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Participatory Research with Fishers to Improve Knowledge on Small-Scale Fisheries in Tropical Rivers

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Abstract: Freshwater small-scale fisheries sustain millions of livelihoods worldwide, but a lack of monitoring makes it difficult to check the sustainability of these fisheries. We aim to compare and describe participatory research methods used in studies with fishers in the Tapajos River, a poorly known tropical river in the Brazilian Amazon. We address three interview approaches, two ways to do fisheries monitoring and two approaches for georeferenced mapping based on fishers' knowledge, which can provide data about at least 16 topics related to fisheries. We highlight major advantages and shortcomings of these methods and illustrate their potential with examples of results on fisheries and fish biology of Peacock bass (*Cichla* spp. *tucunaré* in Brazil), an important commercial fish in the Brazilian Amazon. The interviews, participatory monitoring and mapping revealed which fish are more valued by local communities, how fish abundance and sizes varied over time, when fish are more often caught and show reproductive activity, and which sites or habitats fish need to reproduce. In addition to providing useful data from many sites in a cost-effective way, participatory methods can bring the additional benefit of including local stakeholders in the monitoring, management, and research activities.

Keywords: fisheries sustainability; Peacock bass; Tapajos River; Brazilian Amazon; interviews; fisheries monitoring; abundance trends; mapping; fisheries management

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1. Introduction

A large share of the world's fishing, especially in developing countries, corresponds to artisanal or small-scale fisheries conducted mostly at local or regional scales, at the household or family level, providing food security and jobs for millions of impoverished people [1]. Although less studied and less considered in management policies, freshwater or inland small-scale fisheries are of great importance in sustaining millions of livelihoods worldwide, especially in developing countries [2–4]. Small-scale freshwater fisheries are also an important economic activity throughout the Brazilian Amazon [5,6], but excessive fishing pressure has decreased the size and abundance of large and more valued commercial fish in some Amazonian regions [7–11]. These small-scale freshwater fisheries exemplify the challenges to conciliate the food security of impoverished people, fisheries' sustainability and conservation of the richest fish biodiversity in the world [6,12–14]. However, most small-scale fisheries in the Brazilian Amazon remain unmonitored and unstudied, and there is little information about the biology and ecology of exploited fish species that contribute to the food security of local people, making it difficult to evaluate the sustainability of these fisheries in the Amazon and elsewhere [3,15]. As an example, most

(78%) of 90 fish species consumed by Amazonian people are listed as unknown in the International Union for Conservation of Nature (IUCN) red list, evidencing knowledge gaps on these fish [16].

Local people, who have been interacting daily with natural resources for a long time and orally transmit information and skills across generations, have a well-developed local ecological knowledge related to exploited resources, including fish [17,18]. However, this knowledge, which remains largely unrecorded and unknown to scientists, may disappear due to environmental and socioeconomic changes occurring in the Brazilian Amazon and elsewhere [19]. Interviews that aim to record fishers' knowledge can provide useful information for fisheries management, help to fill monitoring and knowledge gaps, and provide new hypotheses about biological processes that are difficult to study, such as fish trophic relationships, migrations and reproduction in the coastal and freshwaters [20–28]. The interviews can also provide fishers' knowledge about past events or temporal trends in abundance, catches or changes in composition of fishing resources, including overexploited or threatened species, but most of these studies have addressed coastal or marine fish [29–38], with fewer studies of freshwater species [8,9,11,39]. Another promising approach consists of generating geo-referenced maps based on fishers' knowledge about the distribution, habitat preferences, nursery sites, or spawning grounds of exploited fish or invertebrate species [23,40,41].

Involving local people in monitoring can yield large amounts of data in a relatively short time span, being sometimes the unique source of information or an invaluable complement for scientific-based monitoring of natural resources, such as invertebrates, game animals, nesting turtles or fish [42–49]. Therefore, participatory approaches are considered a cost-effective way to monitor fishing resources, to fill important gaps, and to highlight the relevance of fishing resources to support livelihoods [3]. Besides providing much needed data for management, participatory research can also improve capacity building through the training of community members, raise awareness among local people on the need to manage resources and empower local communities to participate in management decisions [43,48,50]. Indeed, data gathered through the involvement of local people can be more readily applied to local management of resources [43,48], compared with data gathered by researchers, which can take many years to influence management actions [51].

The main goal of this study is to describe some of the main participatory methods, including interviews, mapping and monitoring, that have been used by our research team to work with fishers in poorly known Amazonian rivers, and provide examples of results. We also aim to compare these methodologies, discussing their main advantages and shortcomings and the potential for these participatory methods to improve the research and management of poorly known freshwater fisheries.

2. Materials and Methods

We do not intend to undertake a comprehensive review of the broad array of participatory or citizen science research methods available in the literature [45,46,52], but rather to describe and discuss in more detail some of the main methodological approaches that our research group has used to conduct research with small-scale fishers in in the Brazilian Amazon. This study reviews participatory research conducted in 30 fishing communities located along more than 250 km of the Tapajos River, in the eastern Brazilian Amazon (Figure 1), during three consecutive research projects across five years—from 2013 to 2018. Across the three research projects, we conducted eight field trips distributed along the following months and hydrological seasons: receding and low water (August 2013, July 2014, July 2016, October 2016 and September 2018) and flooding and high water (December 2013, April 2014, March and April 2017, March 2018). For the research projects conducted in 2013–2014 and 2016–2017, we undertook one research trip approximately every three months. For the more recent project (2018–2019), we conducted two research trips in 2018. The two authors were involved in all three projects with the collaboration of a research team comprising seven undergraduate students, six graduate students, and two professors.

We focused on the Tapajos River as a major case study for three reasons. First, we had been working along a broad extension of this river over the last seven years, analyzing several related topics on fish and fisheries, thus we accumulated a good deal of experience about this socio-ecological system. Second, prior to our research activities there since 2013, we can assume that fish ecology and fisheries are poorly understood in this river basin, so participatory research involving fishers had great potential to rapidly improve the scarce knowledge of the Tapajos River. Third, although poorly known, the Tapajos River basin has been threatened by environmental impacts, including contamination from heavy metals [53] and planned dams in the Tapajos and its tributaries [54–57].

The Tapajos is a clear water river of 1992 km that flows into the Amazon River [58]. The Tapajos is still relatively poorly known regarding fish ecology and fisheries, but some recent studies have described and analyzed the fisheries, fish ecology and fishers' knowledge on fish migration and temporal variation in catch composition [10,11,24,59,60]. According to these studies, the ichthyofauna of the Tapajos River basin includes approximately 982 species [61]. During our previous research in the Lower Tapajos River, we sampled a total of 147 fish species, and 46 species or groups of species that are regularly caught by fishers [62,63]. Fisheries in the studied communities in the Tapajos River are essentially small-scale, providing an important role in food security and income [60]. The most caught fish belong to order Characiformes, such as the jaraqui (*Semaprochilodus* spp.), aracu (*Leporinus* spp., *Schizodon* spp.) and charuto (*Hemiodus* spp.), to order Perciformes, such as peacock bass (*Cichla* spp.), pescada (*Plagioscion squamosissimus*) and acaratinga (*Geophagus* spp.) and to the order Siluriformes, such as the large catfish dourada (*Brachyplatystoma rousseauxii*) and filhote (*B. filamentosum*) [11,59,63]. These fish together comprise 87% of the total biomass landed in a previous fisheries survey [63], and are the most cited fish in interviews with fishers [11,60]. The composition of fish catches does not differ between hydrological seasons, and fisheries occur mostly in the river channel with paddle canoes or small outboard engine boats [59,63].

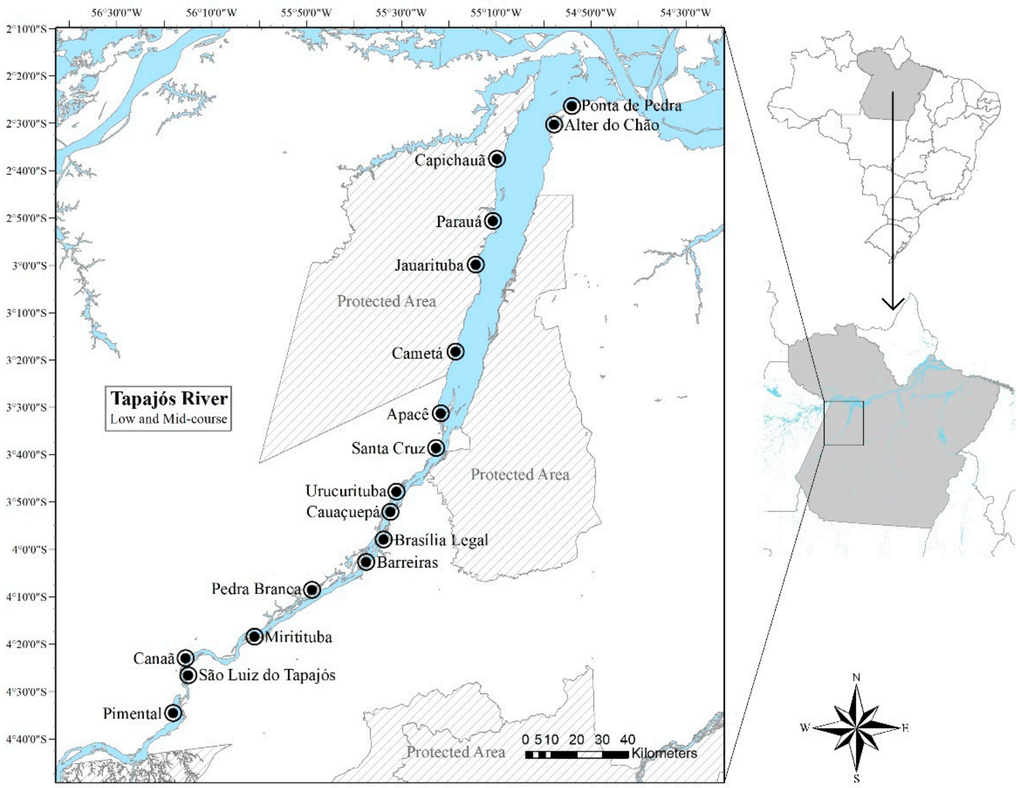

Figure 1. Location of the fishing communities (circles) studied in the Middle and lower Tapajos River, in the Brazilian Amazon. Map: Kaluan C. Vieira, modified from [60,62].

