UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
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Dissertação de Mestrado

Fishers' knowledge identifies potential socio-ecological impacts downstream of proposed dams in the Tapajos River, Brazilian Amazon

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* The terminologies ‘fisher’ and ‘fisherman’ are both defined as: “A person who catches fish for a living or for sport” (Oxford University Press, 2018). Although fisherman is more commonly used (Carolsfeld *et al.,* 2003), the author considers the term ‘fisher’ more gender neutral, for which it will henceforth be used to describe fishermen and women.

ABSTRACT

Brazil's hydroelectricity sector is rapidly expanding with several planned dams in Amazonian rivers. While the impacts of dam development on fisheries located upstream from dams have been acknowledged, impacts on fisheries downstream have been overlooked by impact assessments. This study generates fishery baseline data to analyse the socio-ecological vulnerability of small-scale fisheries located downstream from the proposed São Luiz do Tapajós dam in the Tapajos River. 171 fishers were interviewed in relation to their socio-economic situation and the fishery resources they depend upon, along a ~275 km stretch of river downstream from the dam. The results indicate that fishing is an important activity, constituting a key source of food and income for the fishers and their communities. The fishers' socio-ecological vulnerability differed according to the fish species they relied upon, their fishing site, equipment used and their dependency on fishing. However, river impoundment is expected to affect the socio-economic and emotional well-being of all fishers, putting their livelihoods and those of their families at risk. The results suggest that by ignoring the effects of dams on downstream communities, the São Luiz do Tapajós dam's impact assessment severely underestimates the downstream area and thus the number of people who would be affected. It is concluded that a thorough evaluation of all the downstream fishers needs to be included in the official impact assessment before river impoundment is begun, and that development plans should be based on these findings.

Key words: *Socio-ecological vulnerability, São Luiz do Tapajós hydroelectric dam, Small-scale fisheries, Riverine communities*

RESUMO

O setor hidroelétrico brasileiro está expandindo rapidamente com muitas represas planejadas em rios amazônicos. Embora os impactos da construção de represas em pescarias localizadas rio acima das represas tenham sido reconhecidos, o impacto em pescarias rio abaixo foram negligenciados em análises de impacto. Este estudo gera dados de referência destas pescarias para analisar a vulnerabilidade soco ecológica de pescarias de pequena escala localizadas rio abaixo da proposta represa de São Luiz do Tapajós no rio Tapajós. 171 pescadores foram entrevistados em relação à sua situação socioeconômica e aos recursos pesqueiros de que dependem, ao longo de um trecho de rio aproximadamente 275km abaixo rio da represa. Os resultados indicam que a pesca é uma atividade importante, constituindo uma fonte essencial de comida e renda para os pescadores e suas comunidades. A vulnerabilidade soco ecológica dos pescadores diferiu de acordo com a espécie de peixe da qual dependem, seu local de pesca, equipamento usado e sua dependência da pesca. No entanto, é esperado que o represamento do rio afete o bem-estar socioeconômico e emocional dos pescadores, colocando sua subsistência e a de suas famílias em risco. Os resultados sugerem que ao ignorar os efeitos de represas em comunidades rio abaixo, a análise de impacto da represa de São Luiz do Tapajós subestima severamente a área rio abaixo e assim o número de pessoas que seriam afetadas. É concluído que uma avaliação rigorosa de todas pescarias rio abaixo deve ser incluída na avaliação oficial de impacto antes que se comece o represamento do rio, e que os planos de construção devem ser baseados nesses resultados.

Palavras-chave: *Vulnerabilidade socioecológica, barragem hidrelétrica de São Luiz do Tapajos, pesca de pequena escala, comunidades ribeirinhas*

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1. INTRODUCTION

Tropical inland fisheries sustain the livelihoods of thousands of fishers and their families (Andrew *et al.,* 2007; FAO, 2018). Despite their importance they often remain data-deficient, undervalued or overlooked by policy or management programmes (Andrew *et al.,* 2007; Doria *et al.,* 2017; Begossi *et al.,* 2018; de Graaf *et al.,* 2018). This is the case in the Amazon basin, where Brazil's rapidly expanding hydroelectricity sector is causing adverse transformations to freshwater ecosystems and the subsistence the local fishers (Begossi et al., 2018; Castello et al., 2013; Castello & Macedo, 2016; Winemiller et al., 2016). Limited information, together with inadequate governance and decision-making that does not take all parties affected by the dam into consideration, exacerbates the impacts of dams (Fearnside, 1999, 2015b; Sá-oliveira, Isaac and Ferrari, 2015; Kirchherr, Pohlner and Charles, 2016; Doria *et al.,* 2017; Hess and Fenrich, 2017; de Graaf *et al.,* 2018). Whereas the upstream impacts of dams, predominantly associated with the flooding of the water storage area, are generally acknowledged by stakeholders, the impacts on downstream fisheries have largely been ignored or only evaluated for the first few kilometres downstream of the dam (WCD, 2000; Hess & Fenrich, 2017; Castro-Diaz et al., 2018).

Damming of rivers has been identified as a cataclysmic event for the aquatic environment, which compromises the structure and functioning of aquatic ecosystems. Among the greatest environmental impacts of dams are the alterations to the river's downstream flow (Castello & Macedo, 2016; Forsberg *et al.,* 2017). Dams suppress and disrupt the flood pulse, which creates the seasonal lateral overflow of rivers and lakes and inundates floodplain areas (Welcomme, 1979, 1985; Junk, Bayley & Sparks, 1989; Poff & Hart, 2002; Castello & Macedo, 2016). These floodplains serve as important sites for the feeding, reproduction and nursing of many fishes (Welcomme, 1979, 1985; Junk, Bayley & Sparks, 1989; Rosenberg *et al.,* 1997; Carolsfeld *et al.,* 2003; Agostinho, Pelicice & Gomes, 2008). Species have evolved specialised biological adaptations to this hydrological signal, in particular with respect to the reproductive and recruitment success of the populations (Welcomme, 1985; Power *et al.,* 1996; Ponton & Copp, 1997; Anderson *et al.,* 2018; Santos et al., 2018). For example, the reproduction of tropical fishes is often set in motion by flooding and many fishes have adapted their gonads to spawn at the beginning of the flood to allow their eggs and larvae to drift into the floodplain areas, increasing offspring survival (Welcomme, 1985; Ponton & Copp, 1997; Bunn & Arthington, 2002; Agostinho *et al.,* 2004; Poulsen *et al.,* 2004; Song *et al.,* 2017). Furthermore, several studies have found positive associations between the occurrence, duration and height of flood pulses and fishery yields (Junk, Bayley & Sparks, 1989; de Mérona & Gascuel, 1993; Ribeiro, Petrere Junior & Juras, 1995; Jackson & Ye, 2000; Agostinho *et al.,* 2004; Isaac *et al.,* 2015). Conversely, reduced river flow caused by damming decreases the extent of flooded areas, which leads to a reduction in food availability and adversely affects species that frequent these areas (Rosenberg *et al.,* 1997; de Mérona *et al.,* 2010; Castello &

Macedo, 2016; Song *et al.*, 2017). Furthermore, it can destroy spawning grounds by making them inaccessible or interrupting spawning cues, adversely affecting the reproductive success and population recruitment of the fish species (Petrere, 1996; de Mérona *et al.,* 2010; Zhong & Power, 2015; Anderson *et al.,* 2018; Santos *et al.,* 2018).

Impoundment further decreases the fitness of species that perform upstream migration to the headwater of tributaries for feeding purposes, to complete their lifecycle or because their spawning grounds are located close to the dam (Barthem, 1991; Jorge & Ferreira, 2016; Forsberg *et al.,* 2017; Silvano *et al.,* 2017). For example, local downstream extinction of the migratory Jaraqui (*Semaprochilodu brama),* which is known to perform longitudinal migrations in the headwaters of tributaries as a necessary part of its lifecycle, has been noted after dam construction in the Tocantins River (Hallwass *et al.,* 2013). Additionally, a study by Barthem and Ferreira (2016) has suggested that Tambaqui (*Colossoma macropomum*) is susceptible the to the construction of the SLT dam because its spawning ground coincides with the planned hydroelectricity dam.

The changes to downstream fish diversity, composition, distribution and abundance upon impoundment also cause the associated fisheries to suffer substantial losses (WCD, 2000; Agostinho *et al.,* 2008; de Mérona *et al.,* 2010; Hallwass *et al.*, 2013; Ribeiro *et al.,* 1995; Santana *et al.,* 2014; Santos *et al.,* 2018). Besides threatening the economic viability of downstream fisheries, these infrastructure projects might also compromise the cultural heritage of fisheries. For example, several studies have noted a reduction in the use of traditional fishing techniques and fishing sites after construction of Amazonian dams (Doria *et al.,* 2017; Castro-Diaz *et al.,* 2018).

Brazil generates around two-thirds of its energy from hydropower (Sperling, 2012; EIA, 2014). Regardless, only around half of the country's total estimated hydroelectricity potential is currently in operation and the country faces a massive surge in hydroelectric dam construction to be able to fully exploit its hydroelectricity potential (Hess & Fenrich, 2017; Latrubesse *et al.,* 2017). The Amazon Basin has the country's highest hydropower potential and hundreds of large (>30MW) hydroelectric dams have been built there, are planned or under construction (Hess & Fenrich, 2017, Castello & Macedo, 2016). Most of the large dams greatly exceed 30 MW and five of them are mega-dams with an installed capacity of over 1000 MW (Castello & Macedo, 2016). One of these mega-dams is the planned São Luiz do Tapajós (SLT) dam, which, when constructed, will be Brazil's fourth largest dam (Hess & Fenrich, 2017).

The SLT is planned to be built on the Tapajos River, which is one of the last remaining free-flowing Amazonian rivers to date (Latrubesse *et al.,* 2017). In August 2016, the environmental licence of the SLT dam was suspended by the Brazilian Institute of Environment and Renewable Natural Resources

(Alarcon & Millikan, 2016; Hess & Fenrich, 2017). However, the completion of the SLT dam is of political interest and the suspension is likely to be reversed (Fearnside, 2015a; Alarcon & Millikan, 2016; Ernst, Hess & Fenrich, 2017). This has already occurred several times within the licensing processes of other Brazilian dams that were considered politically important (Fearnside, 2015b). In fact, the completion of energy transmission lines for the SLT has been included in Brazil's ten-year energy plan, which implies that the SLT dam will be completed as part of the 2028 energy plan (MME, 2017).

Although some negative impacts of dam construction are considered as unavoidable trade-offs, the lack of sufficient baseline information about the dependency of downstream fishers on aquatic resources, as well as the potential underestimation of impacted area, increases the probability of the under-estimation of the dam's impacts (Richter *et al.,* 2010; Fearnside, 2015b; Doria *et al.,* 2017; Hess & Fenrich, 2017; Castro-Diaz *et al.,* 2018). In this sense, the environmental impact study (EIS) made to issue the environmental license of the SLT dam was considered weak and biased by specialists (Fearnside, 2015b).

Local Ecological Knowledge (LEK) is increasingly used to fill gaps in scientific knowledge and to evaluate environmental changes whilst enhancing communication and collaboration between researchers and resource users (Hallwass *et al.,* 2013; da Costa-Doria *et al.,* 2014; Hallwass, 2015). Amazonian fishers have detailed LEK about the environmental resources they depend upon *(Begossi et al.,* 1999; Hallwass *et al.,* 2013; da Costa-Doria *et al.,* 2014). More recently, it has also been successfully applied when evaluating the impacts of large hydroelectricity dams on fisheries (Hallwass *et al.,* 2013; Castro-Diaz *et al.,* 2018).

