapid, low-cost, and multidisciplinary assessment of the status of a fishery in terms of its sustainability (Pitcher et al., 1998, 2013).

A list of 39 attributes was elaborated, with each attribute being separated by a dimension, and the data matrix being derived from the information provided in each interview. The attributes were delimited based on characteristics that are theoretically relevant for the analysis of the sustainability of the system. Prior to the application go the statistical procedures, the data were normalized by the reduced mean ($Z = (x - \mu) / \sigma$) to reduce stress. Two theoretical systems, one "good" and one "bad", were created with the best and worst attributes of each of these variables according to their potential for sustainability, in order to provide benchmarks for comparison purposes.

A *K means* analysis was run. Clustering is a broad set of techniques for finding subgroups of observations within a data set. A Similarity Profile Analysis (SIMPROF) was used to test the significance of the groups, in order to downsize the number of systems. These analyses were run in PRIMER 7.0 (Plymouth Routines in Multivariate Ecological Research).

RESULTS

The multidimensional scaling analysis with SIMPROF arranges the fisheries clearly along vertical and horizontal gradients based on the types of environment, vessel, and fishing gear used (Figure 2). A synopsis of each group performed were summarized in Table 2.

Group 1 – This group include systems practiced by fishers over 18 years old with incomplete elementary education, non-family work relationships, and complementary sources of income, who participate in social programs. They sell their catches to a first intermediary. They use low catch maintenance technology and are organized through class entities and communities. Group that stood out for its technological dimension.

Table 1. Attributes and indicators (numerical or descriptive) used to characterize the fishery production systems of the Tucuruí reservoir in the: social, ecological, technological, economic, and management dimensions.

Dimmension	Attributes	Description
Social	Residence - Far/Near	0 - Far; 1 - Near
	Fishing career	0 - Less 20 years; 1 – 20-30 years; 2 - more than 30 years
	Schooling	0 - no have; 1 - have
	Schooling	0 - illiterate; 1 - fundamental incomplete; 2 - fundamental complete; 3 - High school incomplete; 4 - High school complete; 5 - college incomplete; 6 - college complete; 7 - postgraduate
	Working relationship	0 - independent; 1 - alone; 2 - with family
	Crew fishing compostion	1 - women; 2 - men; 3 - women and men
	Social organization	0 - no; 1 - yes
	Age	0 - Less than 12 years old; 1 - 12 -18 years old; 2 - more than 18 years old
	Social security	0 - not registered; 1 - registered
	Number of family member	0 - more than 10; 1 - 5 - 10; 2 - fewer than 5
	Healthcare	0 - no; 1 - yes
	How many family members contribute?	0 - Less than 2; 1 - 3 or 4; 2 - 5 or more
	Social programs	0 - no; 1 - yes
	Conflicts	0 - no; 1 - yes
	Housing quality	0 (bad) to 3(excellent)
	Workload	0 - More than 8h per day; 1 - 4 to 8h per day; 2 - less than 4h per day
Ecological	Composition of the catch	0 - more than 10 species; 1 - 6 to 10 species; 2 - until 5 species
	Discarded bycatch	0 - high (>50% of total biomass); 1 - Medium (25%<x<50% of total biomass); 2 - low (< 25%)
	Life phase of catch	0 - <25% adults; 1 - 50%>x>25% adults; 2 - > 50% adults
	Dangerous species are caught?	0 - yes; 1 - no
	Are spawning females caught?	0 - yes; 1 - no
	Frerquency of fishing	0 - Twice a day; 1 - everyday; 2 - Twice every other day; 3 - Once every other day
	Divertsity of fishing techniques	0 - High (operates with more than 3 systems); 1 - Medium (in 3 systems); 2 - Low (2 systems); 3 - 1 system
Economic	Marketing	0 - not sold; 1 - sold to first intermediary; 2 - sold to second intermediary; 3 - sold to consumer
	Income	0 - R$ 0 - R$ 30; 1 - R$ 30 - R$ 50; 2 - above than R$ 50 1 US$ base value = R$ 5,00
	Maintenance costs (gear+ vessel)	0 - High (more than R$ 200); 1 - medium (R$ 101-200); 2 - low (Less than R$ 100); 1 US$ base value = R$ 5,00
	Frequency of fishing (costs)	0 - Once every other day; 1 - Twice every other day; 2 - everyday; 3 - Twice a day
	Diversity of fishing techniques	0 - 1 system;1 - low (2 systems); 2 - medium (3 systems); 3 - high (more than 3 systems)
	Preparation of product	0 - Salted; 1 - whole on ice; 2 - gutted on ice; 3 - fillet
Technological	Selectivity of fishing gear	0 - low; 1 - medium; 2 - high
	Product maintenance technology	0 - none; 1 - low; 2 - medium; 3 - high
	Use of vessel	0 - No vessel; 1 - rowboat; 2 - up to 10m, with outboard motor; 3 - over 10m with inboard engine; 4 - aluminum boat with outboard
	Preparation of product	0 - whole in ice; 1 - gutted on ice; 2 - salted; 3 - fillet
Management	Specific legislation	0 - No; 1 - Yes
	Formal organization	1 - No; 1 - Yes
	Informal organization	2 - No; 1 - Yes
	Users represented	0 - none; 1 - low; 2 - high
	Level of environmental awareness	0 - Bad; 1 - Good; 2 - Very good
	Supervision/monitoring efficiency	0 - Does not exist; 1 - low; 2 - Medium; 3 - High

