Environmental Management
https://doi.org/10.1007/s00267-023-01819-8

-*I fish, therefore I monitor*: Participatory monitoring to assess inland small-scale fisheries

José Amorim Reis-Filho[1,2] · Fecundo Ramos-Filho[3] · Leandro Castello[4] · Tommaso Giarrizzo[5]

Received: 30 July 2022 / Accepted: 3 April 2023

Abstract
Analysis of small-scale inland fisheries (SSIFs) is often highly dispersed and tends not reflect the true magnitude of their contribution to society. This is partly due to the insufficient attention given to this sector by the relevant authorities, in addition to its highly diverse characteristics, with complex patterns of operation in a wide range of systems, often in remote areas. Here, by integrating fishers as participatory fishery monitors, we provide fishery-dependent estimates of yields, the biological attributes of the fish species, and the spatiotemporal dynamics of the fisheries of lakes on the floodplain of the São Francisco basin in northeastern Brazil. As the fishers were willing participates in the monitoring, the results revealed well-structured artisanal fishing activities, with the lake system providing high-profile fish harvests from both monthly and annual perspectives. The spatial distribution of fishing effort reflected the adaptation of the fishers to the flood cycle of the river, in order to maintain high fishery productivity throughout the year. The results also indicate that participatory monitoring can help to overcome knowledge gaps and provide a database that is readily applicable to management needs at both local and regional scales. As Brazil is one few world's nations that no longer have national fishing monitoring program, participatory monitoring represents a low-cost solution for the credible and useful data on small-scale fisheries. It would thus appear to be extremely worthwhile to invest in the empowerment of communities in order to overcome the historic vulnerability of productive sector and the food security of the populations that depend on these fisheries.

Keywords Fisher engagement · Artisanal fishery · Small-scale inland fisheries · Participatory monitoring

Introduction

Globally, inland fisheries are data-poor (Welcomme 2011) (Bartley et al. 2015) even as they contribute more than 40% of the world's reported finfish and aquaculture production (Lynch et al. 2016). Wild capture inland fisheries production comprises under 10% of this reported total but the actual harvest is thought to be substantially larger (Welcomme 2011). Compounding this lack of catch data is scant understanding of the dynamics of small-scale fisheries in inland ecosystems (here referred to as small-scale inland fisheries; SSIF; Chuenpagdee et al. 2017). SSIF usually occur in myriads of river margins and lakes, distributed over immense geographical areas of Asia, Africa, and South and Central America; they generally use low-technology methods, small and traditional vessels, and are often limited in their geographical range (Welcomme 2011) (World Bank et al. 2012) (Wanyonyi et al. 2018). In South America, for example, SSIF tend to operate near their households in rivers and lakes, fishing for subsistence and sale (Fisher et al. 2015). Since rivers and lakes are influenced by river hydrological cycles, which control environments for the reproduction and development of many fish species (Castello et al. 2015), SSIF typically have strong seasonality in use of fishing gears, species harvested, and habitats, making

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s00267-023-01819-8.

✉ José Amorim Reis-Filho
amorim@ichtusambiental.com.br

1 ICHTUS Ambiente & Sociedade, 41904-250 Salvador, BA, Brazil

2 Graduate Program in Ecology Applied to Environmental Management, UFBA, 41180-000 Salvador, BA, Brazil

3 Associação de Pescadores e Pescadoras da Ilha de Zezé, 41904-250 Malhadas, BA, Brazil

4 College of Natural Resources and Environment, Virginia Tech, Fish and Wildlife Conservation, Blacksburg, USA

5 Instituto de Ciênicas do Mar (LABOMAR), Universidade Federal do Ceará (UFC), Fortaleza, Brazil

monitoring of these fisheries and implementation of management systems extremely difficult (Islam and Herbeck 2013) (Wanyonyi et al. 2018). However, understanding the dynamics of these SSIF and their catch trends are essential for their conservation and sustainable management.

The lack of reliable data on SSIF means that they remain largely unassessed, especially in tropical developing countries. In Brazil, for example, the national fishery catch registry system collapsed in 2014 (see Reis-Filho and Leduc 2017) (Reis-Filho 2020) (Gonçalves Neto et al. 2021), but the most recent estimate indicates that inland fisheries contributed more than a third of the country's total wild capture fish catch. However, this does not reflect the social and economic importance of SSIF (Bartley et al. 2015) (Cooke et al. 2016). Both policy makers and the general public are largely unaware of the plight of freshwater ecosystems and the fish stocks they support (Cooke et al. 2013) (Lynch et al. 2016). Although freshwater environments are acknowledged globally as priority areas for conservation, human impacts on them (e.g., damage to aquatic habitats, widespread pollution, the loss of hydrological equilibrium, and overfishing) continue to grow (Geijzendorffer et al. 2019).

In light of this situation, a number of alternative approaches have been developed in recent decades to monitor data-poor fisheries (*sensu* Elliott et al. 2019). Artisanal fishery catch are normally assessed via catch estimates from landing sites, whereas the intensity of resource extraction is assessed through ecological surveys, although these surveys are rarely linked to specific fishing grounds (McClanahan et al. 1997) (McClanahan and Mangi 2004). Although large-scale inland fisheries be considered less common and in most cases do not easily lend themselves to mechanization and industrialization (de Graff et al. 2015), the spatial distribution of these fisheries can be determined using surveillance data from observer vessels and electronic logbook catch data (e.g., Bastardie et al. 2010) (Forcada et al. 2010). In the case of SSIF, however, the small size of the vessels and the small scale of the operations limit the application of this type of monitoring. Here, data can be collected using alternative approaches, such as self-sampling, logbooks, interviews, and direct observation (Lokrantz et al. 2009) (Malleret-King et al. 2003) (Mangi et al. 2016). The collection of spatial and temporal data on these fisheries has focused on the use of participatory methods such as sketch maps and diagrams drawn by the fishers to document their activities (Kimani and Obura 2007) (Wanyonyi et al. 2018).