In this study, LEK of the fishers in the lower and middle Tapajos was used to characterise fisheries from 16 communities along a 275km stretch of river downstream from the proposed SLT dam. The primary objective of this study is to generate baseline data about the fishing activity and use of other aquatic resources by small-scale fisheries located downstream of the SLT hydroelectricity dam, which will be used to evaluate the potential vulnerability of the fishers to impoundment. From this baseline data and literature about the biology of fishes in this region, a scenario visualising the potential effects of the dam on the fish and the fishers was developed. The fisher's vulnerability to future hydroelectric developments was assessed and the hypothesis that the impacts of the hydroelectric development on fishing extend beyond the area officially recognised as impacted based on the EIS was evaluated. This study will act as a reference point for future ecological and economic changes.

2. METHODS

2.1 Study area

The Tapajos Basin drains an area of 493.000 km² between the latitudes of 2º and 15° south and 53° and 61° west in the Brazilian states of Pará, Mato Grosso and Amazonas. The Tapajos River expands over 851km and represents the most important tributary of the Amazon's right margin (Figueiredo & Blanco, 2014). It is formed by the confluence of the Juruena River and Teles Pires River, flowing from South to North, discharging into the Amazon River (Figueiredo & Blanco, 2014). The Tapajos River is rich in floodplain areas and marginal lagoons, characterised by flooded forests (*igapós*) as well as lakes, channels (*paranás*) and small bodies of water or creeks that are enclosed by forests (*igarapés*) that principally connect with the main river during periods of high water (Nunes, 2014; Silvano *et al.*, 2017). It is subject to the annual flood pulse where water levels increase from December-January until May-June, and henceforth decrease (ANA, 2018). These changes are perceived by the fishers who divide the year into the periods of rising and high water levels (*epoca cheia*) and subsiding and low water levels (*epoca seca*) (Nunes, 2014).

This study was conducted along a ~275km stretch of the river, downstream from the proposed SLT hydroelectricity dam (4° 33' 7,51" S, 56° 16' 42,76" W) in the state of Pará, Brazil (CNEC Worley Parson Engenharia, 2014). Apart from the division of the river's profile into lower, middle and upper Tapajos by a hydroelectric inventory study (Camargo, 2008), an official division of the river's longitudinal profile appears to be lacking. In order to account for the possible heterogeneity of the fisheries and to be able to develop adequate mitigation measures if considered necessary according to the results of this study, for the purpose of this research, the study area was thus divided into two regions based on the river's geomorphologic heterogeneity and on the previous research within the literature (Hallwass, 2015; Silvano *et al.*, 2017). The approximate distance from São Luiz do Tapajós to the city of Aveiro is 125km, it has a maximum river width of around 5km and is referred to as the middle Tapajos. The approximate distance from Aveiro to Santarem is 150km, it has a river width of around 10km to 15km and is referred to as the lower Tapajos (Fig. 1). The area considered to be impacted socio-economically according to the EIA exceed the area of biological impact (CNEC Worley Parsons, 2014). In order to be conservative, we based our impact study and the evaluation of the hypothesis whether the impacts of the hydroelectric development on fishing extend beyond the area usually recognised as impacted based on the EIS, on the larger, socio-economic impacted area, which is around 50km river distance downstream of the dam, according to the EIA (CNEC Worley Parsons, 2014).

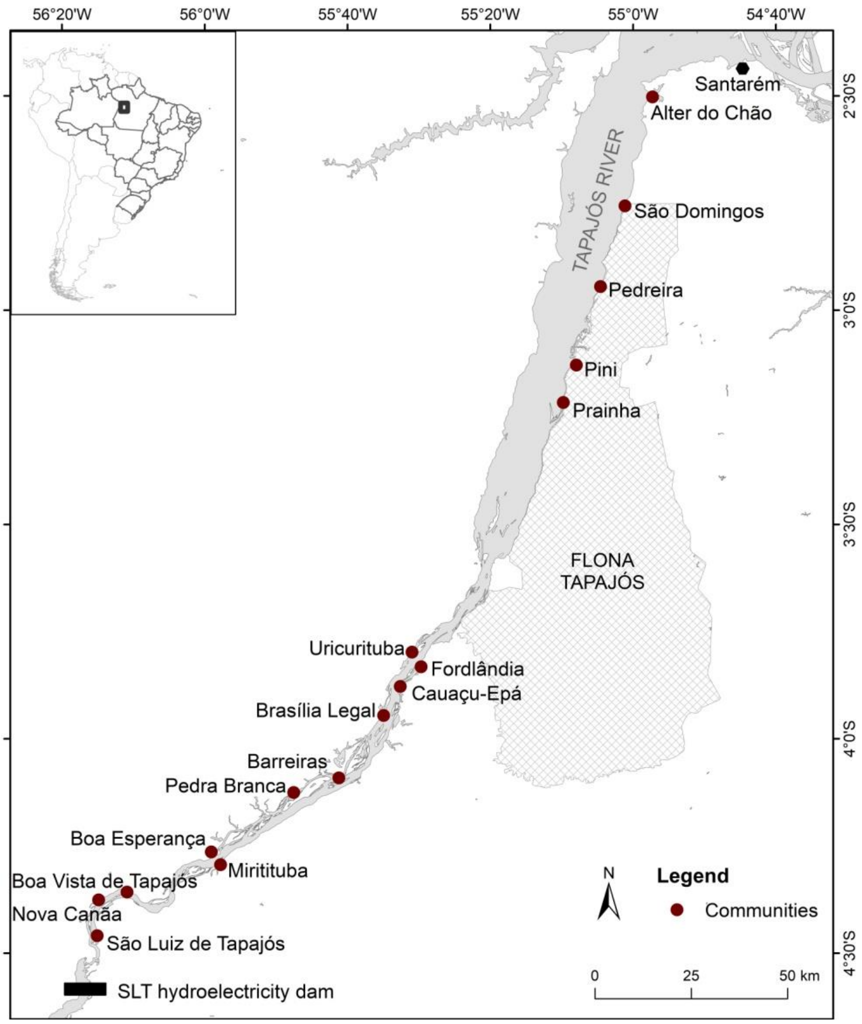

Figure 1. The lower and middle downstream regions of the planned São Luiz do Tapajós (SLT) hydroelectricity dam. Red dots indicate communities where interviews were conducted. The black rectangle indicates the planned site for the SLT dam. The inset shows the location of the studied region in Brazil.

2.2 Data collection

One hundred and seventy-one fishers from sixteen sites were interviewed between March and May 2018. The communities were selected on the basis that there was a minimum distance of around ten kilometres between each one, that they had approximately ten or more fishers and that the fishers from the community consented to participate in the study. An exception regarding the distance between the communities was made for the study sites Miritituba and Boa Esperança, as well as Nova Canãa and Boa Vista do Tapajós, which were geographically closer than ten kilometres. Some of the fishers from these adjacent communities mentioned each other when they were asked to nominate other fishers for interview, which indicated that their fishing activity was not completely independent. Consequently, the communities Miritituba and Boa Esperança, as well as the communities Nova Canãa and Boa Vista de Tapajos, were combined into individual study sites. The interviewed fishers from the city of Itaituiba were all situated within the neighbourhood of Boa Esperança and they will henceforth be referred to as the community of Boa Esperança. Miritituba and Alter do Chão are larger settlements (with up to 13000 people), however they consist of several smaller communities and the present work was conducted at the scale of these smaller communities. For simplification, these individual study sites will henceforth be referred to as communities, independent of their population sizes. Four of the communities studied are situated inside the Tapajos National Forest Conservation Unit (FLONA) (Fig. 1).

Upon arrival in the communities, the research was explained to the community leaders and oral permission to conduct the research was acquired. Next, an interview addressed to the leader inquired general information about the community, following which the leaders nominated fishers known to them to be interviewed (Appendix 1). After explaining the research and receiving their oral consent to participate in the study, these fishers were interviewed and were then asked to indicate other fishers for interview. The procedure continued until no further new names were mentioned, indicating that all fishers who were present in the community at the time of the visit had been interviewed. This so-called 'snowball' method has successfully been applied in similar studies that also interviewed fishers (Silvano *et al.*, 2006; Hallwass *et al.*, 2013). The interview addressed to the fishers was semi-structured and consisted of four parts: 1) Socio-economic profile including personal information, education, financial situation and governmental support; 2) Resources and economic activities including diet; 3) Fishing including fishing equipment and site, fishing yield, time spent fishing and commercialisation of fish; and 4) Catch composition and its development over time (Appendix 2). Since the interview is part of a larger project not all questions were used for the purpose of this study. Fish species were identified by their local common names, some of which encompass groups of species (Table 1).

2.3 Data analysis

2.3.1 Data preparation

The fishers' reported weekly time spent fishing was calculated by multiplying their time spent fishing per day by the number of days spent fishing per week, and then taking the average of all the fishers. A fishers' weekly fishery yield was calculated by multiplying the normal daily weight (kg) of fishery catches by the number of days fished and dividing this by the number of fishers participating in the fishing. Because fishing yields can vary on a daily basis, fishers were asked to state the amount of fish that they most often catch. Then the average yield of all fishers was calculated. Some fishers reported to engage in fishing trips that continued over consecutive days. It was presumed that fishers did not spend the entire time fishing, and thus consecutive days were considered as 12h fishing time within the analysis. For the calculation of weekly fishing yield, overnight fishing trips were not incorporated into the analysis because it was unclear whether the fishers' considered their overnight trips when answering the question of how many days they fished per week. However, this exclusion had a low impact on the estimation of fishing yields, as only 7,2% of the fishers cited overnight trips.

Studies conducted in the Amazon often mention 'Restinga' as an environment and fishing site (McGrath *et al.,* 1993; Isaac and Barthem, 2015; Ferreira, 2016). In this study the 'Restinga' was however taken out of the analysis of fishing sites since it was noted that the definition of what characterised a 'Restinga' differed between fishers from the lower and middle Tapajos. Consequently, a comparison between the regions would be based on different perceptions of what constitutes a 'Restinga'. For the commercialisation question, the answers to where they sell their fish included 'outside of the community (fishmonger, middleman)' and 'in the city'. These two responses were combined into 'outside of the community' for the analysis, since, for the purpose of this study, a more precise separation was not required. For the interviews, the questions about the fishers' economic activities and diets were divided into the dry and wet seasons. After verifying that there was no significant difference between the values in the wet and dry seasons, their averages were considered the average economic activities and diets throughout the year.

The number of economic activities cited was compared among three age categories of the interviewed fishers, which were ≤ 30 years old, 31 to 60 years old and ≥ 61 years old in the lower and middle Tapajos. These age categories were broken down at regular intervals to include younger (≤ 30 years) and older fishers (≥ 61 years), considering the minimum retirement age of women in Brazil in 2018, where women 61 years or older would theoretically be retired.