This study brings methods and results from distinct research projects, and all subjects gave their informed consent for inclusion before they participated in the study. We will address here three main methodological approaches, which are briefly described below.

2.1. Quantitative Interviews

We extensively applied the methodology of individual interviews with fishers based on standardized questionnaires (each interviewed fisher was asked the same questions) containing both closed (yes or no, or alternatives) and open-ended questions, which prompted overall perceptions or opinions of fishers about a given topic. These questionnaires usually included questions about socioeconomic characteristics (economic activities, family size, educational background, among others), fishing dynamics (fishing gear, seasonality, spots, amount and size of fish caught), temporal changes related to fish abundance (comparisons of current and past fishing) and fish ecology (spawning sites, seasons and sizes, feeding behavior). Here, we will show examples of results from only a subset of these questions related to temporal changes on fish sizes and relative importance of fish.

After arriving in a community, we spoke to leaders to explain the research and ask about community interest in participating in the study. We then searched for and selected fishers to be individually interviewed—usually those who have fishing as their sole or main source of income. We identified fishers to be interviewed using a snowball sampling procedure: after the first participants were identified by leaders, we asked interviewed fishers to suggest others, as we had applied in previous studies [11,21,39].

We designed three kinds of interviews to gather fisher's knowledge about temporal variations on size and catches of the most used fish and main commercial fish. One of these interviews, which we conducted with 161 fishers in 8 communities of the Lower Tapajos River (Figure 1), included a question on the size of each fish caught at the time of the interview (actual) and 20 years ago (in the past). This kind of interview provided answers that could be statistically analyzed through a test to compare means or medians (in this case, non-parametric test), such as a t-test or Mann–Whitney test (non-parametric version). The second interview approach was conducted with 171 fishers in 16 communities along the middle and Lower Tapajos River [60], and also included a question about the size of fish caught at the time of the interview (actual situation) and when the interviewee started fishing (past situation). We had already successfully adopted this interview approach in a study with 11 fishing communities in the Lower Tapajos River [11]. Therefore, while the first approach included a fixed time frame, the second had multiple time frames, since fishers differ regarding their levels of fishing experience (time since they started fishing). The third interview approach followed the method adopted in previous studies, with a focus on particular preferred or overfished fish species [9,29,33]. We also followed this interview approach in the middle Tapajos River, in a study involving 75 fishers in 8 communities (Figure 1), in which we asked fishers about their best fishing trip and the largest individual fish caught (in length and weight) of selected preferred commercial fish, besides asking when that event (best fishing, larger fish) occurred, thus also generating multiple time periods for analyses. The second and third interview approaches provided answers that could be analyzed through linear regression or Pearson or Spearman (non-parametric) correlation analyses. These analyses include a measure of time, such as years since the time of interview, which would be the independent variable, and the parameter asked to fishers, such as fish size or catches, which would be the dependent variable (in the case of using regression analyses). Another option to organize these data on multiple timeframes consist in establishing time categories or class intervals, for example of 15 years [36], 33 years [11], among other intervals, usually based on fishers' age or experience [30,35,37,64]. This analytical approach has the advantage of reducing data variability (for example, if most citations are from the same year with few or no citations in other years) but has the disadvantage of not supporting analyses to check trends (correlation or regression), which require more continuous data. On the other hand, the establishment of time categories or time intervals could be useful to support multivariate analyses to compare catch composition between different places (communities or protected areas) along defined time intervals [11]. In this study, we plot major temporal trends on variation on fish sizes according to fishers, and opted to not make statistical analyses, as these data have high variability and we consider that a more in-depth statistical treatment of these data would be beyond the scope of this study.

In all three approaches, we conducted individual interviews and asked fishers to indicate fish lengths (total length) on a tape, so as to provide more accurate measurements, as adopted in previous studies [24,38]. This technique originated from the authors' experience in interviewing fishers who usually show fish sizes by expanding their arms, so the tape made it easier to quantify this information more accurately. The statistical analyses were done using Bioestat [65] software, and we usually adopted non-parametric analyses (Mann–Whitney, Kruskal–Wallis or Spearman correlation), as data usually do not show normal distribution.

During the interviews, we showed photographs of fish to interviewees to identify species. We also sampled fish using gillnets in the Tapajos River and organized a database with photographs of fish, which were compared to common names provided by fishers during the interviews and when recording fish landings [62]. However, sometimes fishers apply one common name for more than one species, thus some names refer to groups of fish species.

2.2. Fisheries Monitoring

After the interviews, we invited some fishers (usually those who fish more often or have more experience fishing) to voluntarily record their first five fishing trips (fish landings) each month over one year, using written forms. Fishers received individual basic training and a toolkit to record fish landings, which included a wristwatch, manual scales, a measuring tape, pencils, and standard forms to be filled out with fishing data (duration of fishing, fishing site, time of fishing, biomass of fish caught, fish size, fish uses, occurrence of spawning fish). Researchers collected forms completed by fishers approximately every four months, over one year. All forms collected were detail-checked by researchers, who excluded forms with incorrect or missing data and digitized the fisheries data after this detailed revision.

In partnership with the Equipe de Conservação da Amazônia (ECAM), we also developed a pilot project involving the Open Data Kit (ODK) method to monitor fish landings in the Tapajos River. This monitoring involved hiring data collectors to record fish landings data in an app installed on smart phones. We successfully implemented this monitoring in three communities of the Tapajos River (Alter do Chão, Parauá and Cametá—Figure 1), which had participated in our previous studies [11,63]. In each community, we held meetings with leaders and interested people to explain the project, ask for their consent to participate, and find a person to conduct the monitoring. We then hired collectors, who were all young villagers (less than 30 years old) usually attending school (secondary school) and skilled with smart phones. These collectors were trained to record the fish landings of all fishers who agreed to provide these data, across 10 days per month, over three months (March, April and May, 2018). We compared the performance of the pilot study using the ODK method with the conventional voluntary participatory method that we had adopted in previous studies [59,63,66], by selecting data from the same three communities and during the same three months in which the ODK was conducted. However, the participatory monitoring was conducted in 2017, one year before the ODK survey.

2.3. Mapping

We conducted participatory mapping using two main approaches. In one, we asked individual fishers to mark on maps (satellite image mosaics with community at the center of a 10 km radius line) the most relevant sites for reproduction (spawning), fishing, and migration routes of seven fish species. The marking was made by each fisher on a transparency sheet, which was superposed to the map. The maps were georeferenced, so that later in the laboratory we scanned and superposed marked transparencies for each community, after which a software program counted and indicated the points (sites) that were marked most often. In the other approach, we conducted the mapping during meetings involving several fishers in each community, and produced one map per community, on which fishers were asked to indicate sites or habitats relevant for migration, reproduction, and fishing. This approach was more qualitative (only one map) and more focused on relevant habitats than on particular fish species.

The three main research methodologies involving participation of fishers (interviews, monitoring and mapping) provided useful and often new information on at least 16 subjects related to fish biology, fisheries and fishers in the Tapajos River (Table 1). Wherever possible, we will compare data gathered from these distinct methods, to highlight their complementarities.

Table 1. Databases and subjects related to fish, fishers and fisheries obtained from each of the three broad categories of participatory methods applied in our research with fishing communities in the Tapajos River and other rivers in the Brazilian Amazon.

Subject	Data	Interviews	Fish Landings	Mapping
Fish biology	Fish diet	Yes		
	Fish migration	Yes		Yes
	Fish size	Yes	Yes	
	Fish spawning (size and season)	Yes	Yes	
	Fish spawning sites	Yes		Yes
Fisheries	Biomass of fish caught (and CPUE)	Yes	Yes	
	Catch composition	Yes	Yes	
	Fishing gear	Yes	Yes	
	Fishing grounds	Yes	Yes	Yes
	Fishing season	Yes	Yes	
	Management options	Yes		
Fishers	Fishers' behavior	Yes	Yes	
	Socioeconomic characteristics	Yes	Yes	
Impacts	Biomass and size of fish in the past	Yes		
	Ecological characteristics	Yes		Yes
	Environmental impacts	Yes		Yes

3. Results and Discussion

Some research results from these methods to understand fish and fisheries in the Tapajos River have already been published [11,24,59,60,63,66]. It is not our goal to show the full range of results obtained from all these methods, but rather to show some examples of data that could be gathered and discuss the strengths, advantages and potential limitations of each methodological approach. We will focus most of our examples on results about fisheries and biological parameters (fish size, reproduction) of the Peacock bass (*Cichla* spp., *tucunaré* in Brazil), which is an important fish for food and commerce both in the Tapajos River [11,60,63] and in the Amazon as a whole [6], besides being highly valued for recreational fisheries [67].