Despite usefulness of these many approaches to monitor data-poor fisheries, there is a need to further develop approaches to produce fisheries monitoring data (Cassels et al. 2005). In particular, South American inland fisheries suffer from a general lack of information and fishery monitoring programs, which hampers their sustainable management (Gonçalves Neto et al. 2021). For this, seeking ways to overcome these challenges and to identify opportunities for increasing the fisher participation on participatory schemes (including natural resources monitoring) is a worthwhile endeavour. Still, inland fisheries can still be managed from different approaches regarding to fisheries independent surveys as vessels monitoring systems and bioacoustics (i.e., remote observation) (Lindseth et al. 2016) and socio-economic surveys (i.e., direct observation) (Fluet-Chouinard et al. 2018), however they are often more costly, less continuous and require higher skill levels (Rago et al. 2005). This is an important issue since participatory approaches may be not applicable broadly because inland fisheries often rooted in socially and culturally complex societies. In turn, fishers are hard-working, quick, and culturally sensitive making them develop a cognitive ability to provide quantitative data on their fishing activities (Garaway and Arthur 2019). Conversely, still there is lack of guidance on how to integrate fisher's knowledge and their experience in the development of effective fishery monitoring programs. This has led many researchers to conclude that new procedures, in addition to traditional catch assessments, are required (FAO 2017) (Youn et al. 2014). To address this complexity, Kolding (2017) has suggested the use of fisher log books, filled in by fishers themselves, to estimate daily catches.

Fishers possess plenty of knowledge that goes beyond knowing how to fish. Therefore, recognizing the potential of these stakeholders in providefishery data like catch estimates, accurate identification of fishing grounds and biological information (e.g., reproductive periods of fish) can be useful in data-poor contexts (Cooke et al. 2016). Given that such data may then to be used to guide and inform policy at the highest of levels, it is critical to ensure that such methods for collecting fisheries data are robust and proper tested. On the other hand, the absence of specific framework for integrate inland fishers in participatory schemes is partly a consequence of challenges in reporting inland fish production (Deines et al. 2017) (Elliott et al. 2019). Nevertheless, to implement any inland fish and fishery tracking, alternative relevant methods and supported by community engagement agendas are essential, and rarely have studies verified whether participatory schemes resulted in tangible (and positive) benefits for reporting fishery data useful to guide policy and encourage sustainable ecosystem management (but see Cooke et al. 2014) (Elliott et al. 2019) (Silvano and Hallwass 2020).

As part of development of natural resources management, Leith et al. (2012) showed how information collected through participatory approaches can be used to assess capacity at a range of geographical and temporal scales. In the context of monitoring and evaluation, rural communities involvement has been used to identify means targeted to improve livelihood outcomes for local communities, and to assess the feasibility of gathered data in useful mechanism to account for tacit knowledge (Bond and Mukerjhee 2002) (Strele et al. 2006). The dispersed and small-scale nature of most inland fisheries (but see exceptions such as salmon culture industry; Asche et al. 2015) place them as generally of low economic and sociocultural priority for data collection efforts. In this paper we argue that the monitoring derived from collective actions identified through participatory schemes need to be better integrated with natural resource management to ensure that future capacity-building programs address direct stakeholders participation, which are legitimate across scales. SSIF thus lack both accurate global-level production and harvest statistics and local-level biological assessment data to inform management activities (Bartley et al. 2015) (De Graaf et al. 2015) (Cooke et al. 2016). As such, the evidence-based approaches to management so sorely needed in inland waters, especially for poor and developing nations can benefit from cooperation and social cohesion among riparian people, for example for resource monitoring. This horizontal integration in identifying and addressing the capacity of participatory schemes need be recognized and can produce useful data would lead to greater reciprocity and trust, therefore, guarantying participation of rural communities into linkages among policy and natural resources.

Here, we identify mechanisms by which natural resources can be accounted for during implementation and ongoing actions of participatory monitoring, in order to obtain reliable and useful statistics on these systems (Allison and Mills 2018) (Deines et al. 2017). Here, the aim of this study was to highlight that inland fishers, while largely assumed to be most interested part in sustainable management are able to produce robust fishery and biological data. This was assessed trough a participatory fishery monitoring (PFM) – i.e., stakeholders integrated in the whole process – performed on the floodplain lakes of a major Brazilian river, which responsible for the food security of over 200 thousand Brazilians (Godinho and Godinho 2003). We posited that by establishing a participatory fishery-monitoring program, community involvement in managing their resources would promote biological, fishery stock and fishing grounds assessment resulting in statistics that are applicable to management agendas. We have drawn on experience of PMF to show how community-based approaches can successfully address fishery assessment and social engagement while still adhering to a scientifically defensible data collection.

Methods

Study area

The study area was the basin of the São Francisco River which is located between parallels 21°W and 7°S, covering a total of 636,920 km^2, which corresponds to 7.4% of the total area of Brazil. Along its course of almost 2900 km, the São Francisco traverses a number of Brazilian states, where its water is used to generate power, support intensive irrigation programs, provide industrial and urban water supplies, as well as for navigation and fishing (Pompeu and Godinho 2006). The floodplain complex in which the fisheries were monitored in the present study encompasses 23 lakes (Fig. 1), all of which are influenced directly by the flood cycle of the São Francisco River during the rainy season. This region has a mean annual air temperature of 27 °C, relatively high evaporation rates, of 2900 mm/year, and is within the Caatinga ecological domain, which encompasses a semi-arid climate (Sato and Godinho 2003). The dry season (April to September) has monthly a mean rainfall of 50 mm, while the rainy and wet seasons (October to March) have a monthly mean rainfall of 250 mm (Fig. 1B). The area of the lakes included in the present study ranged from 0.8 to 4.5 km^2 (dry season) and are located on the right or eastern margin of the São Francisco River. The floodplain lakes of the São Francisco are important fish nurseries, and play a role in recruitment of many migratory species (Pompeu and Godinho 2006). The marginal vegetation of the lakes was heterogeneous, ranging from cattle pasture and shrubby vegetation to tall, dense forests, all typical of the Caatinga biome (Fig. S1).