2.3.2 Scenario development

Alterations to the river's downstream flow and its continuity affects species. In accordance with the biological characteristics that were affected by hydroelectric development within the literature, categories were developed in which species were considered affected if they: 1) use the floodplain; 2) spawn at the beginning or during flooding; and/or 3) have other biological characteristics that make them susceptible to impoundment. In the case of number 3, reasons for susceptibility are explicitly defined at the bottom of Table 1. Lastly, the categories were combined into an integrated scenario to visualise the possible future effects of the dam on the fish used by fishers. The scenario was created based on the five most important fishes mentioned by fishers and the fishes biological characteristics (Table1). In the case of the dissimilarity of biological characteristics between fish species grouped under a common name, they were considered separately within the analysis. Furthermore, for the analyses, individual fisher responses about their most important, henceforth referred to as 'prioritised', fish were grouped by community. The results were interpreted per community because remediation and mitigation measures upon dam construction are unlikely to be applied on scale of the individual fisher but could be applied on the community scale.

Table 1. Prioritised fish from the Tapajos River cited in interviews with fishers (n = 171) and selected biological characteristics used for scenario development. The codes are FP: use of floodplain for feeding purposes or reproduction, SP: spawning at beginning or during flooding (in the Tapajos), OBC: potentially affected by damming through other biological characteristics, such as the following:

[a] Requires reproductive and trophic migration in tributary headstreams to complete lifecycle

[b] Expected to have spawning grounds that coincide with the construction area of the SLT dam

[c] Expected to perform upstream migration in tributary rivers in the wet season

[d] Expected to perform reproductive migration in the direction of the headstreams of tributary rivers

[e] These fish species were grouped as they are from the same biological family and are usually fished together (Silvano *et al.*, 2017)

Common name	**Scientific name**	**Family**	**FP**	**SP**	**OBC**	**Reference**
	Characiformes					
Aracu/Piau	*Anostomoides* spp., *Leporinus* spp., *Rhytiodus* spp., *Schizodon* spp.	Anostomidae	Yes			Dos Santos *et al.*, 2009
Branquinha	*Curimata* spp., *Curimatella* spp., *Cyphocharax* spp., *Potamorhina* spp., *Psectrogaster amazonica*	Curimatidae		Yes		Dos Santos *et al.*, 2009
Charuto	*Hemiodus* spp., *Anodus elongatus*	Hemiodontidae				
Curimatã	*Prochilodus nigricans*	Prochilodontidae	Yes	Yes		Dos Santos *et al.*, 2009

Jaraqui	*Semaprochilodus* spp	Prochilodontidae		Yes	Yes [a]	Santos, 1995; Dos Santos *et al.*, 2009; Silvano *et al.*, 2017
Matrinxã	*Brycon spp..*	Characidae	Yes	Yes	Yes	Dos Santos *et al.*, 2009; Ferreira *et al.*, 1998; Silvano *et al.*, 2017
Pacu	*Metynnis* spp., *Myleus* spp., *Myloplus* spp., *Tometes* spp.	Serrasalmidae	Yes	Yes		Silvano *et al.*, 2017
Peixe-cachorro	*Hydrolycus spp., Rhaphiodon vulpinus, Cynodon gibbus*	Cynodontidae		Yes		Dos Santos *et al.*, 2009
Piranha	*Pygocentrus nattereri*, *Pristobrycon* spp., *Serrasalmus* spp.	Serrasalmidae				
Pirapitinga	*Piraractus brachypomus*	Serrasalmidae	Yes			Dos Santos *et al.*, 2009
Tambaqui	*Colossoma macropomum*	Serrasalmidae	Yes	Yes	Yes [b]	Ferreira *et al.*, 1998; Dos Santos *et al.*, 2009; Jorge & Ferreira, 2016; Silvano *et al.*, 2017
	Clupeiformes					
Apapa or Sarda [e]	*Ilisha amazonica, Pellona* spp.	Pristigasteridae				
	Osteoglossiformes					
Pirarucu	*Arapaima* spp.	Arapaimidae	Yes			Silvano *et al.*, 2017

	Perciformes					
Acará	*Aequidens* spp., *Astronotus* spp., *Caquetaia spectabilis*, *Chaetobranchus* spp., *Cichlasoma* spp., *Geophagus* spp., *Heros* spp., *Satanoperca* spp., *Symphysodon* spp., *Uaru amphiacanthoides*	Cichlidae				
Jacundá	*Crenicichla* spp.	Cichlidae				
Pescada and Corvina [c]	*Plagioscion* spp., *Pachypops* spp., *Pachyurus* spp.	Sciaenidae				
Tucunaré	*Cichla* spp.	Cichilidae				
	Rajiformes					
Raia	*Potamotrygon* spp., *Paratrygon aiereba*	Potamotrygonidae				
	Siluriformes					
Barbado or Piranambu	*Pinirampus pirinampu*	Pimelodidae			Yes [c]	Ferreira *et al*., 1998
Dourada	*Brachyplatystoma rousseauxii*	Pimelodidae	Yes			Dos Santos *et al*., 2009
Filhote	*Brachyplatystoma filamentosum*	Pimelodidae				
Jandiá	*Leiarius marmoratus*	Pimelodidae				
Mapará	*Hypophthalmus* spp.	Pimelodidae		Yes		Ferreira *et al*., 1998; Dos Santos

						et al., 2009; Silvano *et al.*, 2017
Piramutaba	*Brachyplatystoma vaillantii*	Pimelodidae	Yes			Dos Santos *et al.*, 2009
Piranambu	*Pinirampus pirinampu*	Pimelodidae				
Pirarara	*Phractocephalus hemioliopterus*	Pimelodidae	Yes	Yes		Ferreira *et al.*, 1998; Dos Santos *et al.*, 2009
Surubim	*Pseudoplatystoma* spp.	Pimelodidae	Yes	Yes	Yes [d]	Ferreira *et al.*, 1998; Dos Santos *et al.*, 2009; Silvano *et al.*, 2017

2.3.3 Statistical analysis

Statistical analyses and graphical representations were completed in RStudio (RStudio Team, 2016) and ggplot2 (Wickham, 2016). Outliers were fully incorporated into the analyses and displayed in the graphics. Normality of data was checked with the Shapiro-Wilks test and homogeneity of variances with the Bartlett test. Data that did not fulfil the requirements for parametric tests were either log-transformed to achieve a normal distribution and homoscedasticity, or non-parametric tests were used.

To compare the relative importance of the fishes between the lower and middle Tapajos, fishes were ranked according to the number of fishers that mentioned them to be among their five most important species. Permutational Analyses of Variance (PERMANOVA) using the Bray-Curtis distance and randomisation (1000 permutations) (Bray & Curtis, 1957) were used to verify the significance of the dissimilarity among the prioritised fishes and the fishers' use of both fishing equipment and site. This analyses was also used to deduce the reasons behind the potential dissimilarities, for example whether the potential differences were based on the community or region the fishers belong to. The fisher was used as the unit of analysis. The analyses were based on categorical data, for example whether or not the fishers mentioned a fish species or used a particular fishing equipment or site. The dissimilarity of the prioritised species from the different communities and regions was visualised through a redundancy analysis. Since Acaratinga (*Geophagus proximus*) was considered separate from the remaining species of its genera by the majority of fishers, it was considered separate from the Acarás in this analysis.

Differences among time spent fishing (h) and fishing yield (kg) between the middle and lower Tapajos were checked with the Wilcoxon Signed-rank sum test. For the cross-regional comparison of categorical data, such as fisher's employment, diet and commercialisation of fish, the Fisher's Exact Test of Independence was used. This compared the frequency distribution of the number of fishers who reported the studied variables between the lower and middle Tapajos. This test was also used to check for significant differences in the socio-economic characteristics between the dry and rainy seasons, and hence low and high water levels.

3. RESULTS

3.1 Socio-economic profile and fishing

The interviewees' ages ranged from 20 to 86 years, with a mean age of 48 years (±13.25 [SD]) and a mean community residence time of 38.6 years (±16.27 [SD]). Ninety-four of the one hundred and seventy one interviewed people (55%) spent their whole lives in the communities. The fishers had been fishing for an average of 30 years (± 14 [SD]). Around one-sixth of the interviewed fishers were illiterate, and none of them had higher education.

The average fisher's household consisted of four people including the fisher. Around one-sixth of the households (13%) housed seven to twelve people, while the rest of the households were occupied by six or less people. The sizes of households did not differ between the middle and lower Tapajos (Fisher's Exact test, p>0.05).

In the lower Tapajos fishers start to fish earlier, on average at 17 years old, compared to at the age of 19 in the middle Tapajos. Employment significantly differed between the middle and lower Tapajos (Fisher's Exact test, p<0.01). In the lower Tapajos most fishers (87%) either pursued two (52%) or pursued three or more (35%) economic activities, while in the middle Tapajos most fishers (91%) only pursued one (57%) or two (34%) economic activities (Fig. 2). Twenty-two percent of the fishers' partners pursued an economic activity that contributed to the household income. Of these, around one-third (32%) also practised fishing as an economic activity.

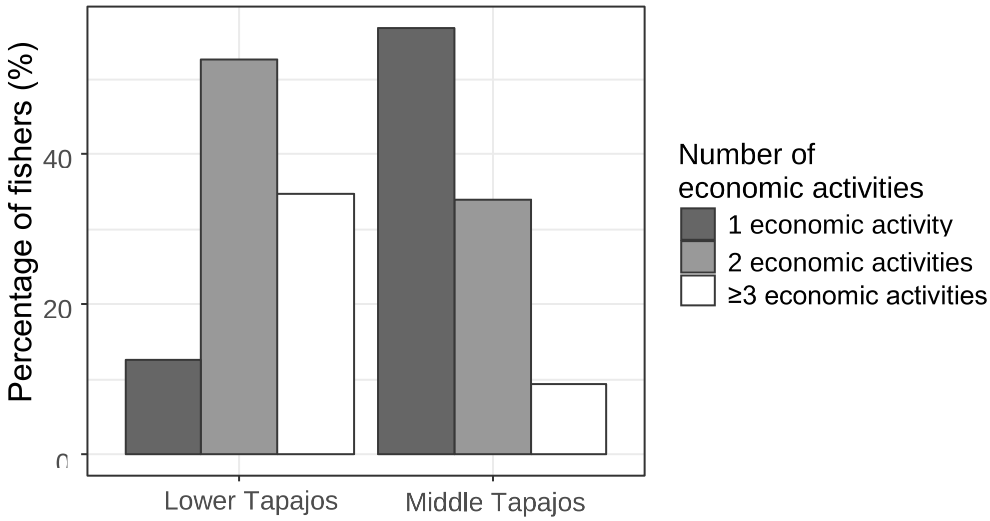

Figure 2. Percentage of fishers who pursue one, two or three or more economic activities in the middle (n=123) and lower (n=48) Tapajos.

All community leaders identified fishing as being among the most important economic activities of the community. Several of them also practised fishing. The fishers considered fishing their most important economic activity (Fig. 3A) and fish their most important source of animal protein (Fig. 3B), irrespective of whether they were from the lower or middle Tapajos. However, in the lower Tapajos around half of the fishers (45%) consider fishing as their most important economic activity and 47% consider it as their second most important economic activity, which is significantly different (Fisher's Exact test, p<0.001) from the middle Tapajos where nearly all of the fishers (88%) consider fishing to be their most important economic activity (Fig. 3A). Besides fishing, 61% of the fishers in the lower Tapajos and 17% of the fishers in the middle Tapajos engage in small-scale agriculture. Other important income sources were hunting, small-scale animal husbandry or aquaculture, government jobs, non-timer forest products, tourism and handicrafts.