3.1. Interviews: New Data on Past Situations

The interviews with fishers have provided many kinds of useful data on fish ecology and fisheries. Basic, yet relevant information, relates to the kinds of fish most used or most relevant to fishers in the studied communities in the Tapajos River. In a survey conducted in 2018 with 171 fishers in 16 communities along the Tapajos River [60], we asked fishers to list the five most important fish they catch and to rank the cited fish according to their relative importance (currently, and in the past), from 1 (more) to 5 (less) important. We then standardized this data by subtracting the ascribed value from 11, thus adjusting the scale of importance from 10 (more important) to 6 (less important). We did this to make results more intuitive, whereby a higher number indicates higher importance. The data on relative importance can be complementary information on cultural and economic value of each exploited fish, besides the absolute or relative number of citations of each fish by all the interviewed fishers [60]. As an example of the results from these data on fish importance, we found that larger fish species tend to be given a higher importance by fishers (Kruskal–Wallis H = 74.5, $p < 0.0001$), and that the Peacock bass is highly important now, as it was in the past (Figure 2). Larger fish tend to be preferred and more intensely exploited in tropical multispecies fisheries [68], and the Peacock bass has been a targeted fish species in the Tapajos River for a long time [11].

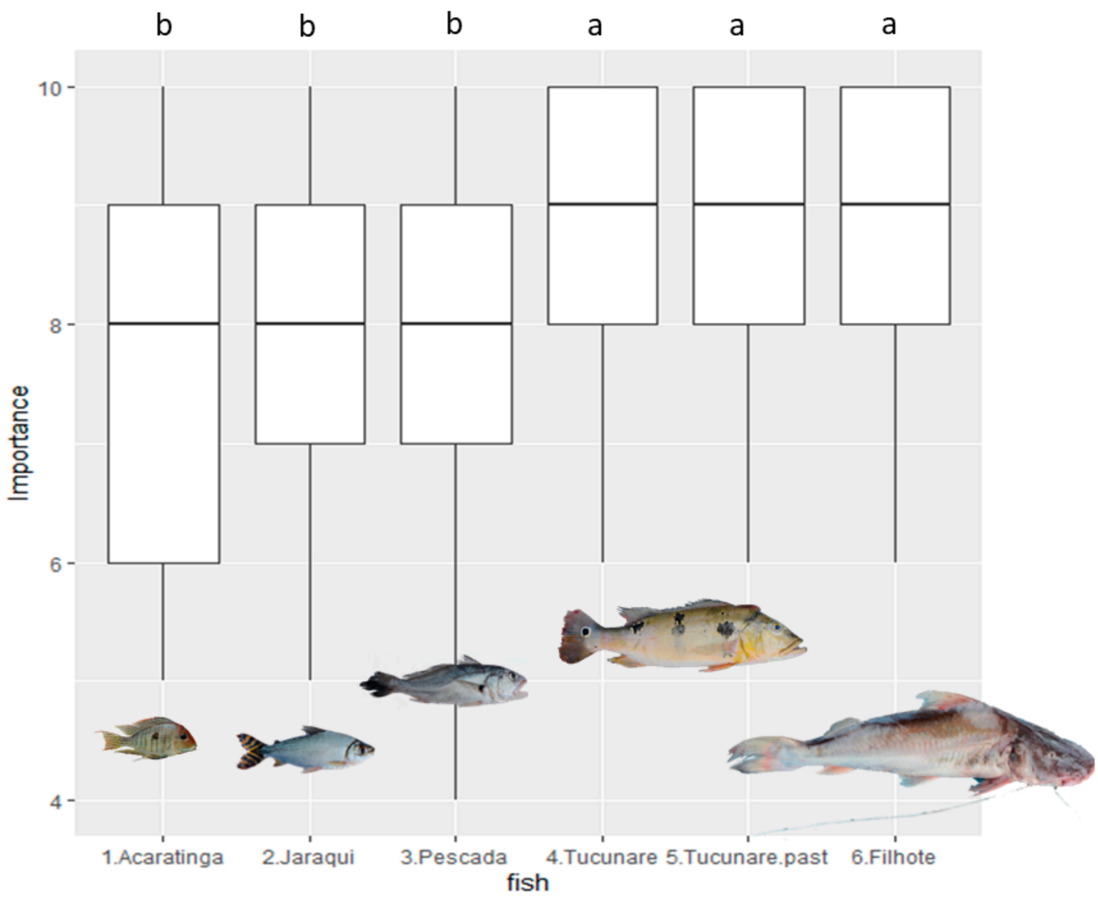

Figure 2. Median values (horizontal lines within the boxes) of importance attributed during interviews to five fish species (or groups of species), arranged in order of body size (from smaller to larger). Data from Peacock bass refers to the importance attributed by fishers currently (in 2018) and in the past (when each interviewed fisher started fishing). Letters correspond to significantly different medians according to Dunn's post-hoc tests (**a** > **b**, $p < 0.05$). Acaratinga (*Geophagus* spp., photo from *Geophagus* sp., n = 43 fishers), Jaraqui (*Semaprochilodus* spp. photo from *Semaprochilodus taeniurus*, n = 105 fishers), Pescada (*Plagioscion squamosissimus*, n = 110), Tucunaré or Peacock bass (*Cichla* spp., photo from *Cichla pinima*, n = 82, in the past n = 87), Filhote (*Brachyplatystoma filamentosum*, n = 51).

A widespread application of interviews with fishers consists in getting data about the most used, caught or preferred fish species in the context of unmonitored or poorly-known tropical small-scale fisheries, such as those in Brazil [16,39,60,69,70]. These interview-based data are usually positively related to fisheries data [39], which indicates the potential of fishers'-based information to support management policies for poorly studied fisheries [17]. However, there could be some discrepancies between reported (interviews) and monitored (catches) data on resource use. For example, in the Tocantins River, in the Brazilian Amazon, fishers tend to overestimate their citations on use of the most valuable species, such as the Peacock bass (tucunarés), whereas they underestimate less valued fish, such as pescada (*Plagioscion squamosissimus*) [39]. A study conducted in Madagascar shows that, when comparing interviews with actual hunting data, the interviewed hunters can better and more precisely record use of hunted species during the last year (as opposed to the last month) and during periods of lower resource abundance [71]. Moreover, the few studies that have compared interview and harvest data (hunting or fisheries) indicate that the two datasets are correlated and interviews can thus be a reliable indicator of resource use [39,71]. Furthermore, in most situations, such as for inland fisheries in tropical countries, interviews with fishers or other resource users would be the sole data source available to check intensity of resource use [3]. The information on most used fish from interviews with local fishers have also been useful to evaluate environmental impacts from dams; for example, changes in fish abundance caused by a dam built more than 20 years ago in the Tocantins River [39], or the potential impacts of the planned dams in the Tapajos River [60].

The interview data provided invaluable information from fishers' knowledge on the past situation of fish in the Tapajos River, especially for the Peacock bass, which is an important commercial fish (see fish landings data below). The interviews undertaken in 2013 with 203 fishers in 11 communities indicate that, according to fishers, there was a change in composition of exploited fish in the Tapajos River, with a decrease in catches of some large commercial fish and an increase in catches of smaller and less valued fish [11]. Indeed, such change in composition was less remarkable in protected areas that include people (Extractive Reserve and National Forest), where some larger and valuable fish are still caught [11]. Therefore, interviews with fishers can provide new information on changes related to fishing resources, and help evaluate the effects of protected areas on fisheries [43]. These data could not have been obtained otherwise, due to the absence of regular and continued fisheries monitoring in the Tapajos and most other rivers in the Brazilian Amazon [16,72].

The results from our three interview approaches provided useful and complementary information about temporal changes in catches and size of the Peacock bass in the Tapajos River. The number of interviewed fishers is not the same as mentioned above in the methods, because not all fishers identified the Peacock bass among the five most caught fish, although most fishers did mention it.

The first interview approach indicated that the size of Peacock bass regularly caught was larger in the past (20 years ago) than at the time of the survey in 2016 (Mann–Whitney U = 2672.5, p = 0.0047, Figure 3). Nevertheless, the decrease was not so accentuated, as the actual median size (43.5 cm) according to fishers, corresponded to a 16% decrease compared to the median size of 51.5 cm reported for 20 years ago (Figure 3). The biological literature reports maximum lengths of 52 cm for *Cichla pinima* and 74 cm for *Cichla ocellaris* [73,74], which are the two most common species of Peacock bass found in the studied regions [62]. These values are within the range of sizes reported by fishers, who also mentioned larger sizes of Peacock bass being caught. However, the smaller maximum sizes recorded in the biological literature, as compared to our interviews, could reflect the lack of biological data about these and many other fish species in the Brazilian Amazon [16].

The second interview approach indicated an overall and non-linear decreasing trend of the regularly caught size of Peacock bass reported by fishers in the Middle Tapajos, as sizes reported being caught in the past (up to 70 years ago) were usually larger than sizes reported more recently, despite large variation in the data (Figure 4). This plot (Figure 4) included only the sizes of Peacock bass reported being caught in the past, or when each fisher started fishing, and did not include sizes reported as actually caught. We opted for this data selection to better visualize trends and the past situation. We could observe a trend because interviews included younger and less experienced fishers (less than 10 years since they started fishing), as well as older and more experienced fishers, thus providing size estimates across approximately 60 years (Figure 4). In previous studies, our research group focused on more experienced fishers only, by adopting a criteria of selecting only fishers with at least 10 years of fishing experience [11,24,25,39], or even older than 40 years [21]. However, to analyze trends over time on some parameters, such as fish size or catches, it is worth also including younger and less experienced fishers in interviews, to be able to analyze trends including recent years and potential influences of fishers' age on perceived trends [30,32,33,35,37,64]. Furthermore, the young fishers are those that usually employ a higher fishing effort (fishing pressure) currently, so including them in interviews could help to evaluate the current situation of fisheries and future trends.