Developing collaborative participatory fishing monitoring

A participatory fishing monitoring program was developed in 2012 and 2013 using a collaborative approach with feedback from local fisher groups (Fig. 2). The participants in this study included 239 floodplain lake fishers to establish a collector network (Fig. 2A). The fishers self-reported were supported by technicians who collected additional fishery data and provided regular training to improve the accuracy of the self-reporting (Fig. 2B). An independent team of fisheries technicians conducted impromptu visits to the communities to verify compliance with the monitoring schedule and procedures. Given concerns about the status of the fisheries in the study area, quantitative and spatial data were gathered using a variety of methods, including fishery-dependent censuses, sketch maps, the mapping of fishing activity via GPS tracking, and the compilation of fisher knowledge (Elliott et al. 2019). The community participation followed the model of Functional Participation (see Porter-Bolland et al. 2013), which refers to interactive involvement of local people in predetermined activities, such as collecting data. The interaction between researchers and fishers followed recommendations provided by Bunce et al. (2000) regarding respectful and low disturbance of transdisciplinary practices. This approach and the periodic

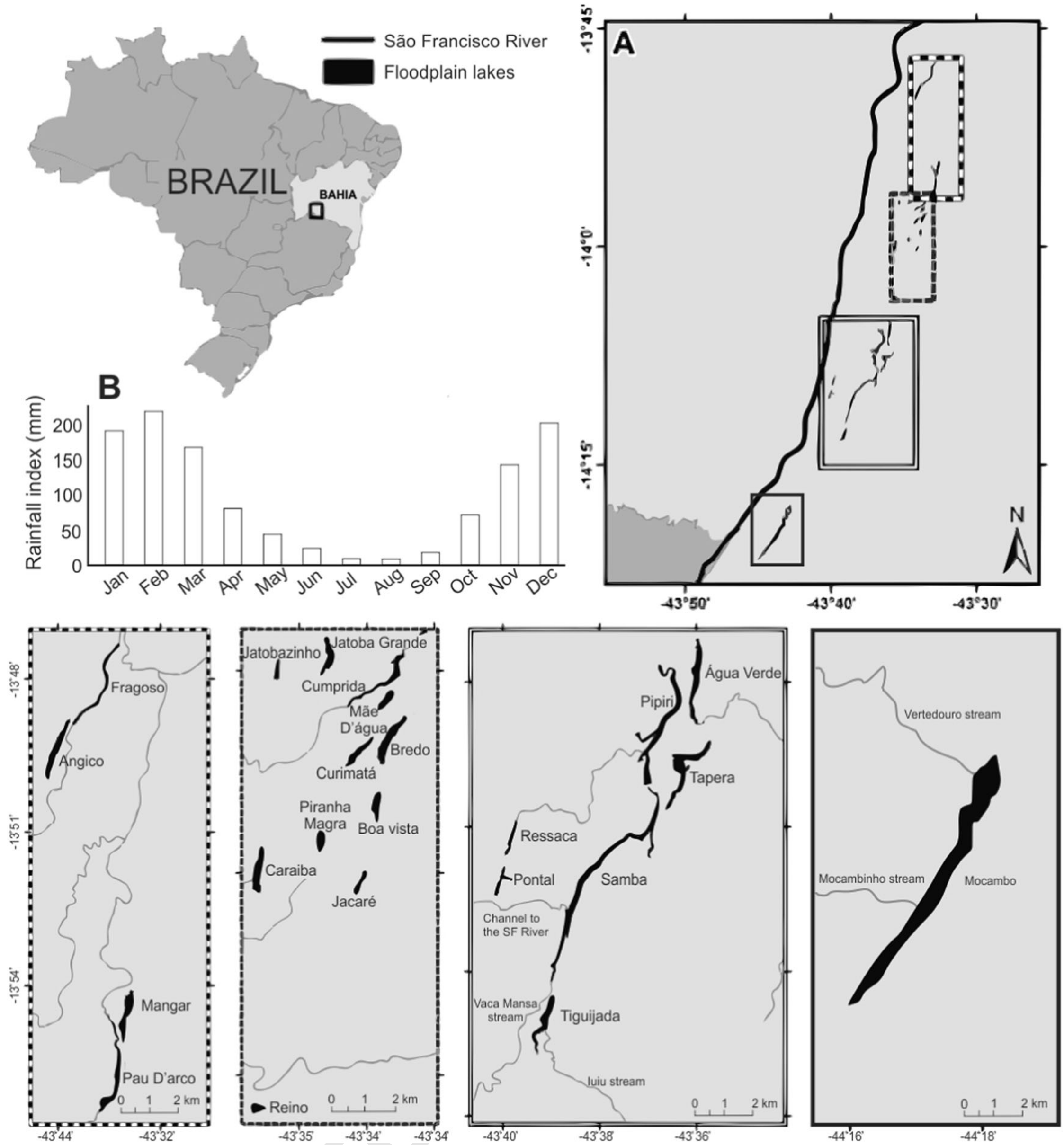

Fig. 1 The study area showing the location of the floodplain lakes exploited by local artisanal fisheries. **A** Overview of the lake system. **B** Rainfall index (mm) in the studied region

meetings for the presentation of outcomes to the fishers (Fig. 2G, H), along with familiarity and trust established between the researchers and fishers along years carrying out project, likely contributed to the reliability of the data collected. The approach based on participant observation (see Bernard, 2006) involved getting close to people and making them feel comfortable enough with the researcher team presence so that it was possible observe and record information about their lives. This established rapport allowed to learning to act so that fishers go about their business as usual when the researchers team show up. A chart of the monitoring schedule and procedures is presented in Fig. 3. The methodological approach to evaluates the degree of fisher community involvement in the PFM was through of turnout rate (i.e., number of fisher retained in PFM along years).

Describing fishing parameters based on the analysis of landings

Fishery data were provided by the fishers when they returned to port after each fishing trip; they went to one of the nine monitoring points (Fig. 2E, F). The raw data obtained by these fishers corresponded to the daily catches

Fig. 2 The principal steps in the participatory fishery monitoring from the implementation of the project to the discussion of the results with fishers and stakeholders. **A** Meeting fishers to present the general aspects of the monitoring process. **B** Training of fishers by the technical team (yellow arrow). **C**, **D** Participatory of sketch maps of the fishing grounds. **E**, **F** Fishers conducting participatory monitoring; **G**, **H** Periodic meetings for the presentation of outcomes to the fishers

from gillnets. Each species monitored by the fishers was registered under its common and the scientific name. Taxonomic experts provided in situ verification as part of the observer network. In these cases, the fishers took photographs to verify the species, and retained a labeled subset of their catch for verification by experts (similar to the