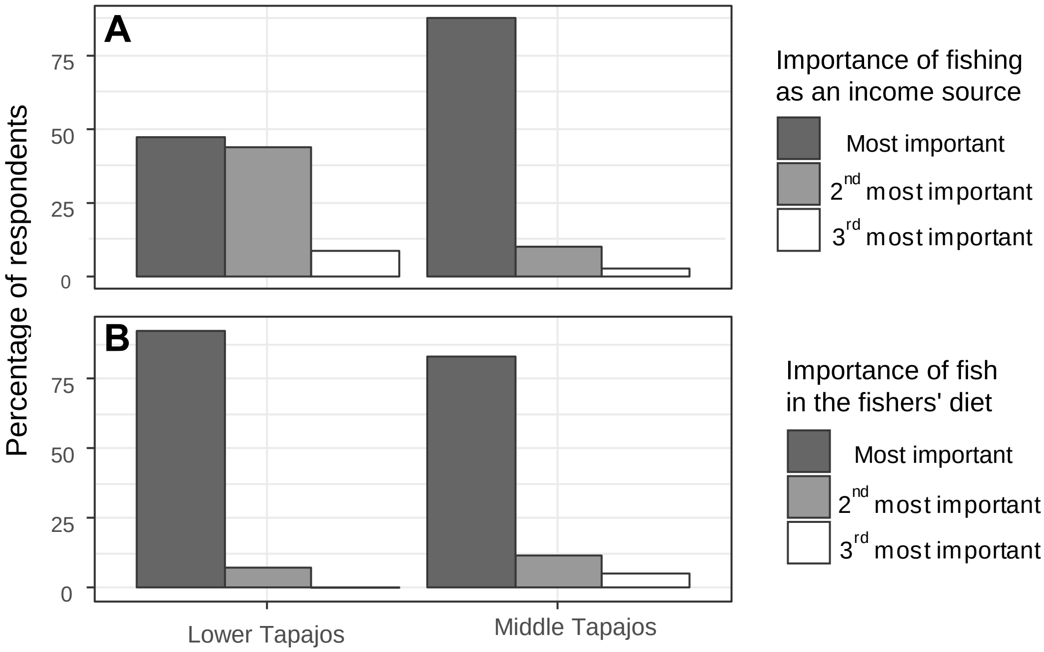

Figure 3. [A] Importance of fishing as an income source and [B] the importance of fish as a source of animal protein in the fishers' diet.

The fishers from the lower and middle Tapajos show significant differences (Fisher's exact test p<0.01) in their commercialisation of fish (Fig. 4). Approximately two thirds (75%) of the fishers from the middle Tapajos sell their fish outside of the community, whereas significantly fewer fishers (8%) from the lower Tapajos commercialise their fish in this way. Significantly more fishers from the lower Tapajos (81%) than from the middle Tapajos (49%) sold their catch within the community. In the lower Tapajos, nearly one fifth (17%) of the fishers did not commercialise their fish.

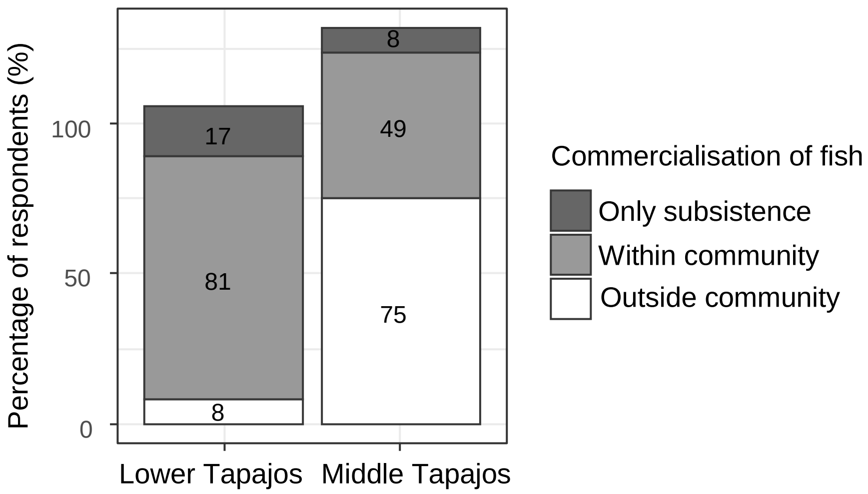

Figure 4. Commercialisation of fish by fishers of the middle and lower Tapajos. Commercialisation within and outside the community were not mutually exclusive. The sum of the proportion of respondents exceeds 100% because the fishers could cite more than one type of commercial to the fish caught.

The time spent fishing per week varied from 2.5h to 77h in the lower Tapajos and from 3.5h to 84h in the middle Tapajos. On average, fishers fished four days per week in the lower Tapajos and five days per week in the middle Tapajos. Fishers from the middle Tapajos spent significantly more time fishing per week than those from the lower Tapajos (Wilcoxon signed-rank test, $p<0,001$). On average, individual fishers from the middle Tapajos fished for 40h per week compared to 17h per week in the lower Tapajos (Fig. 5A). Only two fishers in the lower Tapajos (<5%) spent more than forty hours fishing per week compared to the fifty-one fishers (40%) that fished for longer than forty hours in the middle Tapajos (Fig. 5A). Ten out of the one hundred and twenty-three fishers (8%) from the middle Tapajos engaged in overnight fishing trips, whereas in the lower Tapajos only one out of the forty eight fishers (2%) did so. The fishers predominantly went fishing alone or in pairs with only 8% of the fishers working in groups of three or more. When in pairs, their fishing partner was either another fisherman or the fisher's partner or child.

Weekly fishery catches varied from 1.7kg to 245kg in the lower Tapajos and from 2kg to 300kg in the middle Tapajos (Fig. 5B). Fishers from the middle Tapajos catch significantly more fish in terms of weight per week (Wilcoxon signed-rank sum test, $p<0,001$). On average they catch 76kg of fish per fisher per week, compared to the 39kg caught per week in the lower Tapajos (Fig. 5B).

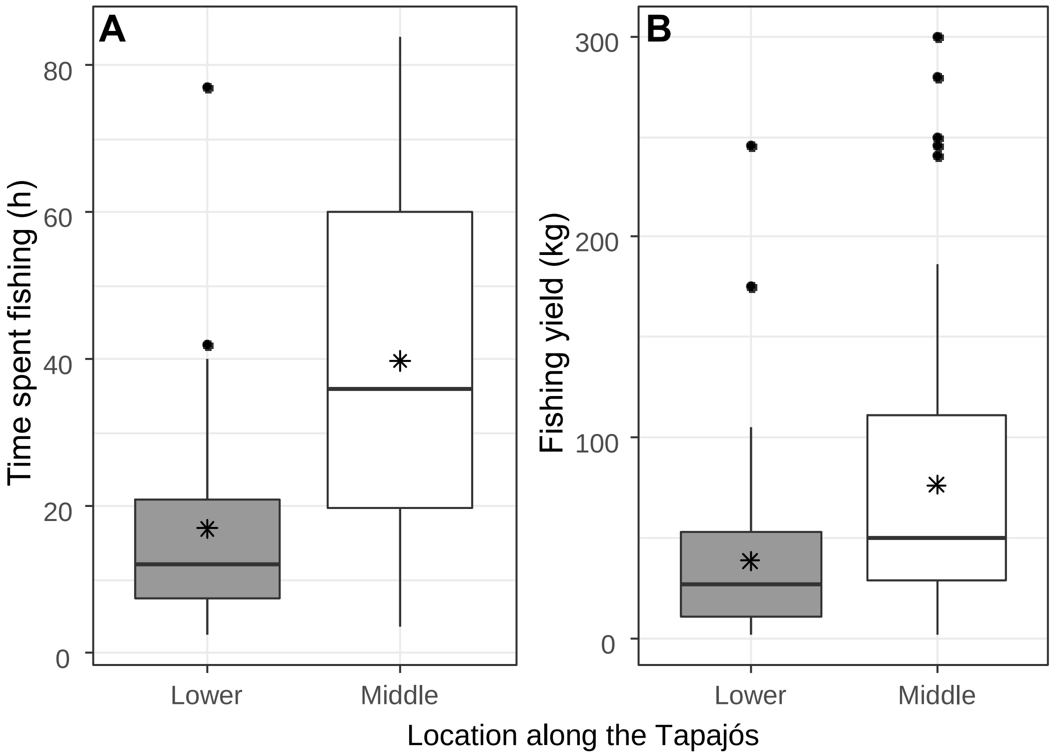

Figure 5. [A] Fishers' weekly time spent fishing and [B] Fishers' weekly fishing yield in the lower and middle Tapajos. Mean values are represented by the asterisks. Outliers are plotted as individual data points.

Gill nets and hook and line were the preferred gear in both the middle and lower Tapajos, followed by cast net, longline, fishing rods and several spearfishing tools, including harpoons, tridents, spears and bows and arrows (Fig. 6). Fisher's choice of fishing gear did not differ among communities nor between regions (PERMANOVA > 0.05).

The fishing site used by fishers differed among communities, between the middle and lower Tapajos (PERMANOVA, $p<0.001$) and within seasons (wet: $c2 = 64.1$, $p < 0.0001$; dry: $c2 = 109.8$, $p < 0.0001$) and middle Tapajos (wet: $c2 = 167.2$, $p < 0.0001$; dry: $c2 = 296.1$, $p < 0.0001$). Nearly all fishers use the river to fish in both, wet and dry season, and the lakes were the second most commonly used site (used by around two thirds of the fishers). Around half of the fishers from the lower Tapajos (52%) used the flooded forests, compared to one sixth (15%) of the fishers from the middle Tapajos. Forest streams and channels were used by fewer fishers (Fig. 7 A & B).

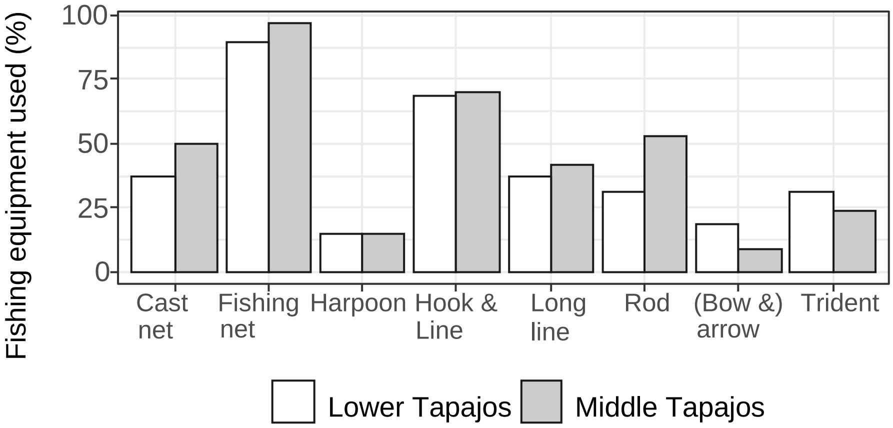

Figure 6. The types of fishing equipment used by the fishers. The uses of different types of fishing equipment were not mutually exclusive.