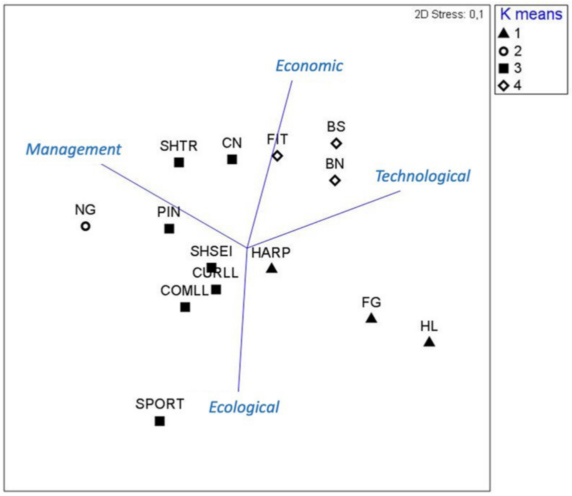

Figure 2. Multidimensional scaling of the similarity profiles of the fishery production systems applied to the area of the Tucuruí reservoir in northern Brazil, showing the five groups described in the text. To check the systems codes, see Table 2.

The Harpoon (ARP) is a fishing system for the capture of the peacock bass (*Cichla* sp.). This technique is used primarily in the reservoir, in shallow areas with rocky bottoms or the presence of tree trunks that provide shelters for these fish. The fishers use small boats equipped with a long-tailed outboard motor known locally as the 'rabeta' and use pneumatic harpoons.

The Fiber Gillnet (FG) system uses gillnets made from polyamide monofilament yarn and is practiced in the reservoir or downstream from the dam using fixed gear or drift nets to capture mapará (*Hypophthalmus marginatus* Valenciennes, 1840) and *Plagioscion squamosissimus* Heckel, 1840). Small rowboats or boats with 'rabeta' outboard motors.

The handline (HL) is a system used to fish peacock bass, *P. squamosissimus*, *Brachyplatystoma filamentosum* Lichtenstein, 1819, and *Brachyplatystoma rousseauxii* Castelnau, 1855. This system is used in the reservoir near the dam, at fish aggregation sites, or downstream from the dam in the river channel. The system uses a line, hook, and natural bait. The fishers use small rowboats or 'rabeta' outboard motors to access the fishing grounds.

Table 2. Principal characteristics of the fishery production systems used in the Tucuruí reservoir in Brazil. ARP = harpoon; FG = fiber gillnet; HL = hand line; NG = Nylon® gillnet; FG = cast-net; SPORT = sport fishing; CURLL = curricão long line; COMLL = common long line; PIN = pindá; SHTR = shrimps' trap; SHSEI = shrimps beach seine; FIT = fish trap; BS = beach seine; BN = block net.