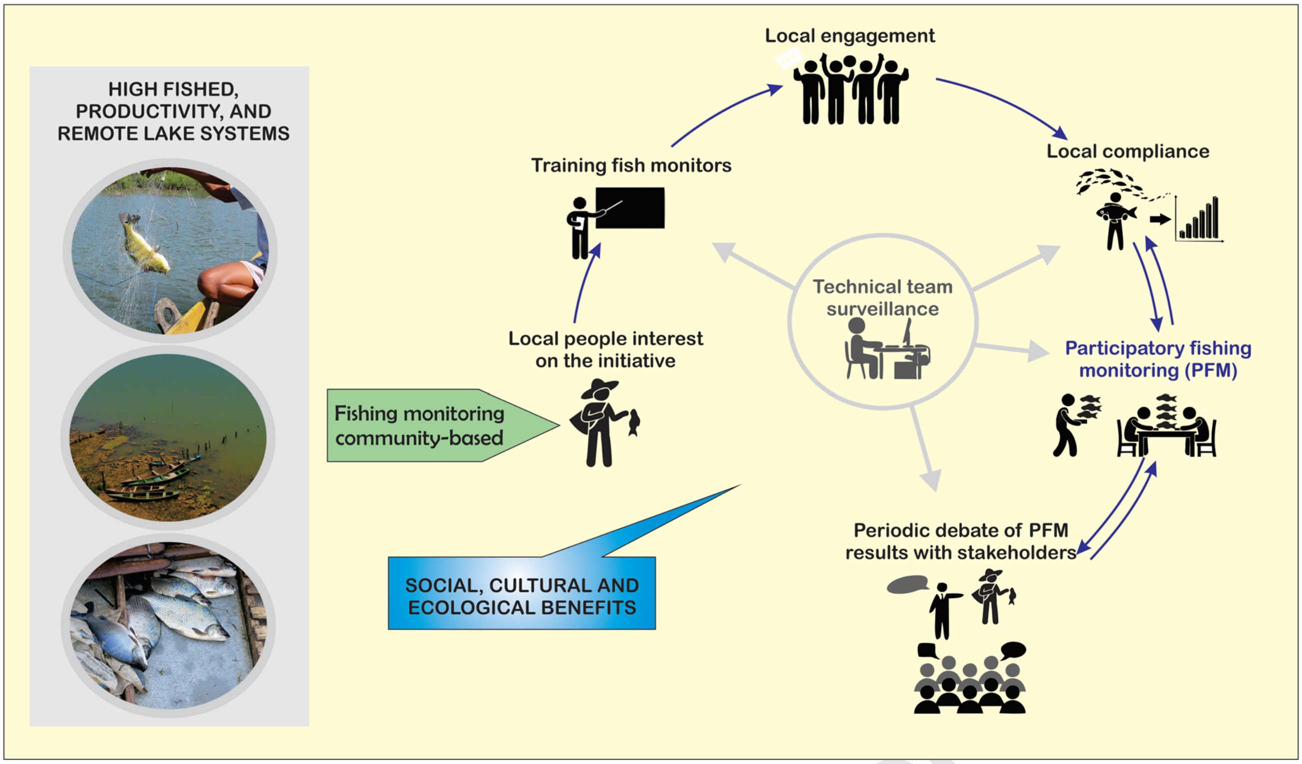

Fig. 3 Monitoring schedule and procedures involving all the stages of participatory fishing monitoring developed in the studied floodplain lake fishing communities

guidance provided by Elliott et al. 2017). To identify each species accurately and standardize samples to ensure comparability with the catch records from other areas and studies, fresh specimens were compared with online databases, such as FishBase (www.fishbase.org) and the Smithsonian Tropical Research Institute (www.neotropicalfishes.org), and reference materials published in scientific journals (Reis et al. 2003) (Pompeu and Godinho 2003).

Fishers were also trained to record multispecies fisheries catch in a standard and comparable way (Fig. 2B). The data included: hour, day, month, and year of the catch, common (local) name of the species, gear used, catch-per-unit-effort (CPUE) by abundance (number of fish), and biomass (CPUE in kg), and total length (TL, cm) of the specimens captured. Each species was assigned to one of two resource groups (adapted from Cota-Nieto et al. 2018): 1) a target resource (i.e., species of major importance in terms of their contribution to the overall volume of catches, which have clearly defined fishing strategies) or 2) a secondary resource (i.e., species of minor importance that provided additional income, discarded by-catch, and fish for domestic consumption).

Whenever possible, the species most caught by the fishers were dissected in the field by trained fishers to identify the gonadal maturity stage macroscopically (Fig. 4). The number of samples analyzed was a proportion (1:4) of the total number of specimens landed per species. These data were used to determine the length and weight composition of the catch and the body length of the species at maturity. Sexual maturity was defined as the L_{50} (body length at which 50% of the individuals were mature) estimated from the samples. A binary logistic model was used to construct a maturity ogive, based on 1-cm length classes, to predict the probability that an individual was mature based on its TL (Brown-Peterson et al. 2011).

Mapping fishing activity using sketch maps

Participatory mapping involved the sketch-mapping of fishing grounds (i.e., lakes, swamps, and channels connecting the lakes). The fishers annotated and modified a base map, adding details on the community's fishing grounds, including their names and reference points (Fig. 2C, D). The fishers identified specific fishing grounds on the map, including catch landing sites, streams, villages, and other lakes that are not fished. The fishing grounds were identified on the maps and labelled with their dimensions, and classified as (i) principal target, (ii) least fished, and (iii) reserve areas (following Furletti et al. 2013) (Wanyonyi et al. 2018). Reserve fishing areas refer to lakes that were not fished for a certain period, either to conserve resources