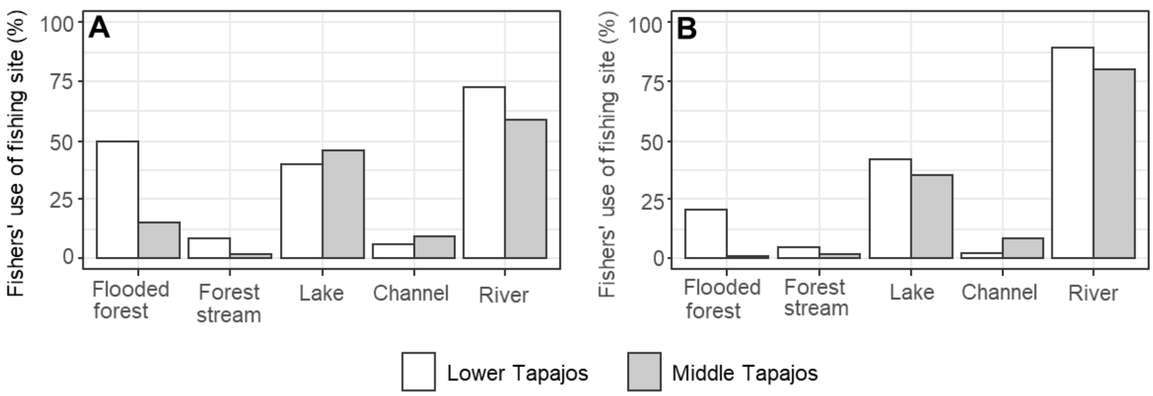

Figure 7. Fishers' use of fishing site in wet [A] and dry [B] season in the lower and middle Tapajos. Different spearfishing tools are represented by the different shades of purple. The use of fishing equipment and site was not mutually exclusive.

When asked for their five most important species, twenty-six species or groups of species were named, nineteen in the lower and twenty-five in the middle Tapajos (Table 1; Fig. 8). Five species or species groups accounted for more than 50% of the relative importance of prioritised species across both regions. In the lower and middle Tapajos around half of the fishers considered Aracus, Tucunaré and Pescadas to be among the five most important species groups. In the middle Tapajos species of Jaraquis were also important while in the lower Tapajos Acara species were considered important (Fig. 8). Of the Acaras species group, Acaratinga (*Geophagus proximus*) was the most important, mentioned by 86% of the interviewees.

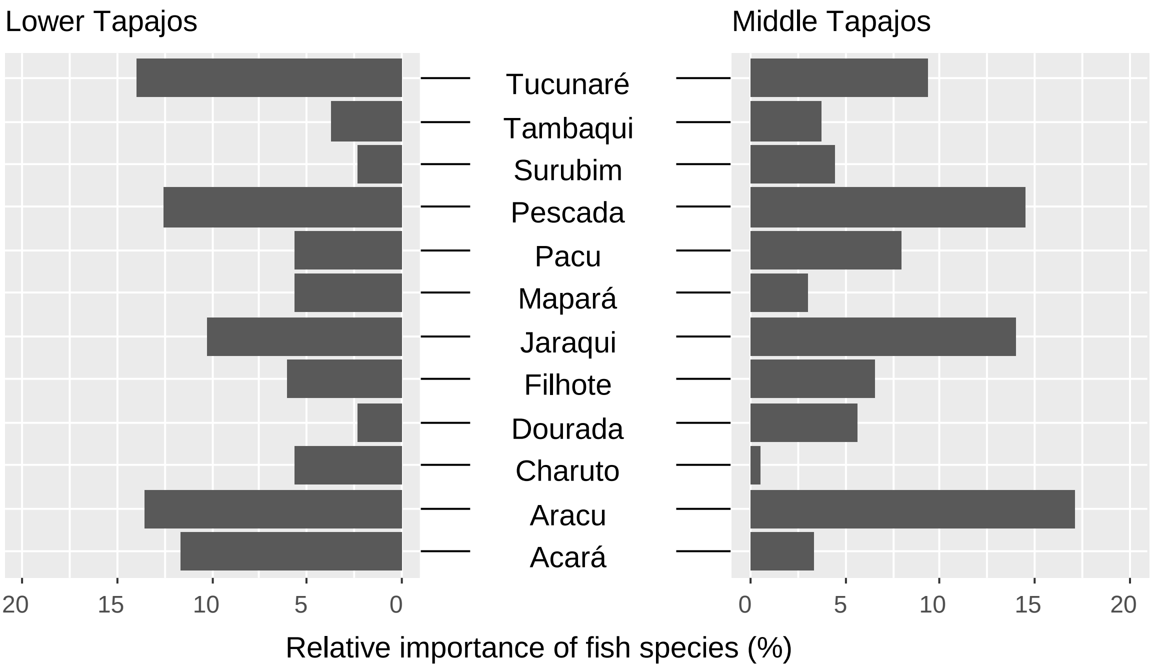

Figure 8. Relative importance of prioritised fish in the lower and middle Tapajos. Each fisher could cite up to five prioritised fish species and each citation was considered an individual data entry. The species relative importance is expressed as the percentage of the total fish citations (lower Tapajos n= 214 citations; middle Tapajos, n = 565 citations). Only the fish species that represent an average of 2,5% of the relative importance considering citations from both regions are shown (for example, if the relative importance of a species if 2% in lower Tapajos and 3% in middle Tapajos, the fish is shown). The scientific names of fish are listed in Table 1.

The prioritised fish significantly differ among fishers and depend on whether they are from middle or lower Tapajos and which community they are from (PERMANOVA, $p<0.001$). Acarátinga, Apapá, Charuto and Tucunaré were the most important fish for the lower Tapajos, whereas fishers from the middle Tapajos prioritised Aracú, Barbado, Dourada, Jandiá, Matrinxã, Pirapitinga, Pirarara and Surubim (Fig. 9). Regarding the communities, Acarátinga and Tucunaré were particularly important for fishers from Prainha, Pini and São Domingos. Fishers in the communities of Nova Canãa and Boa Vista do Tapajós prioritised Matrinxã, and the community São Luiz do Tapajós Jandiá, Pirarara and Pirapitinga (Fig. 9).

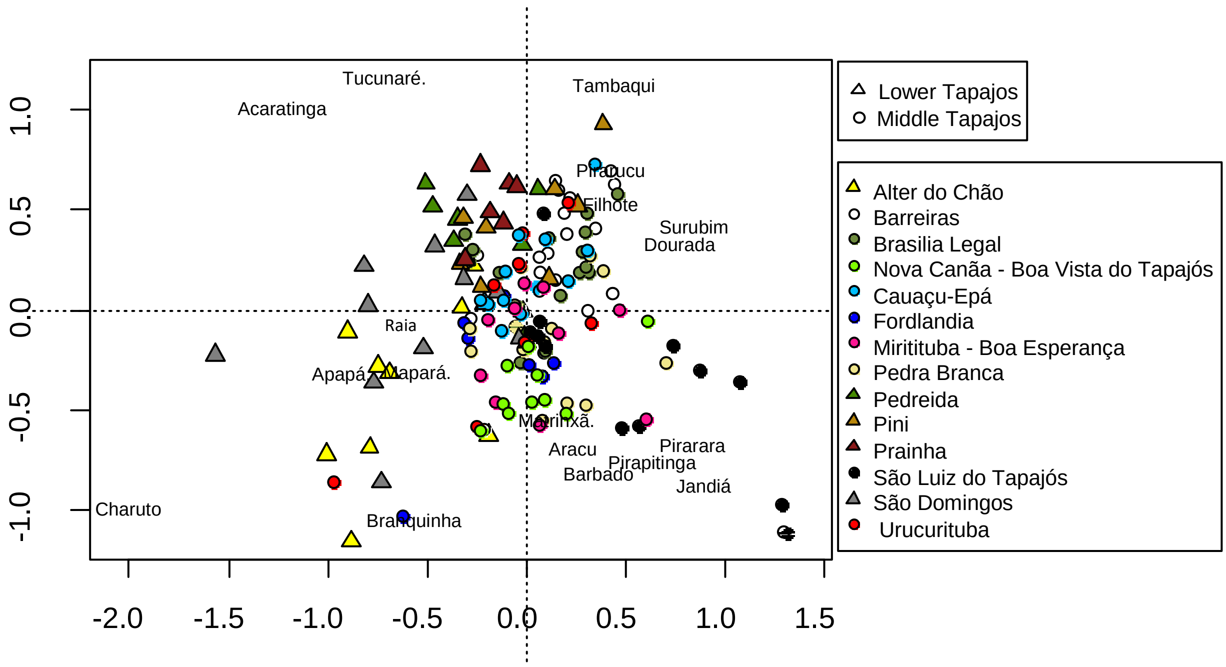

Figure 9. Fishers grouped according to their prioritised fish. Redundancy analysis with axes 1 (11% of explained variance) and 2 (8% of explained variance) grouping the interviewed fishers according to their prioritised fish from lower and middle Tapajos Each dot represents a fisher (n = 171), the colours refer to communities, and the symbols indicate the region of the river (lower or middle Tapajos). The analysis shows the prioritised fish that most contributed to the dissimilarity of cited fish from both regions, middle and lower Tapajos. The scientific names of fish are listed in Table 1.

3.2 Impacts of fishers within the susceptibility scenario

Within every community, there is at least one prioritised fish that could be adversely affected by the construction of the SLT dam (Fig. 10). The scenario considered the frequency with which a prioritised fish was cited by the fishers during the interview and that each citation of a fish accounted as one. Overall, around one-third of the total number of the prioritised species would be adversely affected because of their dependency on the floodplain (38% affected) and/or because they spawn either at the beginning of or end of the flooding (33% affected). Fishes with other potentially affected biological characteristics make up around one fifth (22%) of the prioritised species. When integrating the categories, fishers of the communities 'Nova Canãa and Boa Vista', Barreiras and São Luís de Tapajos would experience the strongest adverse effects while fishers of the communities of Prainha and São Domingos would be the least affected (Fig. 10). In this category, on average more than half of the prioritised species would be affected. This means that the fishers potentially experience negative effects on around half of their fishery catches and shows that the effects of the dam could spread far downstream.