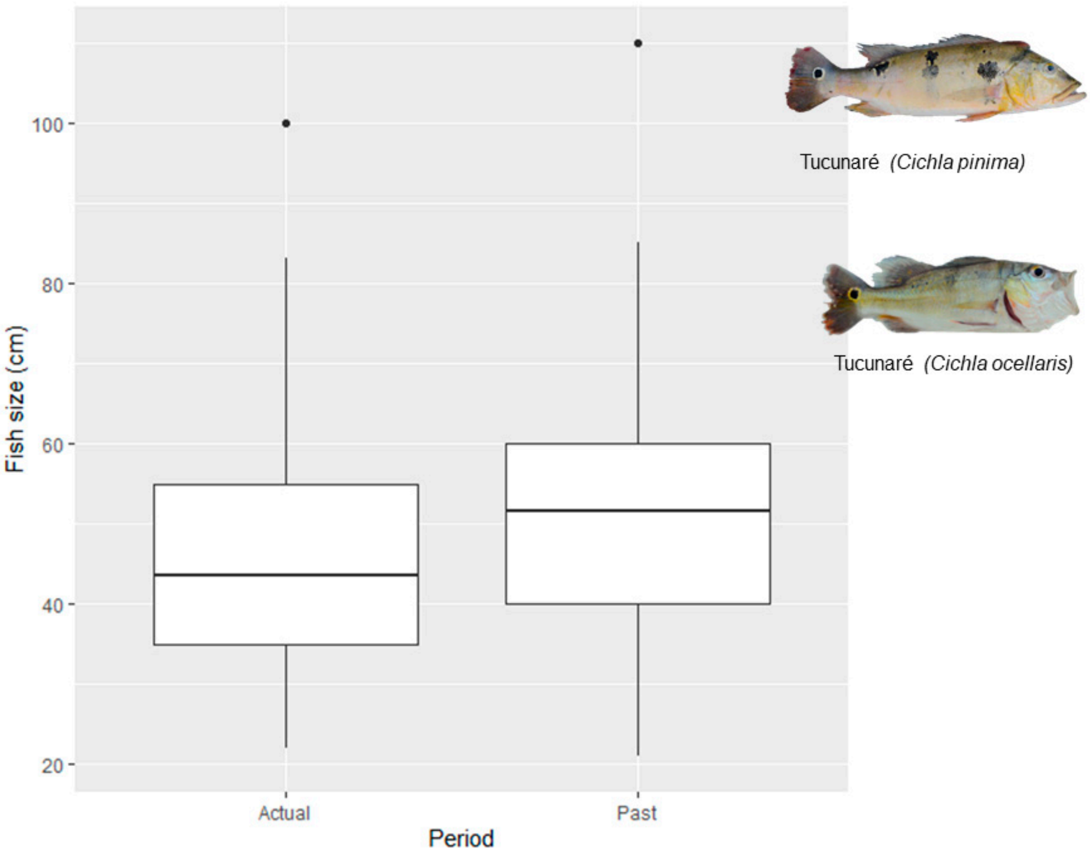

Figure 3. Median values (horizontal lines within the boxes) of the size of Peacock bass (*Cichla* spp., photos of the two most common species) reported by fishers during interviews conducted in 2016 in 8 fishing communities in the Lower Tapajos River. Actual: the size of Peacock bass at the time of interview, 2016 (n = 106 fishers), Past: the size of Peacock bass 20 years before the interview (n = 66). The difference in the number of fishers occurred because some fishers did not mention fishing for Peacock bass 20 years ago. Boxes indicate upper and lower quartiles. Fish photos: R.A.M. Silvano.

The third approach also indicated a non-linear decreasing trend of size of the largest Peacock bass caught, according to fishers in the Middle Tapajos (Figure 5). However, in this case, the timeline corresponds to the time when the fish was caught, so at least some fishers reported catching the largest fish in the same year as the interview, while the oldest reported catches occurred about 29 years ago (Figure 5). As expected, the range of Peacock bass sizes reported in this approach were larger, including many sizes above 60 cm (Figure 5) than those reported in the previous interview approach (Figure 4), as in this third approach, we purposely asked fishers to report the largest fish they ever caught. Nevertheless, it is interesting that both approaches provided a similar trend. Moreover, these analyses could be somewhat improved by transforming the data to be able to do parametric statistical analyses, or even some modeling including other variables, such as fishing community, socioeconomic characteristics of each fisher, among others. We also could get other data from this third interview approach, including the weight of the larger fish caught (in kg) and the total amount (in kg) of Peacock bass caught in the best fishing trip, which could also be correlated with the time when these events had occurred. The reported weight of the larger Peacock bass caught by the interviewed fishers was positively correlated with reported length (Pearson correlation r = 0.5, $p = 0.0004$, n = 40), but the largest fish caught in weight (kg) was not related to time (years before the interview, Spearman correlation rho = 0.29, $p = 0.082$, n = 38). Nevertheless, we consider that data on fish length may be a better indicator of temporal trends for the purposes of this study, because more fishers mentioned length (n = 50), thus providing a larger sample size. Fish length was also more accurately measured by using a tape measure during the interviews. The fishers' age was not related to the largest size of Peacock bass cited (rho = 0.21, p = 0.13, n = 54), thus indicating a lack of a shifting baseline effect [30,75] on fishers' perceptions regarding the largest Peacock bass caught. The shifting perceptions among fishers from different ages regarding the abundance and size of fishing resources have been documented often in previous studies, which usually indicates that older fishers tend to remember and cite larger fish [29,33,35,37]. Interestingly, the largest catch of Peacock bass, according to the interviewed fishers, were not related to time (years before the interview, rho = 0.16, p = 0.28, n = 47), thus indicating that catches of this fish may not have experienced a remarkable decrease across the last 29 years. However, the interview question did not consider the effort (amount of fishing gear or time spent fishing) employed in the largest catches, making it difficult to make more precise inferences about the variation in Peacock bass stocks. Although, potential changes in effort (gear, time, fishing fleet) are gradual and hard to be recorded by fishers and have usually not been addressed in studies on fishers' knowledge about best catches [33,37]. Nevertheless, these changes in fishing effort can affect catches, and so effort could be added to temporal trends [32]. For example, the interviewed fishers recorded the increase of catfish (*Brachyplatystoma rousseauxii* and *B. filamentosum*) catches concurrently with an increase in the availability of motorized boats and the use of large gillnets in the Tapajos River channel [11].

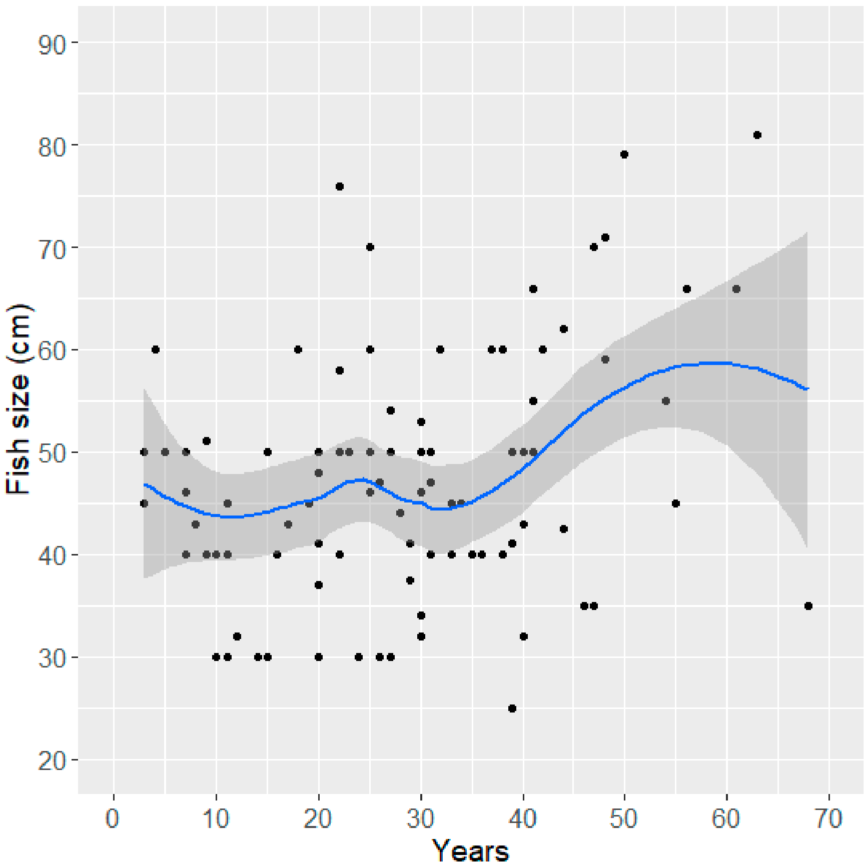

Figure 4. Correlation between reported sizes of regularly caught Peacock bass (*Cichla* spp.) by fishers (n = 93) and years before the interview was conducted (2018), which was estimated according to the time when each fisher started fishing, in 16 communities along the Tapajos River. The scale of the y-axis starts at 20 cm, to better show the amplitude of data. Grey shadows indicate the 95% confidence limits from the fitted line.