Group	Code	Gear	Target species	Environment	Working relationship
1	ARP	Arbalet/pneumatic weapon	Cichla spp.	Reservoir	Non-family
	FG	Gillnet	*Hypophthalmus marginatus*, *Plagioscion squamosissimus*	Reservoir and river	Family
	HL	Line with hook	Cichla spp.; *Plagioscion squamosissimus*; *Brachyplatystoma filamentosum*; *Brachyplatystoma rousseauxii*	Reservoir and river - downstream	Non-family/alone
2	NG	Gillnet	*Brachyplatystoma filamentosum*; *Brachyplatystoma rousseauxii*	River - downstream	Partnership
3	FG	Cast-net	*Plagioscion squamosissimus* *Prochylodus nigricans*	River - downstream	Non-family
	SPORT	Stick with artificial bait	Cichla spp.	Reservoir	Non-family
	CURLL	Bottom long line	*Brachyplatystoma filamentosum*; *Brachyplatystoma rousseauxii*	River - downstream	Non-family
	COMLL	Bottom long line	*Brachyplatystoma filamentosum*; *Brachyplatystoma rousseauxii*	River - downstream	Non-family
	PIN	Stick with live bait	Cichla spp.	Reservoir	Family
	SHTR	Trap	*Macrobrachium amazonicum*	Reservoir and river - downstream	Family
	SHSEI	Beach seine	*Macrobrachium amazonicum*	River - downstream	Non-family/alone
4	FIT	Trap	*Pimelodus blochii*; *Leporinus affinis*	River - downstream	Non-family/alone
	BS	Beach seine	*Hemiodus unimaculatus;* Curimata sp; *Geophagus proximus*	River - downstream	Non-family
	BN	Beach seine	*Hemiodus unimaculatus;* Curimata sp; *Geophagus proximus*	Reservoir and river - downstream	Non-family

Group 2 – Include only one system debated due to the performance issues of the fishing gear and therefore stood out in the management dimension.

The Nylon Gillnet (NG) is a system that uses gillnets made of multifilament polyamide yarn, which is practiced downstream of the dam with either fixed or drifting nets, for the capture of the *piraíba* or lau-lau catfish (*B. filamentosum*) and the Amazonian migratory catfish (*B. rousseauxii*). This system uses small and medium-sized vessels powered by inboard engines, 'rabeta' outboards or oars.

Group 3 – This group is formed by systems in which the fishers are over 18 years old and have a low level of education (incomplete primary education), and usually have complementary income activities. They have families with 5–10 members and participate in social programs. The cost of maintaining the equipment is low (less than US$ 20.00) in comparison with other systems.

The shrimp trap (SHTRA), known locally as the 'matapi', is a fishing system practiced in both the reservoir (for subsistence and the capture of bait) and downstream from the dam (for sale). The matapi traps target *Macrobrachium amazonicum* (Heller, 1862). In the reservoir, the traps are set at the docking piers of the islands, while downstream from the dam, the fishers travel 5–7 km to at their traps.

The cast-net (CN), known locally as the 'tarrafa', is a system that uses cast-net, to capture primarily white hake (*Plagioscion squamosissimus*) and curimatã (*Prochylodus nigricans* Agassiz, 1829). This system is used downstream from the Tucuruí dam in rocky environments, close to rapids and deeper stretches of the river. These fishers use small vessels powered by 'rabeta' outboard motors or oars.

Pindá (PIN) is a fishing system used to capture peacock bass. This system targets areas in the reservoir near islands, where tree trunks and aquatic vegetation are found in the water. Bamboo poles and live bait are used. The fishing grounds are reached in small boats equipped with 'rabeta' outboard motors, with shorter distances being covered using rowboats.

The Shrimp beach seine (SHSEI) is a system that uses a seine net with wooden handles at each extremity, which is dragged by two fishers simultaneously. This system is used on beaches or shallow sandbanks for the capture of freshwater prawn, in particular, *M. amazonicum*.

The Curricão Longline (CURLL) is an alternative longlining system used to capture *B. filamentosum* and *B. rousseauxii*. This horizontal longline is anchored permanently or temporarily at the ends of its main line and a float at the permanently anchored end. These lines are also deployed downstream from the dam at the channel margins, using small boats powered by 'rabeta' outboard motor.

The Common Longline (COMLL) is used to capture *B. filamentosum* and *B. rousseauxii*. This type of linguine is horizontal with anchoring weights and floats at the ends the principal line. These lines are deployed downstream from the dam at the channel margins (the river channel as it was prior to the impoundment). The fishers use small vessels powered by 'rabeta' outboard motor.

Sport Fishing (SPORT) is a system based on the use of a rod and reel with artificial bait. This system targets the peacock bass (*Cichla* sp.) along the margins of islands within the reservoir, in the vegetation and fall tree trunks. Small boats with outboard motors are used in this system.