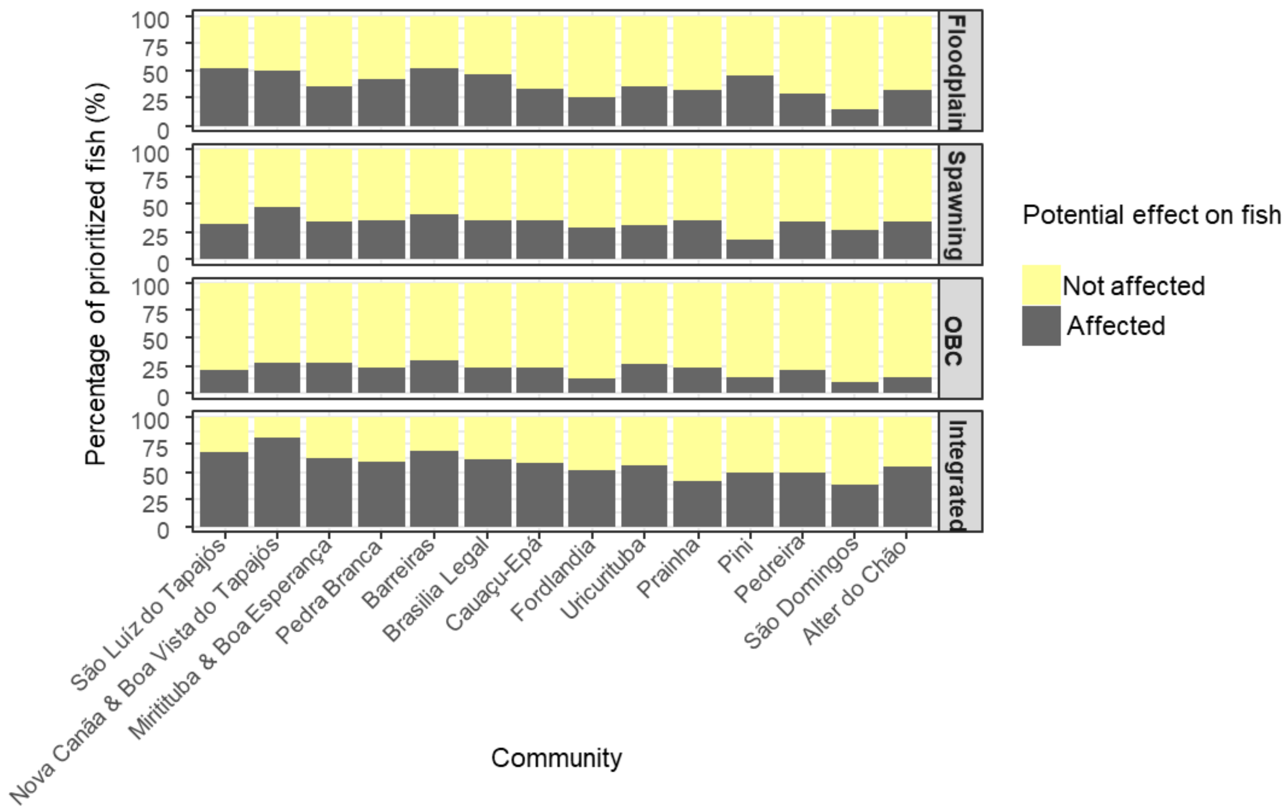

Figure 10. Estimated potential effects of damming on fishing, according to the proportion of prioritised fish and their susceptibilities to impoundment. São Luiz do Tapajós is the closest community to the dam and distance from the dam increases from left to right. The affected categories (floodplain, spawning and other) are those defined in Table 1. The affected percentage of the 'Integrated' scenario combines the percentage of species affected within the other categories and gives the total percentage of species that would be affected upon dam creation.

4. DISCUSSION

Upon development of the SLT hydroelectric dam, freshwater ecosystems and their associated fisheries will be adversely affected. Missing fishery baseline studies and the probable underestimation of the downstream area impacted by the dam are expected to exacerbate the dam's impacts. Characterising the fisheries and appropriately defining the area and people that are likely to be affected will improve the understanding of the challenges the communities will face upon dam development and may help develop appropriate techniques to decrease the dam's impacts. Based on the fishers' socio-economic profiles and the fish they prioritise, we found that fishers from all communities would be affected if the dam was built. As such the area impacted by the SLT would greatly exceed that which is officially acknowledged. This would endanger the livelihoods of the fishers who are economically and emotionally linked to the river fisheries.

4.1 Fishers' socio-ecological susceptibility to dams

Fishers pursued several economic activities, however they regarded fishing as their most important economic activity. Even though Amazonian fishers are known to engage in multiple economic activities to sustain their income (McGrath *et al.*, 1993; Batista *et al.*, 1998; Hallwass *et al.*, 2013), several studies regarding small-scale fisheries in the Amazon identify fishing as their most important income source (McGrath *et al.,* 1993; Ruffino, 2002). In addition, within the majority of families in the study region the fisher was the only person who pursued an economic activity that contributed to the household income. Many of the households were large, meaning that many people were dependent on this income. The great majority of the interviewees were men, making these results consistent with studies conducted in the Amazon which noted that women predominantly conduct household activities and do not pursue a secondary economic activity (Mulheres *et al.,* 1981; Castro-Diaz *et al.,* 2018). The expected losses in fishery catches from damming would therefore negatively affect the fishers' most important, and sometimes sole, income source. For example, studies by Castro-Diaz *et al.,* (2018) have shown that the reduced fishery catches after implementation of the Belo Monte dam in the Amazon made it economically unviable for some fishers to continue to pursue fishing as an economic activity (Castro-Diaz *et al.,* 2018).

The potential reduction in fishery catches that will occur upon damming and its consequences for the economic well-being of the fishers could lead to emotional disruption at the household level. Indeed, several studies highlight the negative consequences of job loss on the emotional well-being of the affected people and their families (Winkelmann & Winkelman, 1998; Howe, Levy & Caplan, 2004), and the study by Wilson *et al.,* (1993) further notes family breakdown as a consequence of unemployment. Furthermore, in the study region fishing was generally identified to have a high importance within the community and several of the community leaders also fished. Studies by Bodin and Crona (2008) also noted that fishers in rural communities take up key roles in community leadership. The emotional stress that the members of the community that depend on fishing could experience upon damming might be further extrapolated if they have leadership roles, which could potentially result in decreased well-being on the community and regional scale.

The results show that fishers have a comparably high illiteracy rate and that a low proportion of them have higher education qualifications when compared to the national standard (MEC, 2013; IBGE, 2018). Low levels of education are common in rural parts of the Amazon. For example, studies by da Silva and Begossi (2009) have shown illiteracy rates of 40% in riverine populations while studies by Hallwass *et al.,* (2013) found that the fishers that attended school did so for less than four years. This low level of education decreases the fishers' chances of taking up alternative employment to compensate for their economic losses from damming. For example, studies by (Åberg, 2003) have linked low education with poor chances of finding employment. The fishers' problem of finding new employment could further be complicated by poorly developed community infrastructure. Communities are frequently only accessible by dirt-roads and depending on the season some of the communities are exclusively accessible by motorbike or boat. This makes it difficult for the fishers to take up alternative employment outside the community. Lastly, most fishers have been found to spend their entire lives in the communities with their families. This is consistent with the study by Hallwass *et al.,* (2013) that also noted the high residence time of fishers in another region of the Amazon. Since their lives are based in the communities, their desire to move to find new employment elsewhere is likely to be low. Additionally, Castro-Diaz (2018) has shown that after implementation of the Belo Monte dam in the Xingu River, downstream fishers did not recognise alternative economic activities to compensate for their decrease in fishing profits. The shift to employment activities that they are already acquainted with, such as hunting, agriculture and livestock production, could generate negative effects on the environment. For example, the majority of interviewed fishers in the lower Tapajos live within a conservation unit and an increase in hunting could intensify pressure on wild species that are susceptible to hunting (Silvano *et al.*, 2017). Increased pressure on forest resources has, for example, been observed after the installation of the Son La hydropower plant in Vietnam (Minh, Bui and Schreinemachers, 2011). In addition, land conversion due to increased involvement in animal husbandry and small scale agriculture may enhance soil erosion and lead to deforestation (Fearnside, 2007; Malhi *et al.,* 2008; Bigda-Peyton, Nowicki and Wodehouse, 2012; Orr *et al.,* 2012; Silvano *et al.*, 2017; Begossi *et al.,* 2018; Santos *et al.*, 2018).

The fishers considered fish to be their most important source of animal protein. This is similar to other regions of the Amazon (Begossi *et al.*, 2018). Indeed *per capita* fish consumption of Amazonian people is suggested to be among the world's highest, with an estimated average consumption of around 400g to 550g per day (Cerdreira, Ruffino & Isaac, 1997; Batista *et al.*, 2000; Isaac & Barthem, 2015; Begossi *et al.,* 2018; Santos *et al.,* 2018). Due to the importance of fish within the fishers diet the projected decline in fishery yields upon dam construction has the potential to affect food security on both the household and regional scale throughout the year (de Mérona *et al.,* 2010; Begossi *et al.,* 2018; Castro-Diaz *et al.,* 2018; Santos *et al.,* 2018). For example, studies have shown that after construction of the Tucuruí dam in the Amazon Basin, downstream fisheries were unable to satisfy the demand of resident populations for fish (Santos *et al.,* 2018). The decline of fish could also increase the price of fish whilst creating a dependence on external sources of animal protein (Begossi *et al.,* 2018), which was, for example, the case after the implementation of the Belo Monte dam (Castro-Diaz *et al.,* 2018). External food sources are often more expensive, can be nutritionally poor and more difficult to obtain (Batista *et al.,* 2000; da Silva &Begossi, 2009; Orr *et al.,* 2012; Begossi *et al.,* 2018; Castro-Diaz *et al.,* 2018).

Within the communities of this study this is a particular problem because of their poor infrastructure, which could make it difficult and costly to obtain food from external sources.

The results of the scenario show that fishers from all communities strongly rely on fish that could potentially be affected by the construction of the SLT dam. When considering all categories of the scenario, more than half of the prioritised fishes could potentially be affected across most of the communities. For example, the communities with more than 50% of the prioritised fishes affected reach more than 100 km downstream, twice the size of the directly impacted area, according to the previous EIS (Fig. 9 and 1). This is consistent with the studies by Hallwass *et al.*, (2013) and de Mérona *et al.* (2010), which noted negative post-impoundment effects on a great number of fishes that are considered important to the fishers. If the fish are affected by the damming their fitness will decrease, which will have negative effects on their abundance and ultimately on the fishers' catch. This decrease in fishery catches has been observed after implementation of several Amazonian dams. For example, after implementation of the Amazonian Tucuruí dam downstream fish catches per unit effort decreased by 65% in the two years following dam development (Ribeiro, Petrere Junior and Juras, 1995) and a long-term study by Santana et al., (2014) noted a 19% decrease of the contribution of downstream fisheries to total local fishery production following dam construction. Similar trends were observed after the implementation of other Amazonian dams such as the Santo Antônio and Jirau hydroelectricity plants, where downstream fisheries suffered losses of 34% in their mean monthly catches (Santos *et al.*, 2018).

Based on the scenario, fishers of communities located further downstream than those included in the SLT dam impact assessment prioritise fish that could potentially be affected. Several studies report far-reaching impacts of dams downstream (WCD, 2000; Marmulla, 2001; de Mérona *et al.*, 2010; Hallwass *et al.*, 2013). For example, studies conducted in the Amazon by de Merona *et al.*, (2010) and Santos *et al.*, (2018) have identified post-damming impacts on landing data up to approximately 200km downstream from the dams. Based on the results of the present paper, it is possible to conclude that the impacts of the SLT dam could greatly extend past the area included in the impact assessment. Hence, restraining the impact of the SLT dam to ~50km below the dam (CNEC Worley Parsons, 2014) is a large understatement of the real impact of the dam, which would jeopardise the livelihoods of the interviewed fishers if the dam was built.

The scenario attributes the highest susceptibility to damming to some of the communities closest to the dam. In the vicinity of the dam several studies report an important decrease in water levels (Marmulla, 2001; Manyari & de Carvalho, 2007) and the study by Sá-oliveira *et al.*, (2016) even reports occasional drying out of the areas immediately below a dam. Low water levels can lead to a separation of marginal aquatic environments from the main river. As a consequence, fish can become isolated and trapped in the marginal environments, with potential lethal consequences (Marmulla, 2001; Bunn & Arthington, 2002; Manyari & de Carvalho, 2007). Large-scale fish death in marginal pools has, for example, been reported after the completion of the Tucuruí dam (La Rovere & Mendes, 2000). In addition, accumulation of deoxygenated water and water enriched in toxic gases has been noted immediately downstream of dams (La Rovere & Mendes, 2000; Marmulla, 2001). This has, on some occasions, led to the mass mortality of fish located immediately below the dam (de Merona, Lopes de Carvalho & Bittencourt, 1987; La Rovere & Mendes, 2000; Marmulla, 2001). On the other hand, high concentrations of fish have often been observed immediately below the dam, resulting in productive tailrace fisheries (Marmulla, 2001; Godinho & Kynard, 2008; Pelicice, Pompeu & Agostinho, 2014). These fisheries particularly benefit from the high abundances of migratory and piscivores species, which include some of the highly valued commercial fishes that were prioritised in the study area such as the Surubims, Tucunare and the Douradas (Carolsfeld *et al.*, 2003; Godinho, 2007; Pompeu, Agostinho & Pelicice, 2012; Monaghan *et al.*, 2015; Pelicice, Pompeu & Agostinho, 2015). Even though initially highly productive, the tailrace fisheries are often unsustainable because they are often overexploited, which eventually leads to a decrease in fish abundance (Fearnside, 1999; Marmulla, 2001). For example, at the Tucuruí dam, tailrace accumulation of fish resulted in an increase in captures at the foot of the dam in the first two years after closure, but this was followed by a subsequent decrease to below pre-damming values (de Mérona *et al.*, 2010). All of these effects are strongly felt by the communities closest to the dam, which is why careful monitoring is necessary in these locations. In addition to monitoring, mitigation measures would have to be implemented to reduce the dam's negative impact on the tailrace, whilst trying to sustainably manage the benefits of tailrace fisheries.