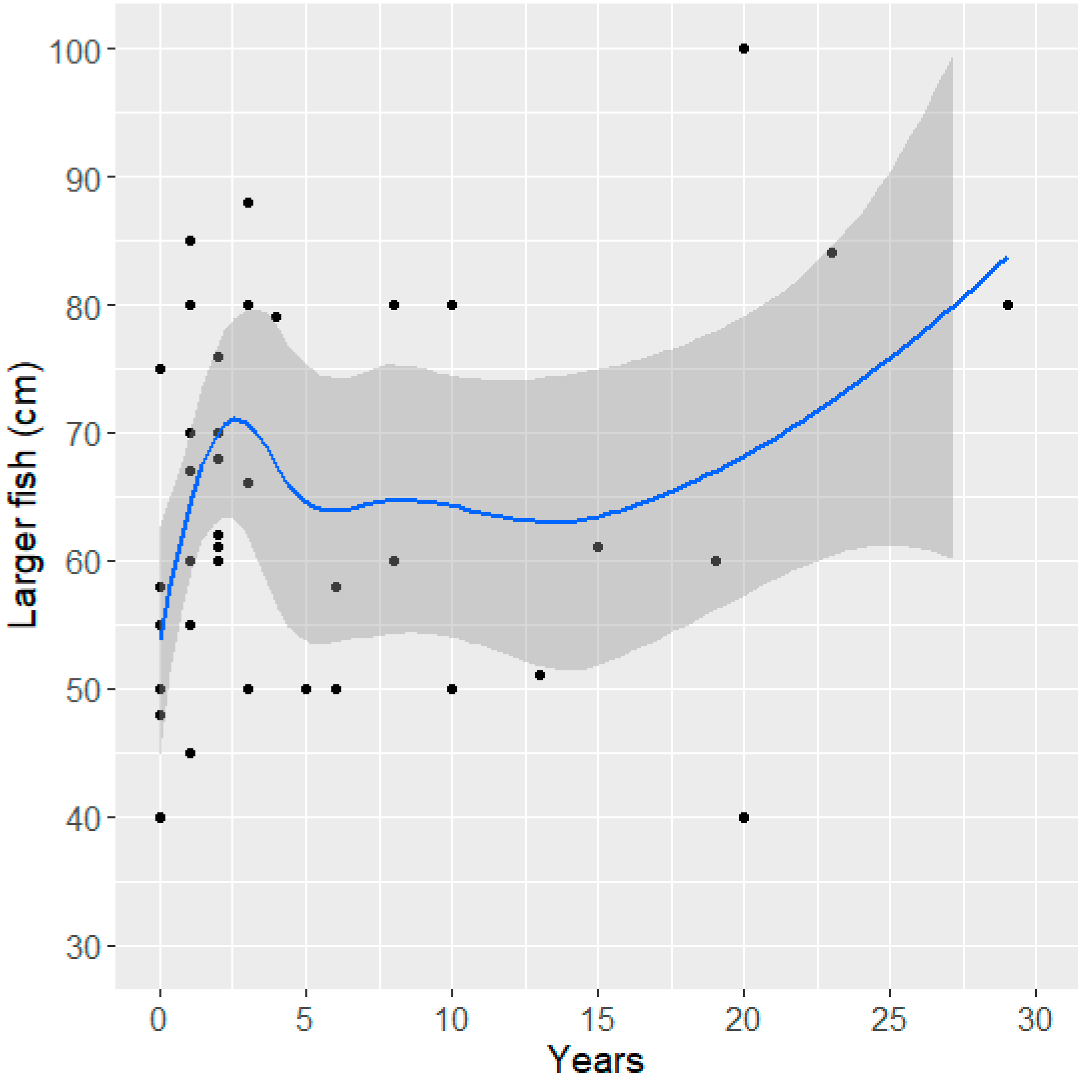

Figure 5. Correlation between reported sizes of largest caught Peacock bass (*Cichla* spp.) by fishers (n = 44) in the Middle Tapajos River and years before the interview was conducted (2018), estimated according to the time when the fish was caught. The scale of the y-axis starts at 30 cm, to better show the amplitude of data. Grey shadows indicate the 95% confidence limits from the fitted line.

When comparing data from the three interview approaches, different fishers mentioned similar median sizes of Peacock bass caught currently (at the time of the interview), during distinct surveys conducted in the lower and middle Tapajos River in 2016 and 2018 (Figure 6). This convergence on cited Peacock bass median sizes of around 40 cm indicated the reliability of the interview data, although the sizes mentioned in interviews were larger than the median size (37 cm) of the largest Peacock bass regularly caught and measured by fishers during the participatory monitoring of fish landings (Figure 6). Therefore, it might be that the interviewed fishers had slightly overestimated the size of Peacock bass regularly caught, but the full range of sizes of Peacock bass caught and measured are within the range of sizes mentioned in interviews, even considering the sizes mentioned for the largest Peacock bass (Figure 6).

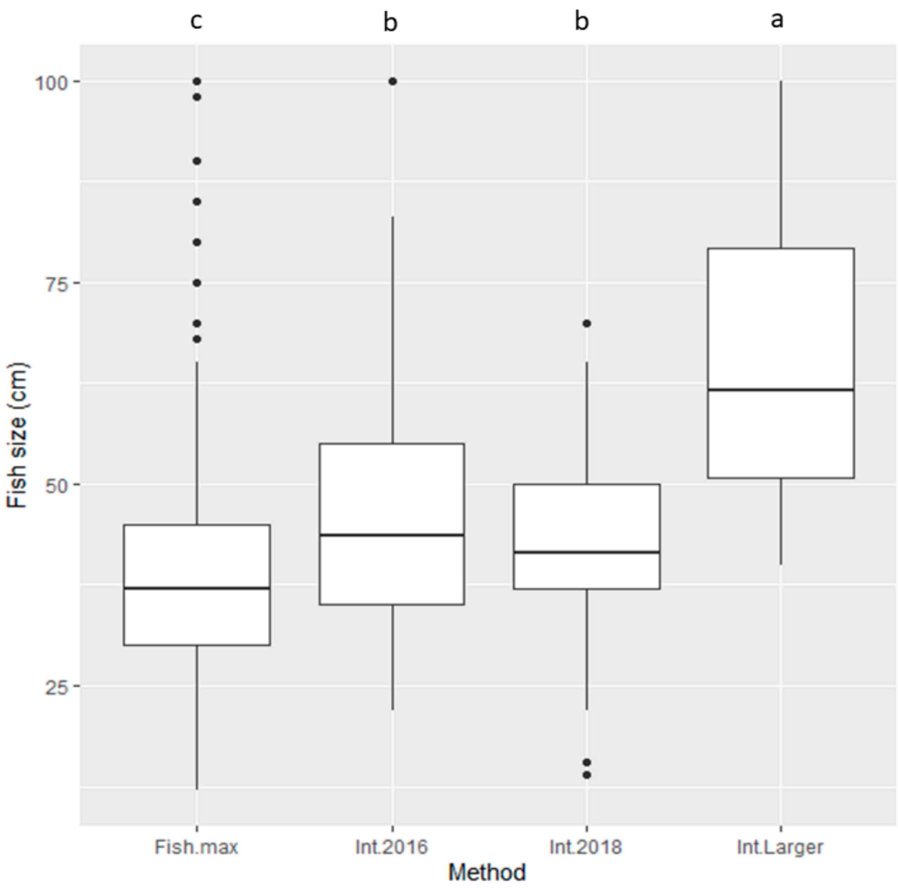

Figure 6. Median values (horizontal lines within the boxes) of the size of Peacock bass (*Cichla* spp.) estimated though four participatory research methods in the Tapajos River. Fish max: size of the largest Peacock bass caught and measured by fishers themselves during a survey involving participatory monitoring of fish landings in 2016. Int 2016: interviews with fishers (n = 106) in 8 communities in the lower Tapajos in 2016, asking about the size regularly caught of Peacock bass at the time of the interview. Int 2018: interviews with fishers (n = 93) in 16 communities along the Tapajos River, asking about the size regularly caught of Peacock bass at the time of the interview. Int Larger: interviews with fishers (n = 44) in 9 communities in the middle Tapajos River, asking about the largest size of Peacock bass ever caught. Boxes indicate upper and lower quartiles and dots are outliers. Letters correspond to significant different medians according to Dunn's post-hoc tests (**a** > **b** > **c**, $p < 0.05$).

The combined data from all three interview approaches dealing with Peacock bass sizes in the Tapajos River indicated a usual size of approximately 40 cm, and most of the Peacock bass individuals cited would be above 35 cm (only 25% of Peacock bass cited in 2016 interviews would be smaller) and most of the largest Peacock bass cited would be between 54 and 76 cm (75% would be smaller than this size) (Figures 4–6). Although there are declining trends in size over time, these are not so pronounced; relatively large sizes are still cited in more recent years (Figures 4 and 5), and some fishers mentioned that they caught the biggest Peacock bass recently (in the last five years—see Figure 5). We also did not observe a trend on declining total catches (in kg) over time according to fishers, and the fishers' age was not related to the reported sizes of largest Peacock bass caught, contrarily to the shifting baselines observed in previous studies on coastal fish [30,33,35,37]. The data gathered from fishers' knowledge can be useful in assessing potential fishing effects on the populations of this fish species, possibly being the sole source of population data for the Peacock bass in the Tapajos River. Overall, these results may indicate that, although showing signs of decline, Peacock bass populations are not yet severely depleted or overfished in the Tapajos River. This suggests that fishing stocks of Peacock bass could be in a better situation than stocks of other commercial fish species in other Amazonian rivers, such as the tambaqui (*Colossoma macropomum*), pirarucu (*Arapaima gigas*) and large catfish [8,9,11,76]. Other studies on fishers' knowledge have shown more severe declines over time in size or abundance of target fish species in marine [29,33,35] and freshwater ecosystems, including the Brazilian Amazon [9]. Therefore, our results from interviews with fishers, which not only complement but are reinforced by data on fish landings (see below), indicate that there should still be an opportunity to sustainably manage Peacock bass stocks in the Tapajos River.