Group 4 – This group is formed by systems that involve male fishers over 18 years old that have low schooling levels and have been involved in this activity for less than 20 years. The system is practiced near the fisher's residence, and involves a non-family working relationship, associated with representative entities. The fishers are also registered in the state social security program, participate in social programs and have complementary incomes. The income of each fishing trip is US$ 10–15.00 and the maintenance (half-yearly) and operational (monthly) costs are up to US$ 20.00.

Fish Traps (FIST), also known as 'matapis'. This passive capture technique is now rarely used, but some traditional fishers still practice this technique. The trap is similar to the shrimp matapí, but it is larger in size, appropriate for the capture of small fish such as mandi (*Pimelodus blochii* Valenciennes,1840) and Flemish Piau (*Leporinus affinis* Günther, 1864). The trap is cylindrical, with the internal edges turned inward into a cone shape, which prevents the fish from escaping. This trap is deployed downstream from the dam.

The beach seine (BS) is used on beaches downstream from the Tucurui dam and is usually deployed by two or more fishers using a canoe or boat with 'rabeta' outboard. The nets have mesh of 50–60 mm. The nets are deployed in a semicircular motion and dragged toward the beach. The principal species captured by this system are jatuarana (*Hemiodus unimaculatus* Bloch, 1794), acará-tinga (*Geophagus proximus* Castelnau, 1855), and *Curimata* sp.

Block nets (BN), known locally as 'Boqueio', are a fishing system deployed in shallow areas close to the islands in the reservoir and along the margins of the river downstream from the dam. The system is used to capture *H. unimaculatus*, *G. proximus*, and *Curimata* sp). The system uses gillnets and rowboats and or boats with a 'rabeta' outboard motor.

The Table 3 shows the measurement, obtained by *k means* analysis, of how similar the fishing groups are to each other. The highest similarity was observed between group 2 and 3.

Table 3. Quadratic distance matrix between the *K-means* groupings of the fishing systems identified in the area of influence of the Tucuruí Hydroelectric Dam - Brazilian Amazon.

	1	2	3	4
1	0	27.69	16.84	17.32
2	27.69	0	14.65	21.49
3	16.84	14.65	0	17.33
4	17.32	21.49	17.33	0

DISCUSSION

The dimensioning of the characteristics that define the different types of fishing system has been used to elucidate more efficient forms of management, given that it considers different structural dimensions, and not only those of an ecological nature. This approach was only applied to fisheries management practices in Brazil in the mid-1990s (Bentes et al., 2012). Since this time, the so-called ecosystem approach to fishery management has gained space and credibility from managers who see the method as an important tool for the consolidation of more realistic public policies.

It would be useful to apply this management approach to the specific context of hydroelectric plants in Brazil, which have a major impact on the fishery practices of traditional communities and artisanal operations. These impacts typically involve modifications of the hydrological cycle and local aquatic systems, which may invalidate some traditional fishing practices and modify existing fishery patterns (Petrere Junior and Agostinho, 1993).

After an initial period of environmental instability and high productivity following the impoundment, the local fish community will typically begin to adapt itself to the new ecosystem. The success of the colonization process will depend largely on the presence of species pre-adapted for survival in the environments created by the impoundment (Fernando and Holcík, 1982), such as sunken trunks and logs, macrophyte beds, and extensive pelagic areas. Sedentary species tend to be more successful in reservoirs because they usually have simpler life-cycle dynamics (Agostinho et al., 1999).

The management of fishery resources in Brazilian reservoirs tends to be precarious and is typically based on poor scientific data and inadequate technical practices. Historically, that is, since the 1970s, management initiatives have included fishery controls and stocking, although neither tend to be very effective. An early type of initiative was the construction of fish ladders, which are designed to mitigate the impacts of dams on fish migration. At Tucuruí, the lack of any effective long-term monitoring impedes the systematic evaluation of these initiatives. In the meantime, the traditional local fishing practices have been remodeled or redesigned to adapt to the novel aquatic environments and the need for new fishing systems.

In the present study, the 14 fishery systems were defined and distinguished easily and clearly, when each system is considered individually. When compared, however, the attributes of some of the systems converge considerably, which hampers their validation, and led to the definition of five groups. The classification proposed here nevertheless has a broader scope, in particular, through the subdivision of the artisanal fishery systems, which resulted in a combination of ecological, technological, and socioeconomic attributes, which were subsequently validated statistically (Bentes et al., 2012).