The results of this study show differences in fisheries between the lower and middle Tapajos. Differences in time invested in fishing, commercialisation and prioritisation of fish and fishing sites are the most notable. This heterogeneity of fisheries has also been observed in other regions of the Amazon (Batista *et al.*, 1998; Castello, McGrath, *et al.*, 2013; Hallwass & Silvano, 2016). The commercialisation of fish outside of the community was less important in the lower Tapajos, which can be attributed to its weak infrastructure. Fishers in the lower Tapajos generally divided their time between several sources of employment, whereas fishers in the middle Tapajos regarded fishing as their primary employment and net fishing yields were higher. The behaviour of the fishers from the lower Tapajos might be a response to the reduced opportunities for the commercialisation of fish outside of the FLONA. In the lower Tapajos fishing might not guarantee large incomes, but it does provide a small income and a source of animal protein which therefore prevents malnutrition (Bené, 2006; Begossi *et al.*, 2018). Despite the differences, the livelihoods of the fishers in both regions are tied to the fisheries and mitigation measures need to be tailored to their specific needs. For example, the main concern in the middle Tapajos is that the loss of fisheries would remove most of the fishers' only source of income, whereas in the lower Tapajos there are particularly high concerns about safeguarding the food security of the fishers.

The differences in prioritised fish among the communities could be explained by the transfer of knowledge within a community. Even though only one fisher per household was interviewed, the communities often contained several members of a family who are assumed to fish in a similar manner since they could have been taught to fish by their relatives (Berkes, 1999; Hallwass *et al.,* 2013). Indeed, during the community visits it was frequently observed that the fishers' children joined and helped their parents on their fishing trips. These presumptions are consistent with the study by Hallwass *et al.,* (2013) which found that the majority of fishers' fathers in Amazonian communities were also fishers, suggesting intergenerational knowledge transfer. Batista (1998) also noted that children participate in their parents fishing. Therefore, it is suggested that joint fishing teaches younger generations how to fish from an early age, explaining how adolescents become self-sufficient fishers before reaching adulthood (in the lower Tapajos) or shortly after (in the middle Tapajos). In addition, intergenerational knowledge transfer has been identified as an important cultural mechanism, playing an important role in the cultural identities of the members of the community (Diamond, 2001). Indeed, studies show that the time parents invest in their children increases their family bonds and helps their children become socially competent individuals (Coleman, 1990; Wright, Cullen & Miller, 2001). Joint fishing is thus suggested to stimulate the social cohesion of families and maintain the social capital of communities. Conversely, the construction of the SLT dam and the possible consequential decreasing or abandoning of fishing could put an end to these important social mechanisms and lead to the emotional dissatisfaction of the community members.

Twenty-six species and groups of species were mentioned by the fishers when asked for their five most important species. Of these, five species accounted for more than 50% of the proportion of prioritised species. Hallwass *et al.,* (2015) also noted that five species were principally targeted by fishers from several Amazonian communities. Even through in the study region species under a common name can encompass several species, the total number of mentioned species is low considering that studies have identified 305 species in the Tapajos River, which is considered to be a conservative estimate due to the lack of studies in this region (Buckup & Castilhos, 2011; Silvano *et al.,* 2017). The low number of prioritised species implies that these species may be under a lot of fishing pressure and can suffer consequential detrimental effects. Indeed, overexploitation of commercially important freshwater fish has been reported in several regions of the Amazon (Castello, David G. Mcgrath, *et al.,* 2013; Hallwass, 2015; Doria *et al.,* 2018). Besides the decrease in abundance, pressure on aquatic resources makes fisheries more susceptible to the impacts of dams as it increases the fishes susceptibility to recruitment failure, increases their extinction risk and decreases the size of their gene pool (Pérez-Ruzafa *et al.,* 2006; Castello, David G. Mcgrath, *et al.,* 2013; Jorge & Ferreira, 2016). Even though a small number of species are prioritised, Amazonian small-scale fisheries are considered highly heterogeneous regarding the fishes they catch (Batista *et al.,* 1998; Castello, David G Mcgrath, *et al.,* 2013; Hallwass, 2015). In order to compensate for species that would decrease in abundance upon damming, the fishers could fish other less susceptible species. However, the five most important species are more attractive to the fishers because of their higher economic value. Indeed, high-value species have shown to be prioritised throughout the Amazon Basin (Castello, David G. Mcgrath, *et al.,* 2013). As such, being forced to catch alternative, low value, fishes upon damming could result in substantial economic losses for the fishers.

The fishers used a lot of fishing sites and equipment, which is consistent with the findings of Batista *et al.,* (1998), Castello, McGrath, *et al.,* (2013) and Hallwass (2015). The use of fishing sites changed according to which community and region of the Tapajos the fisher resided in. It was noted that the fishers from the middle Tapajos used flooded forest areas as fishing sites less than the fishers from the lower Tapajos did. A possible explanation is that this is due to the changes in the river width of the Tapajos. The lower Tapajos is very large and thus the fish are very dispersed within the river. This decreases the fishers' chances of catching fish and therefore they might prefer habitats where the fish are more densely packed, such as flooded forests. In comparison in the narrower middle Tapajos the fish are more confined, which makes it economically beneficial to fish there. The fish species that the fishers catch might be a consequence of the sites they use. For example, fishers from the middle Tapajos prioritised species that migrate in the river channel, such as the Douradas, Surubims, Barbado and Matrinxa, whereas some of the preferred species of the lower Tapajos, such as Tucunaré and Acaratinga are less commonly found in the middle part of the river. Flooded forests, streams and lakes, which were extensively used by the fishers, can, depending on the season, be separated from the main river because the water levels are too low to connect them. As such, flooded forests, streams and lakes often only house a substantial amount of fish once the water level rises and fish migrate into these areas (Agostinho & Gomes, 2003; Doria *et al.,* 2018). The projected changes to the water level upon damming could impede the use of these fishing sites. For example, Castro-Diaz, Lopez and Moran (2018) noted the loss of fishing sites after the construction of the Belo Monte dam, resulting from changes in the water level. This meant that fishers needed to travel further to find new fishing sites, decreasing their actual time spend fishing whilst incurring additional fuel costs for their boats. This would threaten the economic well-being of the fishers located downstream from the SLT dam if it was built.

Fishing techniques involving nets are the most common gear used in the Amazonian small-scale fisheries, and they are linked to higher yields under most conditions (Castello, McGrath, *et al.,* 2013). Spearfishing equipment such as tridents, harpoons, (bow and) arrows and spears, which were used comparably less, are more complex to use and require experienced users (Mesquita & Issac-Nahum, 2015). Many spearfishing techniques which were used by the fishers downstream of the SLT dam, are commonly used in the areas that rely on the flood pulse and thus could also cease to be used upon damming. For example, after the implementation of the Santo Antônio dam on the Amazonian Madeira

River, the use of a particular spearfishing technique was disrupted and the knowledge about it is likely to be lost in future generations (Doria *et al.*, 2017). Spearfishing techniques have been used by Amazonian fishers for generations and the use of a bow and arrow is considered to be a legacy of indigenous people in the Amazon (Mesquita & Issac-Nahum, 2015). If fishers stopped using these techniques and consequently lost the knowledge about them, the communities cultural heritage could be hampered (Mesquita & Issac-Nahum, 2015). The problem with loosing fishing sites and techniques is particularly relevant in the context of the SLT dam because the potentially affected downstream fishers are predominantly traditional riverside dwellers (*ribeirinhos*) who have lived along the riverbanks for thousands of years (McGrath *et al.*, 1993; Balee, 2013; Fearnside, 2015b). Therefore, the changes to the river upon dam construction, including the loss of fishing techniques and sites, is predicted to cause them emotional stress.

4.2 Study limitations

LEK should be used with caution because it is based on the transfer of information between people, which leaves room for misinterpretation (Maurstad, Dale and Bjørn, 2007; Hallwass *et al.*, 2013). In this regard, the interview question about the most important fishes could be biased towards economically high-value species, as observed in previous studies (Silvano and Begossi, 2002; Hallwass et al., 2013). As such, some low-value species might be fished a lot but mentioned less by the fishers. This is important to acknowledge when developing adequate mitigation measures.

The scenario might be an underestimation of the dam's impacts due to the lack of biological knowledge about many Amazonian fishes (Begossi *et al.*, 2018). For example, several studies have described species belonging to the Characiformes or Engraulidae as being susceptible to damming because they are thought to reproduce at the beginning of or during flooding (Ponton & Copp, 1997; de Mérona & Albert, 1999; de Mérona, Vigouroux & Tejerina-Garro, 2005). However, when looking at the traits of the species of the Characiformes and Engrauidae that were found in the study area, not all could be identified as species that spawn at the beginning of or during flooding. Consequently, for the scenario, only species for which information was available and which could be identified through their biological characteristics to definitely be affected by dam construction were included in the affected category. Therefore, the scenario could be an underestimation and the overall impacts of the dam could be considerably worse. The scenario could further underestimate the dam's impact because it does not consider migratory species that would have their longitudinal migratory movements within the Tapajos interrupted by dam construction. Migratory species were well represented among the prioritised fish, with many of them being large catfish which are considered particularly important for commercialisation (Santos, Ferreira & Zuanon, 2009; Silvano *et al.*, 2017). Furthermore, some studies, indicate that certain migratory species use the Amazonian tributaries such as the Tapajos for spawning and return to their spawning grounds (Barthem, 1991; Ferreira, Zuanon & Santos, 1998; Nunes, 2014).

If this is the case then fishers, especially those of the middle Tapajos which are highly dependent on migratory species, could experience severe losses of these species upon impoundment. The reason why migratory species were not included in the scenario is because recruits of migratory species from the Amazon could compensate for the loss of migratory species downstream of the dam (Ribeiro, Junior & Juras, 1995). However, there is a high risk of that this reliance on recruits is unsustainable because migratory species are expected to decline everywhere in the Amazon since growing number of dams are blocking the way to their spawning grounds and intercept movement of their eggs and larvae (Barthem, 1991; Pompeu, Agostinho & Pelicice, 2012; Castello & Macedo, 2016; Winemiller *et al.*, 2016).