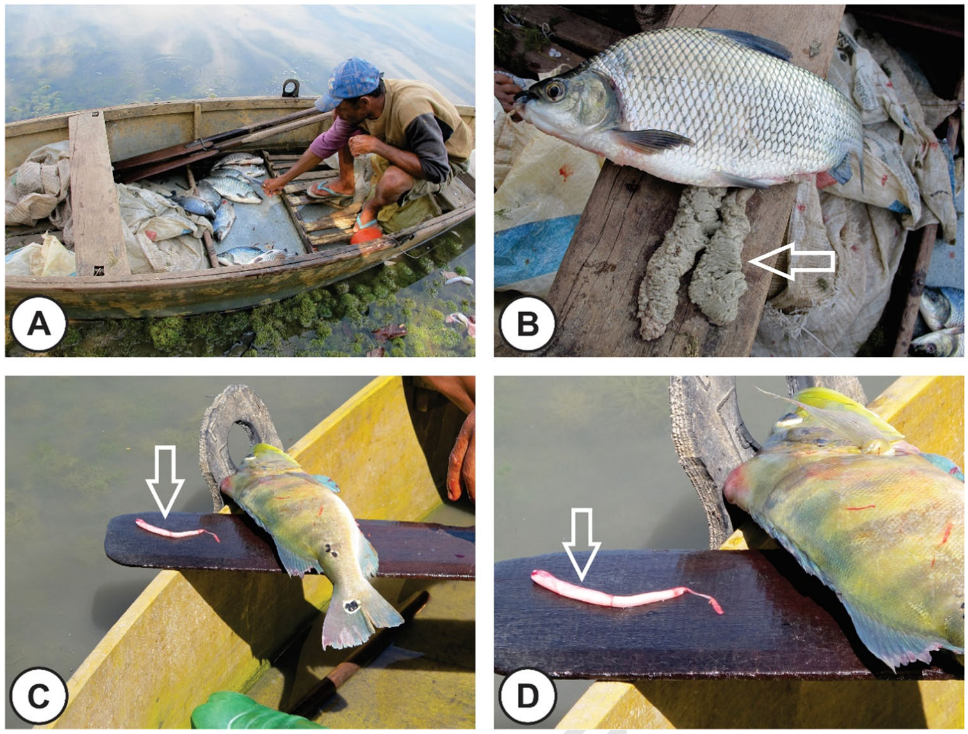

Fig. 4 Verification of the macroscopic gonadal maturity stages of fish caught in the floodplain lakes by trained fishers. **A**, **B** Handling and removal of the hydrated oocytes (white arrow) from a female *Prochilodus argenteus*; **C**, **D** Verification of the mature gonads (white arrow) of a terminal male *Cichla kelberi*

or because of the presence of foraging areas for aquatic and semi-aquatic birds.

Mapping fishing activity via GPS tracking

Following the methodological approach of Wanyonyi et al. (2018), 30 fishers were selected randomly for GPS tracking. These fishers were trained in the use of the GPS devices on the basis of being representative of their fishing villages, and having been indicated by fellow fishers as specialists able to identify all the fishing grounds within the study area. The GPS records were retrieved from each data collector every 15 days and downloaded via the EasyGPS software (TopoGrafix 2016) until all the fishing grounds were mapped completely.

Data analysis

Participatory appraisal to obtain trends on community cooperation and cohesion regard to monitoring scheme followed the model of Functional Participation (see Porter-Bolland et al. 2013). For this, fishing activities were described in general terms through mean monthly catches landed of each fish species and the number of boat trips required to obtain these catches. Estimates of total monthly fishing effort, catch, and harvest were calculated from the sum of the daily observations of fishing trips (Roop et al. 2018). Daily estimates of CPUE (i.e., the number of fish and weight harvested) were calculated using the mean-of-ratios (R_2) equation:

$$R_2 = \sum_{i=1}^{n} (c_i/L_i)/n$$

where i = each fisher, n = the number of fishers monitored, c_i = the catch obtained by the i_{th} fisher, and L_i = the duration (h) of the trips undertaken by the i_{th} fisher.

A Generalized Linear Mixed Model (GLMM) was used to examine spatiotemporal variation in harvest (i.e., abundance and weight) among seasons (i.e., the wet, flood, and dry seasons) and lakes. These analyses were conducted using the 'glmmadmb' package (Fournier et al. 2012) in the R software (R Core Team 2020). As fishery catch data were non-negative integer counts that typically contained a substantial number of zero counts, a negative binomial distribution was adopted (Power and Moser 1999) (Irwin et al. 2013), which is preferable to a Poisson distribution when the count data are over-dispersed (i.e., the conditional variance exceeds rather than equals the conditional mean). The estimated parameters included the variance (σ^2) of the random effect of the day, which was assumed to be independent and distributed homogeneously, N (0, σ^2), that is, the coefficients describing the mean effects of the various levels of location and season on the harvest, and the negative binomial distribution. The *post hoc* Tukey Honestly Significant Difference (HSD) comparison available in the R 'multcomp' package (Hothorn et al. 2008) was used

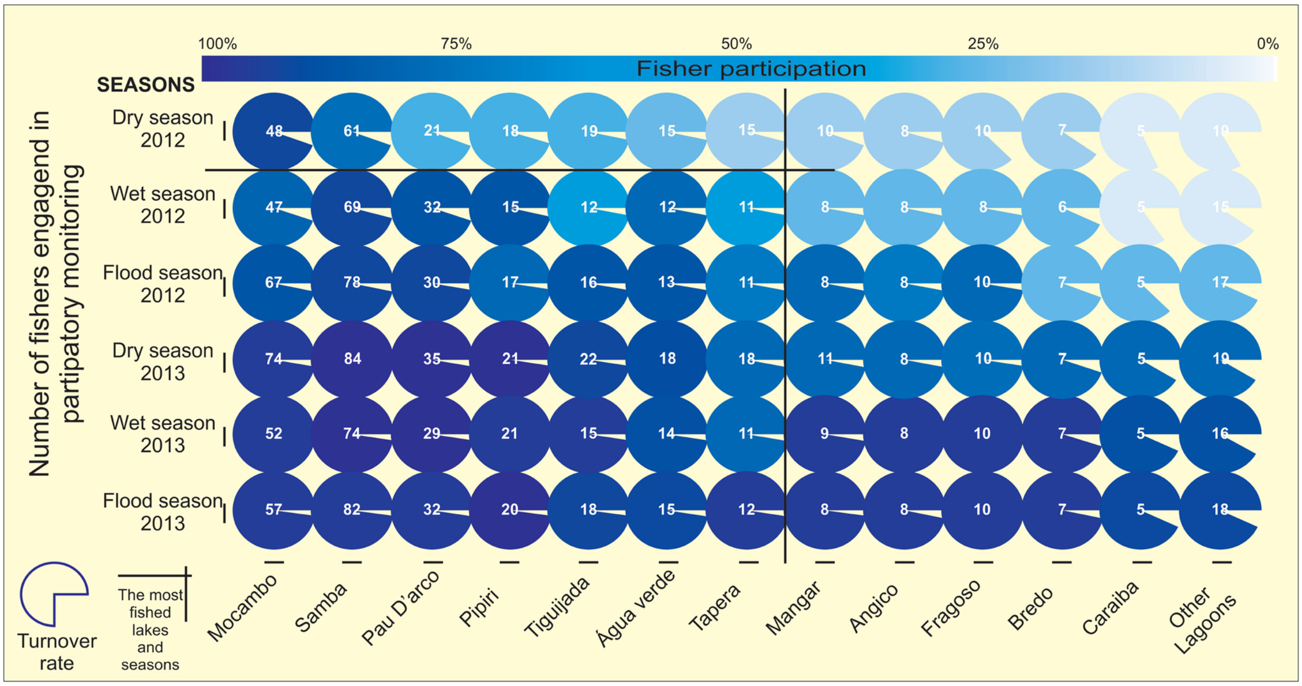

Fig. 5 The number of fishers engaged in the participatory monitoring (2012–2013) of the floodplain lakes. The turnout rate indicates the proportion of the local fishers that participated in the monitoring of each lake and season. The most productive lakes and seasons are highlighted in the bottom-left corner of the figure

to identify significant differences in the harvests among seasons and lakes.