In particular, the prevalence of at least one dimension was established in each group, did not provide a clear definition of the efficiency or absence of efficiency in any of the dimensions. These systems are very artisanal fisheries, but also involve relatively complex actions, which require a certain set of skills, which means that the individuals involved in these systems may not be representative of the region's fishers, in general. In particular, harpoon fishing typically involves more experienced fishers that are also involved in other fishing systems (Cintra et al., 2007).

The flooding of the Tucuruí reservoir caused a range of environmental problems and involved many conflicting political interests. One of the most controversial issues was the prior deforestation of the area to be flooded. Despite several attempts to resolve the problem, the area remained mostly unchanged and practically all vegetation was submerged during the flooding of the reservoir. Fearnside (1999) estimated that the forest was still standing in 88% of the area flooded by the reservoir, forming what are known locally as 'paliteiros', which can be translated as 'logjams', that is, large areas with standing dead trees or accumulated masses of fallen logs. These environments provide ample substrates for the establishment of a number of different species of aquatic macrophyte, which are characteristic of the region, and may be responsible for the abundance of the reservoir's fish stocks, which are composed mainly of iliophagous and carnivorous species. The degradation of this submerged vegetation is nevertheless responsible for significant emissions of methane (CH_4) and carbon dioxide (CO_2). Fearnside (1999) estimated that the greenhouse gases produced by the flooding of the forests under the reservoir would exceed the impacts of the construction of a thermoelectric power plant (Cintra et al., 2007).

In addition to its impacts on the landscape, the construction of a hydroelectric dam has a profound impact on the livelihoods of many local families that depend on fishing as their principal source of income and protein. The shift to new fishery systems, often associated with sport fishing, as reported here, creates conflicting extremes, such as the contrast between subsistence fisheries and fishing tourism. In a highly impacted environment, sport fishing, perceived hypothetically as an ecotourism activity, imposes a new dynamic on the local artisanal fishers, who are required to provide information on fishing grounds and the geographic features of the reservoir. At the same time, however, the universe of the artisanal fishers has expanded to embrace the wider society through the establishment of market relationships mediated by their knowledge of the local fisheries (Souza and Cañete, 2015).

According Agostinho et al. (2007), the impact of hydroelectric dams on the environmental, social, and economic landscapes has stimulated ample and long-lasting debate. It is recognized the need for local fishers to organize themselves as a means of guaranteeing their rights, but the lack of organization of the fishery sector is the principal factor responsible for the proliferation of intermediaries, which results in low prices being paid to the fisher and high prices being charged to the consumer, which is typical of the current situation found in Tucuruí. The consequences of this process are clear – while the work of the fisher is undervalued, the price of the product may be inaccessible to many consumers, especially those of low income.

In addition to the establishment of novel fishing systems, as observed in the present study, the construction of hydroelectric plants also results in a new social and economic order, with major demographic restructuring, the intense exploitation of natural resources, social pressures, and impacts on protected areas (Cavalcante, 2008). The construction of the Tucuruí dam entailed an intense overlap of interests, with the demand for power being satisfied at the cost of local ecosystems. The impact has effects at different levels, intensities, and temporalities, disrupting social, economic, and environmental systems. This renders the ongoing process of technification of the region incompatible with its necessary environmental policies, especially when observed from the perspective of the region's fisheries. The effective planning of fishery policies in the context of these social and environmental changes will require much more than data on the biological characteristics of the fish species.

The recognition of the different fishery systems helps to organize the management initiatives in sectors, supporting a more holistic perspective on these fisheries, which is essential for more viable policies that are consistent with the local reality. It is essential, however, that this tool has the flexibility to adapt to the dynamic nature of the region's fishing systems and should be evaluated regularly to determine the possible changes in the organizational structure of the fisheries that define their systems.

CONCLUSION

Four major groups of fishery systems were defined based on a holistic perspective of this activity. This approach appears to be a promising management tool and accompanies the dynamics of fishing activities in relation to the use of resources and the involvement of the fishers. This point of view is important to recognize gaps and urgent needs within each identified fishing system. According to the particularity of each system, more realistic and creative policies can be established that interfere more efficiently in the conservation of species and the fishing activity itself.

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