On the other hand, as remediation measures will be applied, the scenario could be an overestimate of the impact of the SLT dam on the categories chosen for the scenario. Fish passages shall be built to enable species migration, which suggests that fish would be able to reach upstream areas to complete their life cycle. Furthermore the SLT dam shall be constructed as a run-of-the-river plant, which will decrease its water storage area compared to dams with reservoirs (Grupo de Estudos Tapajos, 2014; WCD, 2000), suggesting that the river flow would be less altered. However, fish passages have proved to be inefficient or even harmful in the context of tropical hydropower development (Pelicice & Agostinho, 2008; Pompeu, Agostinho & Pelicice, 2012) and studies conducted at Amazonian run-of-the river dams have highlighted a variety of impacts on river flow, floodplain habitats and spawning (Castro-Diaz *et al.*, 2018; Santos *et al.*, 2018). Moreover, plans exist for the construction of numerous dams in the Tapajos Basin, some including 43 dams and not all of them are designed run-of-the-river projects (Fearnside, 2015a; Alarcon & Millikan, 2016). Consequently, each of the dams will withhold and change the flow of water, thus increasing the impact on the river ecosystem. In addition, climate change, which has already been identified to influence the flood pulse and decrease precipitation in the Amazon is suggested to worsen and consequently the adverse impacts that changes to the flood pulse and a dryer environment have on floodplain and spawning (Malhi *et al.*, 2008; Schaeffer *et al.*, 2013; Winemiller *et al.*, 2016).

Finally, this study did not consider the possibility that water inflow from tributaries of the Tapajos River could compensate for the water shortages caused by the dam in the lower Tapajos region. However, only one smaller river (<100m river width) flows into the Tapajos River downstream from the proposed SLT dam, which suggests limited buffering on water shortages, at least as far as to the area where the Tapajos narrows (Fig. 1). In addition, several studies show the far-reaching environmental impacts of dams on downstream environments (WCD, 2000; Marmulla, 2001; Forsberg *et al.*, 2017; Hallwass *et al.*, 2013) and it is likely that upon the completion of the extensive dam building plans in the Tapajos

(Fearnside, 2015a; Alarcon & Millikan, 2016), the impacts will be severe enough to reach until the mouth of the river.

4.3 Recommendations for future impact assessments and research

Research is urgently needed regarding the biology of fish species in the area that could be affected by the dam. This research would determine their susceptibility to dam development, better assess the likely impacts of the SLT dam and make suggestions about how these negative effects might be avoided. The research should focus on the biological and reproductive requirements that were used to evaluate the susceptibility of the fishes to damming in this study. Besides this, more general research should focus on the accessibility of floodplains, improving the efficiency of fish passages and the development of measures to remediate the predicted adverse impacts of the dam on the flood pulse (Power, Dietrich & Finlay, 1996; Carolsfeld *et al.,* 2003; Agostinho *et al.,* 2004; Lira *et al.,* 2017). For example improvements to fish passages in several European freshwater ecosystems has led to considerable success in enabling fish to migrate upstream and complete their lifecycle (Marmulla, 2001) and could therefore work in tropical ecosystems. Furthermore, studies by Travnichek, Bain and Maceina (1995) show that flow restoration to natural conditions restored species richness and abundance after impoundment. In addition, systematic monitoring of downstream fisheries such as landing data, fishing effort, market prices and fishing costs should be applied to reinforce complete the baseline data and be more prepared for possible future environmental and economic changes. LEK can be used as a complementary tool to gather this data. Furthermore, the scenario used in this study is a comparably simple and efficient method to assess possible impacts on fishers upon dam construction and can therefore serve as a model to be applied in other rivers in which hydroelectric impacts need to be studied.

To achieve a representative image of the benefits and costs of the SLT dam, it has to be considered in relation to the environment and people affected. Institutions that authorise and fund the SLT dam have to acknowledge the quantity of people and the scale of the area affected. The impact assessment should include a realistic estimation of the affected downstream areas and certainly extend further downstream than the officially acknowledged 25km (CNEC Worley Parsons, 2014; Fearnside, 2015b; Winemiller *et al.,* 2016; Doria *et al.,* 2017). The interviews with fishers indicated at least three main dimensions of potential effects of the SLT dam on people living along the Tapajos River: 1) economic such as the reduced commercialisation of fish and household income, 2) social such as the changes or decreases in the availability of protein and need to change employment; and 3) cultural such as the changes on identity and emotional stress to fishers and their families. It has to be kept in mind that whilst it is whilst it is possible to compensate the fishers for their financial losses associated with dam development, needs associated with the peoples' identities as fishers are more difficult or impossible to compensate for. Preventing construction of the SLT dam because of its socio-ecological impacts on communities located downstream should be considered. If the dam will be build, mitigation measures have to take into consideration the cumulative impacts of the dams as well as the existing challenges the fisheries face, such as overfishing. Due to the heterogeneity of fishing and fisheries across communities among the lower and middle Tapajos, one-size-fits-all mitigation measures are likely to fail. Instead, plans to alleviate the adverse effects of damming have to be developed that consider each community as a distinct management unit and are tailored to the fishers' specific needs.

5. CONCLUSION

It is true that hydroelectricity dams such as the SLT dams generate necessary energy. However, the costs to society and the downstream environments cannot be ignored. The SLT, may compromise food security and affect fishers' economic and emotional well-being, which is intimately linked to the river ecosystem. It is expected to adversely affect households as well as local and regional economies extending hundreds of kilometres downstream from the dam. Ignoring the effects of the SLT, or other dams, on downstream fisheries is a great understatement of its real impacts, which could severely affect the people whose livelihoods depend on the riverine resources. The data gathered through this study may serve as a baseline against which the impacts of the SLT dam, or other anthropogenic impacts, could be assessed in the future. The data may also be used to calculate the true costs and benefits of the SLT dam. Preventing the predicted impacts on downstream communities could be another reason to support the withdrawal of the licence for the SLT dam. If the current decision to withdraw was reversed, adequate mitigation and compensation measures tailored to the specific needs of the communities have to be found. Efforts should be made to fill the gaps of knowledge in relation to the fisheries and to adequately define the quantity of people that would be affected by the dam. Without more careful consideration, declines in small-scale fisheries and the pressure this puts on their associated fishers, their families and both the local and regional economies are certain to accompany the development of the SLT and other Amazonian dams.

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APPENDICES

Appendix 1: Interview used for the community leaders

INTERVIEW COMMUNITY LEADERS

River:______________ Date:______________

Community:____________________ Coordinates:

Name___________________________________ Sex: ( ) M ( ) F

1) Where were you born? How long have you lived in the community?

2) Are there any community organisations? Which? Are there any fishing organisations?

3) How long have you been the (community) leader for? Which organisation are you associated with? How is the leader elected?

4) How many people live in the community? How many families (houses) are there?

5) What are the main activities of the community?

6) How many fishers are there in the community? (Independent of them being a member of a fishing organisation)?

7) Is fishing more important for commercialisation, consumption or both? (*State which of the options is more relevant).* What are the uses of fish in the community?

8) Are there any fishing (management) rules? What are they?

9) If some kind of management strategies exist, when were they established?

10) Do you think that the management strategies are working?

11) What are the principal problems of the community related to fishing?

Appendix 2: Interview used for the fishers

All questions were asked in the native language of the interviewee (Brazilian Portuguese). The questions written below are a translation of those used. Questions marked in blue were analysed within this thesis. Words in italics are meant to guide the interviewer.

Question 19: It was explained to the fisher that "on your own" means without their parents e.g. the moment where they felt that they knew how to fish without parental supervision (often this is the moment where they start to fish to support their own families).

Question 26: It was explained that the questions "How many hours do you spend fishing?" and "How many people participate in the fishing?" are related to the fisher's answer to the questions of "How many kg of fish do you catch in a normal fishing day?"

INTERVIEW IN RIVER: ________________	Date:___/___/___

Socio-economic profile

1) Community:	2) Interviewee:	3) Age:

4) Birth place/Where are you from:	5) Years lived in the community: ___ years	6) Are you the head of the household? ( ) Yes; ( ) No →Who is?

7) How many people, including you, live in your house?

8) Education (of family members) (*circle education of the head of household*→)	None		Primary		Secondary		Higher	
Age/Sex	♂	♀	♂	♀	♂	♀	♂	♀
( ) ≤5								
( ) 6-14								
( ) 15-30								
( ) 31-64								
( ) ≥65								

9) Does your house have/has (a): ( ) Bathroom; ( ) TV; ( ) Fridge/Freezer; ( ) Running water; ( ) Electric light(s); ( ) Internet; ( ) Computer

13) Are you participating in an organisation or cooperation (of any sort)? ( ) No; ( ) Yes → Which:	14) Are you receiving any governmental benefits? ( ) No; ( ) Yes →Which?

15) What is the average monthly income? (*if possible, indicate value in R$*): ( )0-500; ( )501-1000; ( )1001-1500; ( )1501-2000; ( ) > 2000

Use of resources & economic activities

16) Which economic activities do you pursue?	Order of importance 1 (highest), 2,3... Dry season	Wet season	17) Does anyone else in the family contribute to the household income? What is this person/what are they doing?
( ) Fishing			
( ) Hunting			
( ) Livestock farming			
( ) Non-timber forest products: *which?*			

( ) Others:			
( ) Others:			

	18) Importance for diet (*number*)					
	Fish	Game meat *(which animal do you hunt?)*	Chicken	Beef	River turtle	Pig
Dry season						
Wet season						

Fishing

19) When did you start fishing on your own? (*insert age*):

20) How many days do you fish per week:

21) Type & number of fishing vessel(s)	Size	Does it have a motor?	Dif. to when you started fishing? How?	22) Which fishing equipment do you use *and how many do you have *(insert number (1)(2)(...))*	Dif. to when you started fishing? How?
( ) Canoe				( ) Fishing net (gillnet) - Mesh size:	
( ) Bajara				( ) Cast net:	
( ) Boat with integrated ice-storage capacity				( ) Hook & Line	
( ) Boat without integrated ice-storage capacity				( ) Rod	
( ) Others:				( ) Longline	
				( ) Harpoon	
				( ) Trident	
				( ) Others:	

24) Fishing site	Lake	Channel	Restinga	River	Forest stream	Others:
Wet season						
Dry season						

24) Where do you sell the fish? ( ) Within the community; ( ) Outside of the community (fishmonger, middleman); ( ) in the city; ( ) Others (*specify*):

25) Since you started fishing: The value that you receive for selling the fish has: ( ) Increased; ( ) Decreased; ( ) Stayed the same

26) How many kg of fish do you catch in a normal fishing day?

How many hours do you spend fishing? How many people participate in the fishing? *(write total number incl. fisher)*

27) How many kg of fish did you catch in a normal fishing day when you started fishing?

How many hours did you spend fishing? How many people participated in the fishing? *(write total number incl. fisher)*

Current fish species

28) 5 most important species (*note in the order that they speak)*	Order of importance	Abundance since (you) started fishing			←Why?	Medium size (cm), (*show measuring tape to the interviewee)*
		+	-	=		

Fish species when fishing was started		
29) 5 most important species (*note in the order that they speak*)	Order of importance	Medium size (cm) *(show measuring tape*)
30) Have you seen any new fish since you started fishing? ( ) No; ( ) Yes → Which?		
Anthropogenic impacts & Changes		
31) What do you think, which changes have happened or are happening in the region? When did the changes happen or when did they start?	33) How do you or your community deal with the changes?	
32) How does these changes affect your fishing?	34) Do you think that the fishing for your children will be: The same ( ); better ( ); worse ( ); Why?	

Do you know other fishers that could participate in our study? Cite names.