Spatial Access Priority Mapping of fishers (adapted from Yates and Schoeman 2013) was used to document the preferences for specific fishing grounds. To do this, quantitative maps of fishing effort (i.e., intensity) were created. Fishing data also were used to determine the yield from each fishing ground based on the ratio of the catch CPUE (number of fish) *vs*. the harvest CPUE (weight of the fish). This ratio varies between 0 and 1, with values near to 1 indicating larger catches in terms of both the number of fish and their weight. To calculate the Spatial Access Priority (SAP) of fishing, a measure of the importance of each fishing ground, the Log(x) CPUE ratio was weighted relative to its fishing intensity and yield. The GPS data on the fishing lakes were also added to the SAP maps (using the QGIS software from the QGIS Development Team 2009) to map the distribution of fishing intensity and catches/harvests among the fishing grounds and seasons.

Results

Establishing community engagement for participatory monitoring

The fishers were included in the different phases of the monitoring scheme by training them to self-monitor their activities. During the two years of the study, 239 fishers participated voluntarily in the monitoring, of which 198 participated actively throughout the study (see turnout rate in Fig. 5). Overall, the participation of the fishers among the lakes, seasons, and years was over 85%, i.e., a very high turnout (Fig. 5), and in the case of the most productive lakes, participation was around 100%, reflecting the potential of PFM for engaging fishers. Therefore, the number of fishers who could quit the survey at any moment during the monitoring was reduced.

Fishers, composition of the catches, and fishing grounds

Direct measurement by a trained fisher's team was a collaborative way of collecting data on fish catch both in terms of time and resources to carry out it on a large scale. During the PFM, 122,342 fish were caught, with a total weight of 137.9 tons. Twenty-six species were caught in the 23 study lakes with a mean monthly harvest of 5.7 tons. Five species were considered to be target resources, contributing 60.27% of the total abundance (71,997 fish) and 82.19% of the total weight (89.1 tons). The target species were dominated by the curimatá, *Prochilodus argenteus* (34.6% of the fish), followed by the tigerfish, *Hoplias malabaricus* (21.3%), the curimatá-piau, *Prochilodus costatus* (19.7%), and the blacktail piranha, *Pygocentrus pyraia* (6.5%). The other 21 species were classified as complementary resources, with 47,454 fish

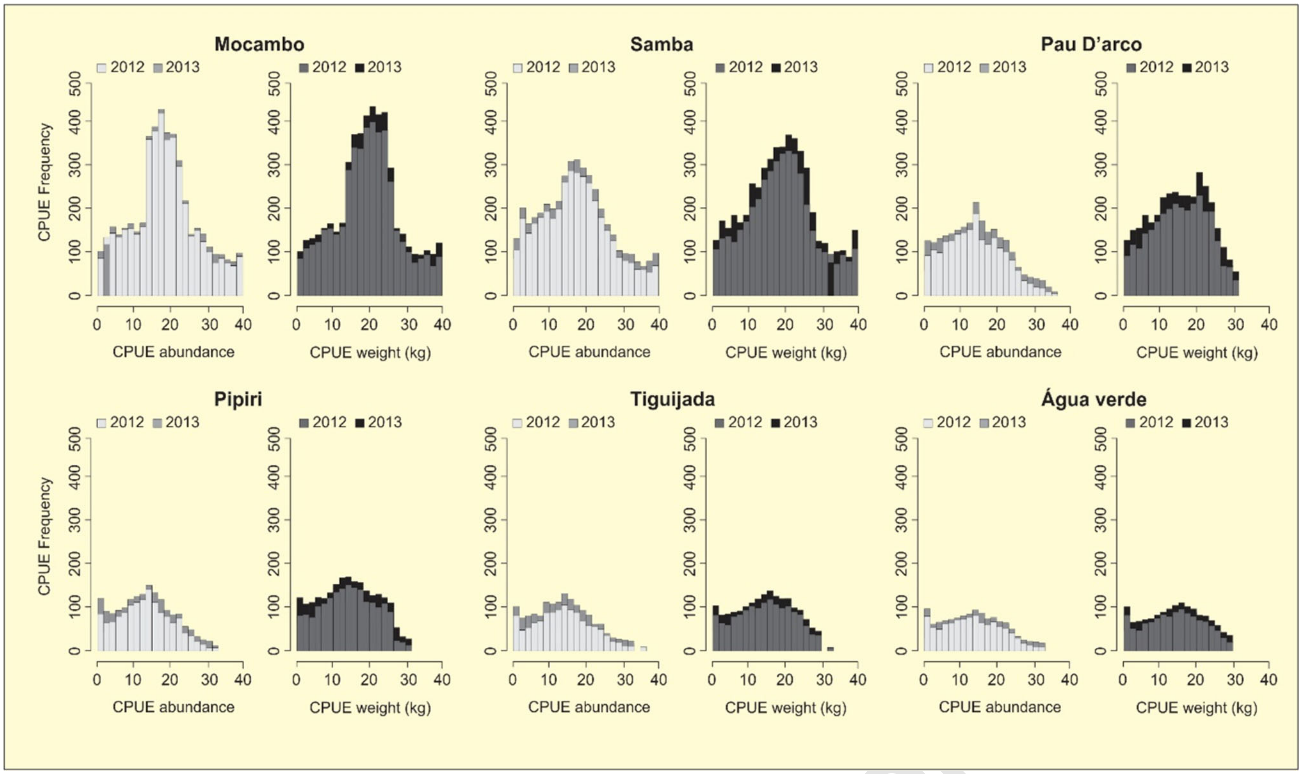

Fig. 6 Histograms of the observed frequencies of CPUE catch (inds.) and CPUE harvest (kg) CPUEs recorded for the most productive floodplain lakes monitored during 2012 and 2013