Methodologically, the three approaches of time scale were useful to record past abundance or sizes of Peacock bass. However, all these approaches rely ultimately on fishers' memories of past events related to fishing, such as the size of fish caught. The lack of a relationship between fishers' age and reported sizes of Peacock bass caught indicate that fishers' knowledge in the Tapajos River is possibly not subjected to age-related bias, such as shifting baselines, memory illusions, or generational amnesia [77]. These past records of fish sizes by fishers could be based on episodic memory (a temporally organized memory of specific events), semantic memory (a general conceptualization of the memories), or a transition between both [78]. The records from 20 years ago are based on a transition from episodic to semantic memory, also called molar memories, in which the repetitions of an event are more easily accessible to records [78], such as the mean sizes of Peacock bass caught around 20 years ago. The punctual episodic, such as the beginning of fisher's careers, the best fishing (fishers' highest catch), the largest fish ever caught, or such events as the damming of a river, are based on episodic memory—that is, a memory temporally organized around specific facts of the interviewee's life. These facts tend to be marked on the fishers' memory and be better remembered [11,32,39,78,79]. We addressed here an important commercial fish in the Tapajos River [11], which is related to food and income and thus tends to be more easily remembered by fishers, as observed in a previous study [39]. Nevertheless, data from fishers' memories are subjected to some degree of imprecision, as fishers may have difficulty accurately remembering past data [77,80], which would be better considered as estimates of fish size. Therefore, it is important to double-check these data and try to increase the sample size of interviewed fishers whenever possible, in addition to carefully considering outliers and confidence intervals of these data.

3.2. Fisheries Monitoring

Although interviews may be a practical and timely approach to rapidly assess the use of fishing resources, especially at broader spatial scales involving many communities [11,16,39,60,69], monitoring of actual resource use is also important to provide more detailed data on intensity of resource use and fishing strategies, among others. In a previous study in the Tocantins River, researchers recorded a total of 606 fish landings (fishing trips) in five fishing communities during one year, by interviewing fishers upon arrival from fishing trips and weighting catches [72,81,82]. However, in the studies in the Tapajos River that involved participatory monitoring of fish landings, during the same period of one year we could analyze 2013 fish landings recorded by 51 fishers in 11 communities in 2013 and 2247 fish landings recorded by 91 fishers in 8 communities in 2016 [59,63,66]. Therefore, participatory monitoring in the Tapajos River provided about three times more data for analyses, compared to monitoring undertaken by researchers in the Tocantins River. Besides the larger amount of data obtained, the participatory monitoring included more than 100 fishers in both studies (some fishers participated in both), who were trained to record fisheries data, evidencing the potential of this approach for capacity building in the studied communities.

There were two major limitations to this method. First, the turnover of fishers who participated voluntarily and therefore could quit the survey at any moment, whereas other fishers were invited, or manifested interest in joining during monitoring. Although this contributed to getting more fishers involved and to spread learned monitoring skills, such turnovers made it more difficult to standardize data, introduced variability, and required more time dedicated to training new fishers. Second, individual fishers can vary regarding their ability or dedication to register fish landings in written forms, which is expected and fair, considering that fishers are not academically trained researchers and are collaborating on a voluntary basis. Therefore, the data produced needed to be carefully checked by researchers and some data or fish landings had to be discarded from analyses. Indeed, the total number of recorded fish landings in both studies in the Tapajos River were even higher, but some fish landings could not be analyzed due to inconsistences, incomplete information, or missing data. Despite all this, it has been a positive experience working with participatory monitoring, and the advantages of this methodological approach surpass its limitations. During meetings in fishing communities at the end of each project, fishers mentioned that they enjoyed the experience of monitoring their fish landings, and most of them would be willing to continue to collaborate in future research. Another limitation is in the discontinuity of monitoring at the conclusion of the research project, due to lack of funding and remoteness of some study communities—some which do not even have regular contact by phone. To maintain monitoring over several years is a common difficulty experienced in participatory monitoring programs, usually demanding cooperation among several institutions [15,43,48]. Although we were not able to continue the participatory monitoring in the Tapajos River, we hope that participating fishers have learned in the process. We produced a book with the main results of the fisheries monitoring [83], which was distributed to participant communities, leaders and local schools. Therefore, participating communities at least have a record of the main results that they could use for management purposes or to prevent environmental impacts.

The fisheries data gathered through participatory monitoring served as a basis for calculating relevant fisheries parameters, such as capture per unit of effort (CPUE, calculated as kg of fish caught per fisher per hour), travel time to fishing grounds, the composition of catches and gear used, among other data. This monitoring also provided useful data about fish biological parameters, including size and spawning individuals (female fish observed with eggs). We opted to ask fishers to record information for spawning females only, as these would be easier to observe and possibly more reliable to identify. Other studies have indicated that fishers may also have knowledge about mature males [48], but we preferred not to increase the burden of data gathering for our voluntary collaborators. Nevertheless, most fish have external fertilization, and so we would expect a synchronization of the maturation and reproduction period between males and females. Therefore, the reproductive period of females should apply to males as well.

The participatory monitoring in 11 communities in the lower Tapajos River in 2013 indicated that the CPUE are higher in communities located in protected areas (Extractive Reserve and National Forest), compared to communities outside, indicating a positive influence of protected areas on local fisheries [59]. Nevertheless, more recent (2016) monitoring in 8 communities in this same region of the lower Tapajos River (but not the same communities as in 2013) indicates that the median catches (in kg) are higher for communities located outside than for those located inside the extractive reserve, whereas the CPUE did not differ between communities located inside and outside this protected area [63]. These results may be due to an enhanced demand for fish and higher fishing effort in some communities located outside the protected area [63]. This more recent monitoring in the lower Tapajos River yielded detailed data that were applied in modeling many potential factors that could influence fish catches and CPUE, including individual characteristics of fishers, habitats, fishing gear, time travelled during the fishing trip, among other variables [66]. Furthermore, according to fishers in the meetings we held at the end of the project, the activity of recording fish sizes and fish observed with eggs (spawning seasons) helped fishers understand the underlying reasons for some of the fisheries restrictions (minimum size and reproductive season) according to federal legislation [72]. Therefore, participatory monitoring could improve fishers' understanding of fisheries rules or laws, making fishers more willing to comply with legislation or management initiatives [43,46,48,49,72,84].

Considering the comparison between ODK and more conventional participatory monitoring through written survey forms, over three months, the ODK collectors recorded 215 fish landings, at 2126.7 kg of fish with an overall average of 23.9 landings per month (Figure 7). In the previous participatory method, fishers in the same communities recorded 209 fish landings, at 2688.9 kg of fish and with an overall average of 23.2 landings per month (Figure 7). This comparison indicated that, the ODK method was at least as efficient as the conventional participatory voluntary method to record fish landings, albeit with variable performance among the three studied communities. The total fish landings, and the average landings recorded per month in all communities, were similar for the two methodologies (around 200 landings), and slightly higher for the ODK method. Indeed, in two of the three studied communities (Alter and Cametá), the ODK methodology seemed to have provided more fish landings, whereas in the other community (Paraua), fewer fish landings were recorded by ODK when compared with the voluntary participatory method (Figure 7). However, we need to consider that the ODK included 10 days of sampling, while we asked fishers to record their own fish landings over five days. We believe that these observed differences in data recording among communities may be due to a lack of experience of some data collectors, or an unwillingness of some fishers to provide information. The community that recorded more fish landings was the Cametá, which may be explained by two characteristics of this community. First, this is one of the better organized communities inside the Extractive Reserve; they showed interest in our project after a general meeting and they have done similar monitoring in collaboration with reserve managers. Second, several people there showed interest in working as data collectors, so three distinct collectors were selected to record fish landings—one collector per month. It is possible that such alternating between data collectors, as well as their interest in participating, assured better records in this community.