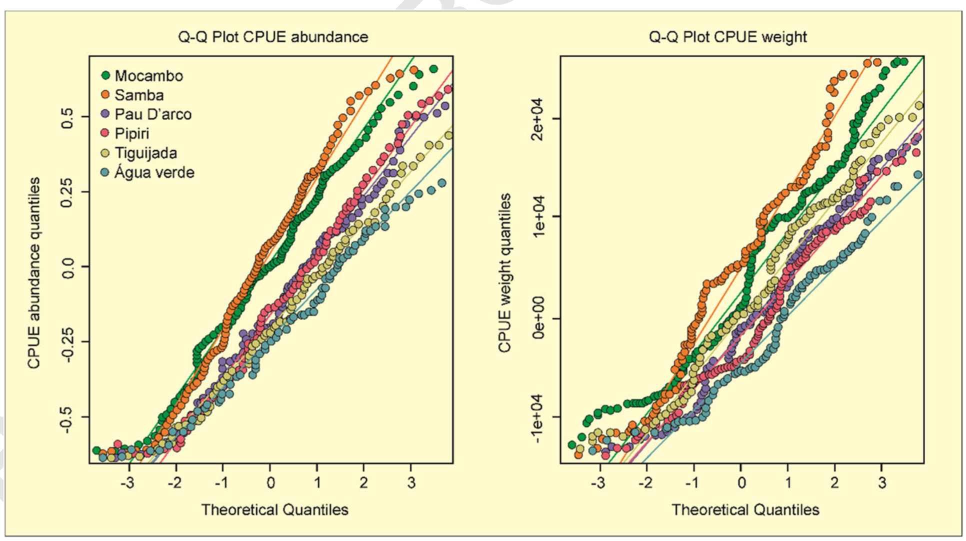

Fig. 7 Quantile-quantile (Q-Q) residual plots of the individual random effects of the fishing day ($n = 548$) based on the fitting of a negative binomial mixed model to the catch CPUE (left panel) and harvest CPUE (right panel) of the floodplain lakes of the São Francisco basin in 2012 and 2013

being caught with a total weight of 19.3 tons. Here, the largest catches were of the pacu caranha, *Piaractus mesopotamicus* (38.5% of the fish), followed by the peacock bass, *Cichla kelberi* (25.9%), and the oscar, *Astronotus ocellatus* (15.2%). The data on all the species documented during the present study are provided in the Supplementary Material (Table S1). Considering the fishing grounds, the Mocambo lake (the largest fishing ground – 4.5 km^2) accounted for a total harvest of 33.4 tons, followed by Samba (24.3 tons), Pau D'arco (15.4 tons), Pipiri (9.8 tons), Tiguijada (9.2 tons), and Água Verde, with 8.4 tons (Fig. 6).

Spatiotemporal trends in the CPUE

Despite the well-recognized sources of error with CPUE estimates, there has been high confidence of fishery data

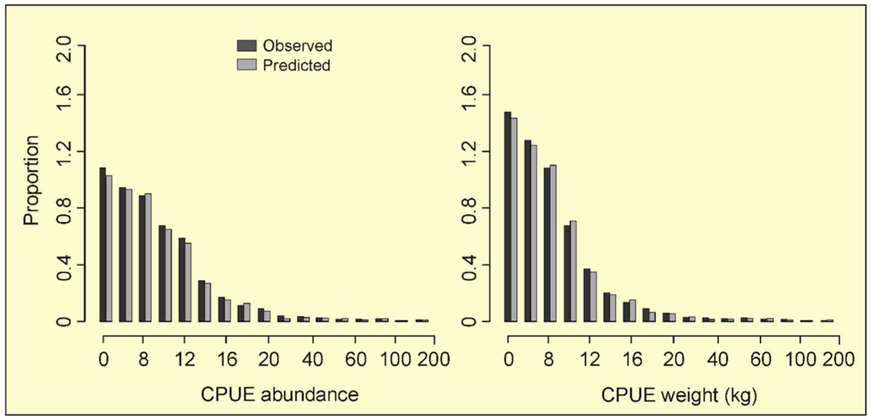

Fig. 8 Observed and predicted values by the models of the catch and harvest CPUEs of the floodplain lakes in the São Francisco basin. The season and location (i.e., the lake) were considered to be fixed effects in the models, while the sampling day was a random effect

obtained from PFM that could accurately quantify the amount of fish was caught. The catch data were center-skewed toward the most productive lakes, with a mean abundance CPUE of 19.4 and weight CPUE of 25.8 (Fig. 6). Quantities of catches and their weights varied significantly among lakes ($p < 0.01$ and $p < 0.001$, respectively), and the dry season catches were significantly larger ($p < 0.02$) than those recorded in either the wet or flood seasons. The individual random effect of the day was distributed approximately normally in both models, with a mean variance of 0.15 (catch CPUE) and 4.5×10^{-4} (harvest CPUE) for the most productive lakes (Fig. 7). Both models thus appeared to predict accurately the catch and harvest based on the additive effects of lake and season, and the random effect of the sampling day (Fig. 8).

Estimates of catches and harvests

Given the expectation that fishers may produce consistent fishery data from a participatory monitoring, the precision of both the catch (abundance) and harvest (weight) estimates varied over time. The regression analysis indicated that there was a strong positive relationship ($r^2 = 0.91$) between the monthly estimates of catches and harvests (Fig. 9). The slope of the regression line indicates that, with every 1-unit increase in the catch, the harvest increases by 1.2 kg. This compares well with the portion of the overall catch rate that was attributable to the harvest (52.5%). The estimated daily catch (i.e., abundance) and harvest (i.e., weight) CPUEs varied significantly among the seasons ($F_3 = 12.78$, $p < 0.002$; $F_3 = 15.44$, $p < 0.001$, respectively; Table 1), with the mean yields recorded in the dry season being significantly larger than those recorded in the wet and flood seasons (Tukey's HSD test; $p < 0.01$). The estimated parameters (catch and harvest) also varied significantly among lakes (catches: $F_{23} = 10.05$, $p < 0.01$, harvests: $F_{23} = 11.42$, $p < 0.01$; Fig. 5 and Table 1). Tukey's HSD of the lake × season factors revealed that both CPUEs varied significantly within the same season ($p < 0.03$ for all