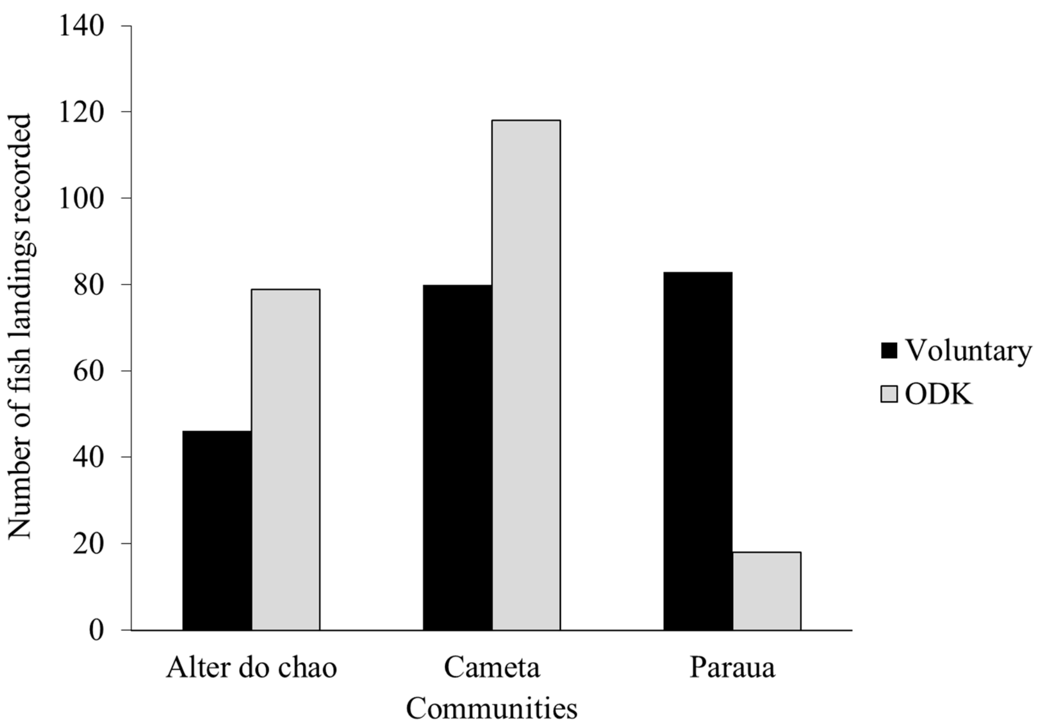

Figure 7. Number of fish landings recorded using the two methods adopted for recording fish landings: participatory or voluntary (fishers voluntarily recorded their own fish landings for 5 days per month) and open data kit (ODK, in which a hired collector in each community recorded landings from all fishers over 10 days per month) in three communities in the Lower Tapajos River, over three months.

Overall, the ODK method could be a fast and practical alternative for monitor fisheries in distant fishing communities in Amazonian rivers. One of the advantages of the conventional participatory method is that it involves more fishers in data collection, who are individually trained, thus helping to disseminate monitoring skills among the communities and possibly contributing to capacity building. One of the advantages of ODK is that data are recorded in digital media and can be sent remotely to researchers, eliminating the need to retrieve and type hundreds of forms hand-filled by fishers. Another advantage is that the ODK allows the collectors to take photos to register fish species caught.

These photos may sometimes provide information on fish not previously sampled or known in the region. Photographs may also present a useful way to better match fish names given by fishers with biological species, which is a common shortcoming of participatory monitoring systems [48].

During participatory monitoring in 8 communities of the Tapajos River in 2016, fishers measured the length of 694 individual Peacock bass caught (minimum and maximum sizes). These data can be used to build a length frequency distribution of the sizes of Peacock bass caught in fish landings, which showed that most of the individuals caught are from 20 to 40 cm in length (Figure 8). These data reinforce the information provided by data from interviews with fishers (see above and Figure 6), as Peacock bass measuring up to 40 cm were among the sizes most caught by fishers, corresponding to 75% of individuals measured (Figure 8). Furthermore, even the largest reported size by fishers (100 cm, Figure 5) was actually measured by fishers (Figure 8), which indicated some reliability of reported sizes. These data on length-frequency would be difficult to obtain through biological sampling alone. For example, a review of several species of Peacock bass (genus *Cichla*) reports measures for 49 individuals of *Cichla pinima* and 34 individuals of *Cichla ocellaris* [73], and our own biological sampling in the Tapajos River brings measurement data for 38 individuals of *Cichla pinima* and 18 individuals of *Cichla ocellaris* [62]. A limitation of the length data from fisheries monitoring is that this information has to be applied at the genus level (*Cichla*), as these data possibly refer to more than one species of Peacock bass. However, the Amazonian fishers are able to name and recognize distinct species of Peacock bass [85], so future interviews with fishers using photographs of fish and asking about Peacock bass names can contribute to improving identification at the species level of at least some of the fish recorded in fish landings. The ODK method can also contribute to these data collection, as fishers or data collectors may be required to take photos of Peacock bass, therefore improving species identification by researchers.

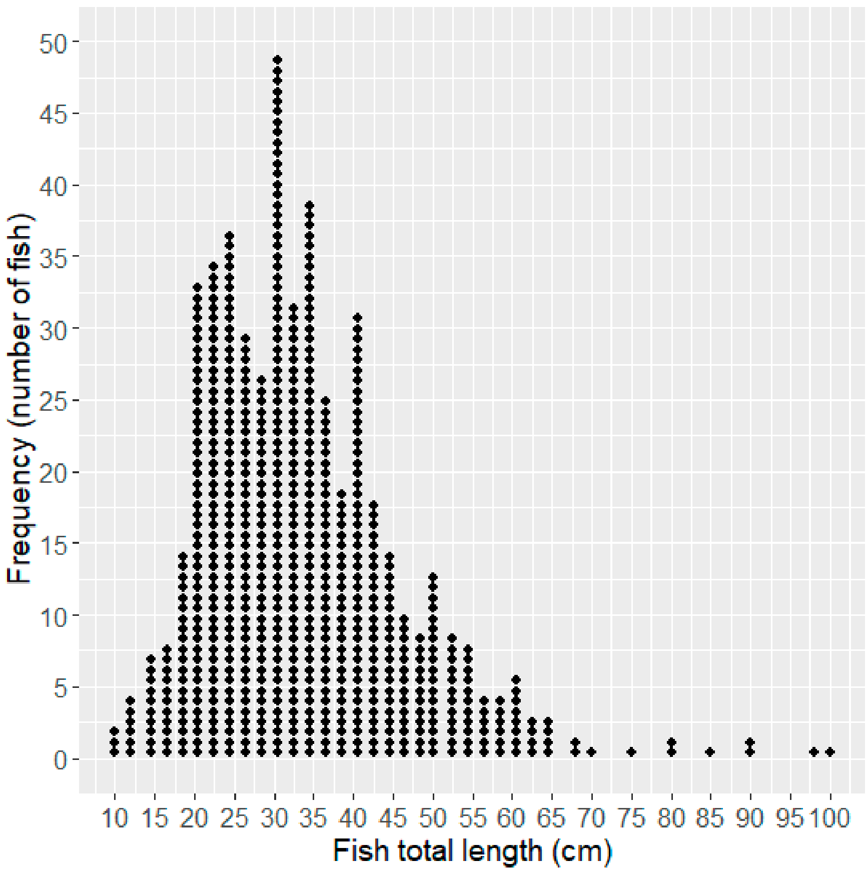

Figure 8. Length frequency distribution of the individual (n = 694) Peacock bass (*Cichla* spp.) caught in fish landings and measured by fishers during participatory monitoring in 8 fishing communities in the lower Tapajos River.

The fishers' knowledge gathered from interviews could provide needed spatial and temporal information about fish reproduction, as observed for coastal and estuarine fisheries [21,23,27,41,86,87], although the reproductive information provided by fishers do not always agree with the biological literature [26,87]. Participatory research, in which fishers record fish with eggs through macroscopical observation of mature gonads, can provide additional data on size distribution and reproductive activity of target and often poorly-known fish species, in the absence of, or as a complement to, more detailed biological studies [48,70,88]. During 12 months of participatory monitoring of fish landings in the lower Tapajos River, fishers caught a total of 6132 individuals of Peacock bass, 236 (3.8%) of which were recorded by fishers as being in the reproductive stage (with eggs). The months in which more fish (more than 4%) were recorded with eggs were July (n = 58 fish with eggs), August (n = 96), during the receding water season, November (n = 22) and December (n = 17), during the low water season. We recognize that these data are subject to variation according to the willingness of fishers to record this information and their ability to identify fish eggs. However, to our knowledge, these would be the unique source of data on reproduction of Peacock bass in the Tapajos River, so such information could be useful, despite its limitations. Considering that the Peacock bass perform parental care [89], it is plausible that it would spawn before the peak of high water (usually from May to June), so the juveniles could have more opportunities for shelter and feeding. The need to find shelter and nests may also limit the reproductive activity of this fish during the peak of the low water season (October). A study conducted in the Bolivian Amazon indicates that the *Cichla* aff. *monoculus* may spawn more than once during the breeding season and the main reproductive period occurs between the end of the dry season (October) and the beginning of the rainy season, in November [90]. Another study on five populations of three species of Peacock bass in two rivers in Venezuela mentions a spawning season from the late low water period and continuing into the flooding period [89]. This information from the literature, although for similar species in other Amazonian regions, partially agrees with data provided by participatory monitoring in the Tapajos River. The participatory monitoring of fish reproduction could be further improved by training fishers to collect and weight fish gonads or use low-technology field microscopes to check for mature eggs [48].

The participatory research aiming to monitor fisheries and fish biology can encompass a gradient of fishers' participation in the development of the research process. The research here reported in the Tapajos River can be viewed as a more basic stage in which fishers actively collect data themselves, but the research questions, sampling design, and data analyses are conducted by scientists only [44,59]. Another stage would include participating fishers and other stakeholders in the process of formulating research questions and defining sampling design, but that data collection by fishers is often closely supervised by scientists [43,46,48]. In an even more inclusive stage, participating fishers and their communities would not only participate in the definition of the main research goals and methods, but would also have total autonomy to collect and analyze data, sometimes even managing research funds [50]. Although less inclusive in the sense of community engagement in the whole research process, our approach to participatory monitoring in the Tapajos River allowed a better standardization of data collection and sample design over a large region of the river encompassing several communities and fishers. Another factor that precluded more inclusive participatory monitoring consisted in the variable levels of organization among the studied fishing communities, ranging from strongly organized toward fisheries management to loose organization. This variability in internal organization is common among communities in the Brazilian Amazon and can influence the involvement of these communities in the management of natural resources [14,49]. Therefore, we opted to include more communities in the study, and over a broader spatial scale in a standardized sampling protocol, even considering that this approach made it unfeasible for each community to participate more in the formulation of sampling design and research questions. Nevertheless, these standardized data over large spatial scales are important to better understand potential impacts from fishing pressure, protected areas, and planned development projects, such as dams in the Tapajos River [10,11,54,55,59,60].

The current lack of fisheries' monitoring and governmental support are obstacles to assess the efficacy of management initiatives or the sustainability of freshwater fisheries in the Amazon and elsewhere [15]. There is thus a need to monitor fisheries in the Brazilian Amazon, but this would demand a considerable effort to record fish landings in multiple communities scattered in remote places, which is beyond the capacity of the national or regional government. Our results indicated that participatory monitoring of the use of natural resources, including fishing, may help overcome the data gaps and make research data more readily applicable to management at local or regional scales in the Brazilian Amazon [14,59], as well as in other freshwater and coastal fisheries [15,43,46,48].

3.3. Mapping

The two methodological approaches adopted to map relevant sites and habitats for fish biology and fisheries yielded quantitative and qualitative results. The mapping performed with 67 fishers in 8 communities along 151 km of the lower Tapajos River produced useful maps indicating relevant sites, for example for fish reproduction (Figure 9). Although the map showed combined reproductive sites for six fish species in the community of Apacê in the Tapajos River (Figure 9), this information should also correspond to the reproduction of Peacock bass, as Apacê was one of the communities where Peacock bass were most caught (2675 individuals) and reproductive individuals were most recorded (n = 198) during the fisheries monitoring. The map indicated a more relevant area for fish reproduction along the floodplain and near islands (Figure 9). This kind of information is strategic and will inform fisheries management and public policy, as this community is located in a peculiar region where the river becomes narrower (Figure 1), outside protected areas and may suffer future impacts from planned small dams in the nearby Cupari river, a tributary of the Tapajos River [57].

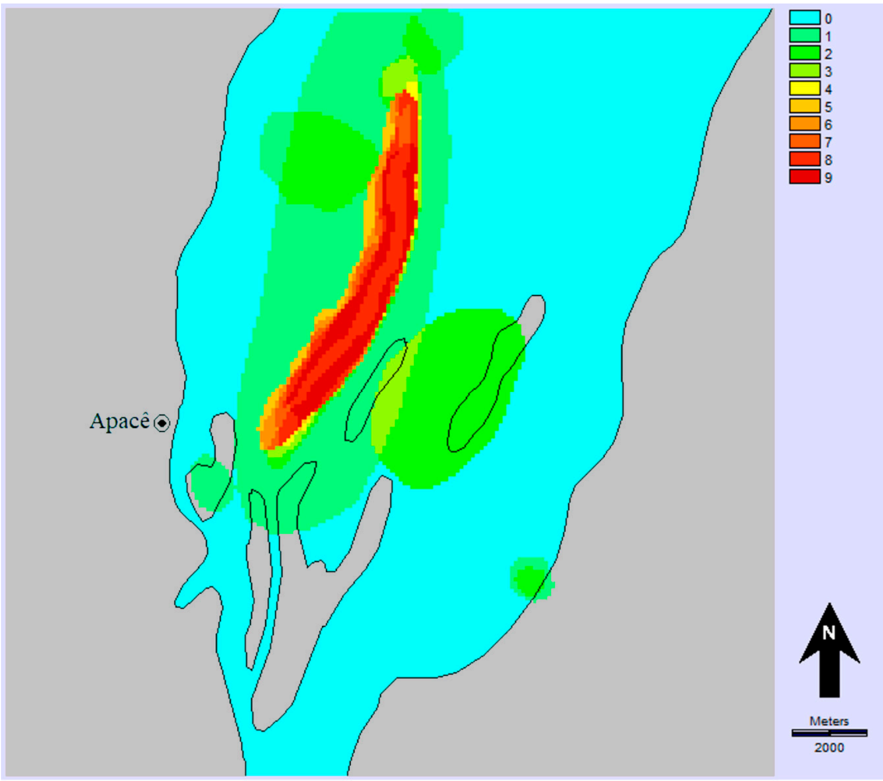

Figure 9. Thematic synthesis map showing the sites indicated by individual fishers (numbers 0 to 9 refer to number of fishers who identified each site) as relevant for reproduction of six fish species in the region around the community of Apacê, in the Tapajos River. Gray indicates land. The coordinates from this window map are 3°35′0″ S to 3°26′0″ S and 55°23′0″ W to 55°14′0″ W. The location of the studied community in the Tapajos River is shown in Figure 1. Map: Sam Boireaud.

The mapping based on meetings with fishers in 8 communities in the middle Tapajos River (one map per community) provided qualitative data on relevant habitats for fish reproduction, migration and fisheries, as shown here for the community of São Luiz do Tapajos (Figure 10). This information could be relevant to establish protected areas to guarantee fish reproduction and to evaluate the effects of environmental impacts, for example, due to the planned dams in the Tapajos River, including one to be built in the community of São Luiz do Tapajos [54,60]. Most of the habitats indicated by fishers in São Luiz do Tapajos (Figure 10) would be flooded and altered by these planned dams, which could also alter the flooding regime and hydrology downstream, hence negatively affecting fish species that need to reach the floodplains or perform reproductive migrations [39,55,91,92].

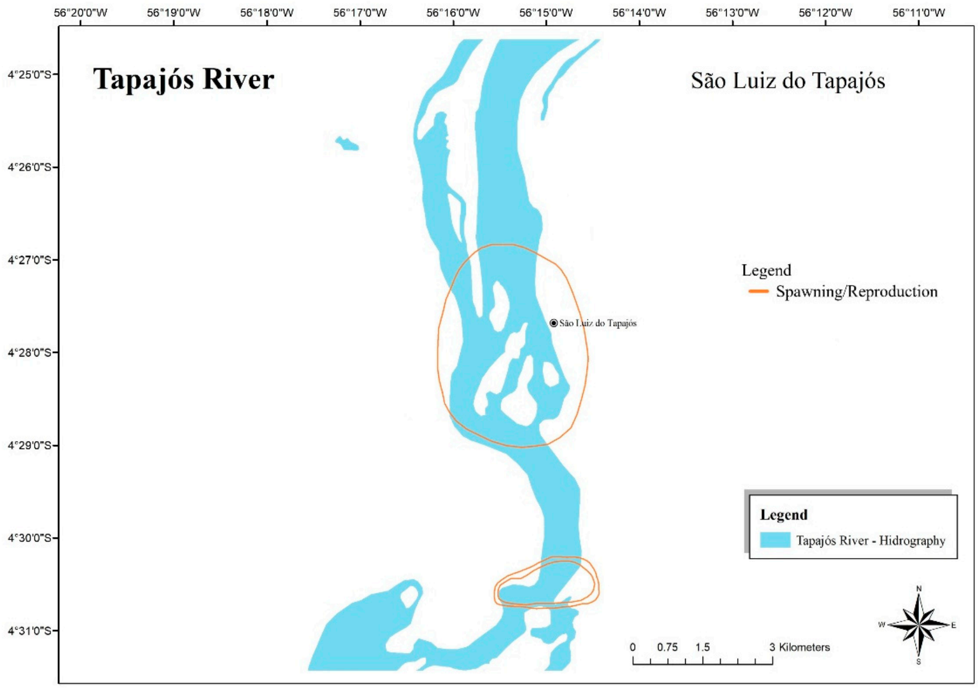

Figure 10. Thematic map showing the main habitats indicated by fishers as relevant for fish reproduction (marked in orange) in the region around the community of São Luiz do Tapajos, in the Tapajos River. The map shows grouped information for six fish species or groups of species: Peacok bass (*Cichla* spp.), jaraqui (*Semaprochilodus* spp.), pacu (*Myleus* spp., *Myloplus* spp.), aracu (*Leporinus* spp., *Schizodon* spp.), dourada (*Brachyplatystoma rousseauxii*) and filhote (*B. filamentosum*). White color indicates land. The area marked on land indicates sites that are regularly flooded during the high-water season. The area double marked in orange is a reproduction site for more than one fish species. Map: Kaluan C. Vieira.

Mapping based on fishers' knowledge has been a useful approach to reveal relevant nursery, migratory, and reproduction sites, to investigate distribution and habitat preferences of fish, to establish sampling designs, or to assess temporal changes of fishing sites of marine and estuarine fish [23,32,37,40,41,46]. The participatory mapping could increase compliance with local management rules, since the critical sites for fish conservation (reproductive and nursery sites, for example) should be agreed with local fishers [43,48]. Our results indicated that this approach can also be applied to support spatial planning in aquatic ecosystems in the Brazilian Amazon, considering that this kind of mapping has seldom been applied to freshwater ecosystems.

4. Conclusions

The participatory methods that we adopted in our research in the Tapajos River provided new and invaluable data to address important knowledge gaps on fish conservation and fisheries management in poorly known and threatened rivers. For example, interviews, participatory monitoring and mapping revealed which fish are more valued by local communities, how fish abundance and sizes varied over time, fish size distribution, fish reproductive activity and which sites or habitats fish need to reproduce. Most of the information presented here regarding the fisheries and ecology of Peacock bass are possibly unique data for this commercial fish in the Tapajos River, notwithstanding it being one of the most important fish for food and commerce in the Tapajos and in the whole Amazon. Besides providing useful data from many sites in a cost-effective way, the participatory research can bring the additional benefit of including local stakeholders in the monitoring, management and research activities, thus increasing capacity building and raising awareness among riverine communities regarding management needs. These methods could and should be more widely applied, not only in other Amazonian rivers, but also in many still unmonitored and poorly studied small-scale fisheries worldwide.

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