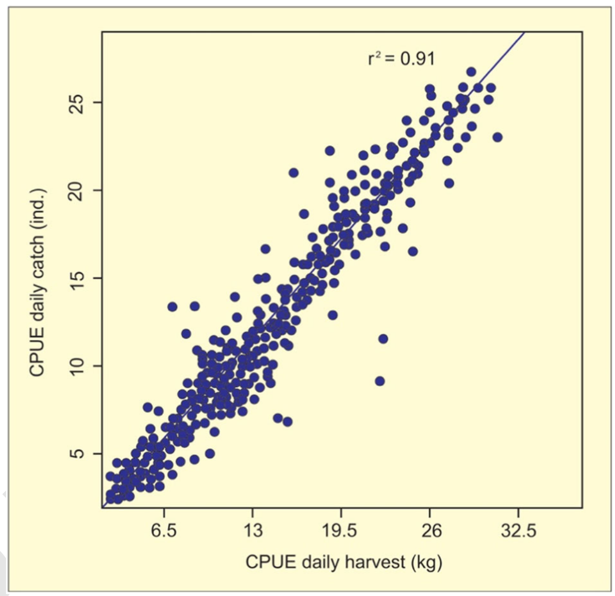

Fig. 9 Relationship between the CPUEs of the daily catches and harvests recorded during the study period on all the floodplain lakes

comparisons). These results suggest that, using the participatory approach, fishers self-reported were able to provide catch estimates which potentially can be a good basis for stock assessments.

Length frequency and reproductive attributes

The fishers measured 48,254 fish during the participatory monitoring and were able to report fish in terms of their length and reproductive aspects. In the first instance, the accuracy with which fishers could obtain these data allowed the building logistic curves of the relative frequency of mature specimens based on their total lengths. These data were used to compile a length frequency distribution of the catches (Fig. 10), which shows that most of individuals captured had a total length (TL) of between 25 cm and 45 cm. In the specific case of the target resources, most

Table 1 The CPUEs of the daily catches and harvests for the principal floodplain lakes monitored during the present study

	CPUE of the catches		CPUE of the harvests	
Lake (season)	Daily mean	SE	Daily mean	SE
Mocambo (wet)	15.2	3.2	17.8	2.4
Mocambo (flood)	21.6	3.9	25.9	1.2
Mocambo (dry)	24.2	2.7	28.1	2.7
Samba (dry)	14.5	3.9	15.9	3.1
Samba (wet)	15.9	2.5	18.8	3.5
Samba (flood)	17.8	3.4	21.4	3.7
Pau D'arco (dry)	12.1	1.8	12.9	2.4
Pau D'arco (wet)	13.5	2.6	14.4	1.9
Pau D'arco (flood)	13.2	2.9	14.9	2.8
Pipiri (dry)	7.5	2.7	8.8	1.4
Pipiri (wet)	7.9	3.1	9.5	0.9
Pipiri (flood)	7.9	1.5	12.1	1.3
Tiguijada (dry)	7.1	3.8	7.9	2.5
Tiguijada (wet)	7.5	3.2	8.6	2.3
Tiguijada (flood)	7.7	2.9	9.2	2.6
Água verde (dry)	6.1	2.8	7.2	1.9
Água verde (wet)	6.9	2.4	8.2	1.7
Água verde (flood)	7.3	1.5	8.9	2.1
Other lakes (dry)	5.4	3.4	6.8	2.9
Other lakes (wet)	6.7	2.9	7.9	3.1
Other lakes (flood)	7.7	3.2	9.1	2.5

SE Standard Error of the mean

(65%) of the curimatá (*Prochilodus argenteus*) were no more than 35 cm in length (Fig. 10A). The tigerfish (*Hoplias malabaricus*) specimens all had TLs of 10–38 cm, with a mean of 22–25 cm (Fig. 10B), while the blacktail piranha (*Pygocentrus pyraia*) had TLs of 12–36 cm, with a mean of 20–26 cm (Fig. 10C). In the complementary resources, the TL was 10–42 cm in the peacock bass, *Cichla kelberi* (Fig. 10D), 25–45 cm in the pacu caranha, *Piaractus mesopotamicus* (Fig. 10E), and 15–25 cm in the oscar, *Astronotus ocellatus* (Fig. 10F).

Fishers also were able to evaluate the reproductive status of the females of the three principal target species and one complementary resource, the peacock bass. The curimatá and the tigerfish both presented mature gonadal stages predominantly during the flood season, whereas the hydrated oocytes of the blacktail piranha and peacock bass peaked during the dry season. The total length at 50% maturity (L_{50}) was estimated to be 28.9 (±3.9) cm for the females of the curimatá, 18.8 (±4.2) cm in the tigerfish females, 20.5 (±1.9) cm in the peacock base and 20.8 (±3.2) cm in the blacktail piranha (Fig. 10).

Spatial fishing patterns and comparison with the sketch maps

The spatial analysis identified the lakes with high intensity fishing, which varied among the seasons (Fig. 11). The sketch maps produced by the fishers in the participative workshops were consistent with the distribution of the fishing grounds and the seasonal pattern of the operations. The preference maps identified a concentrated level of activity in the lakes during dry season (Fig. 11A), whereas during the flood and wet seasons, the fishing territory expanded into the floodplain surrounding these lakes (Fig. 11B). This seasonal displacement of the fishing territory also showed that the harvests were larger during the dry season, in comparison with the other two seasons. This is emphasized by the ratio of the weight and abundance CPUEs (graph mosaics in the maps) which shows a stronger correlation of the harvest during the dry season (Log(x) CPUE ratio close to 1). Some lakes were identified by the fishers as reserve fishing areas, which had very low levels of fishing activity, or none at all (Fig. 11).

Discussion

Using the floodplain lake system of São Francisco River as a case study, a transdisciplinary monitoring scheme was developed and implemented to satisfy the urgent need for reliable fishery data from the region. Although all the data were gathered by the local fishers themselves, which required a highly adaptive approach, the estimates of catches and harvests, as well as the reproductive data and the spatial analyses provided a robust and comprehensive evaluation of the trends in the local fishery dynamics. These estimates should thus be considered to be reliable, and equivalent to the findings of monitoring programs conducted by qualified technicians (Cardoso and Freitas 2007, 2008) (Lopes et al. 2016). By doing so, we demonstrated the utility of participatory approaches and collaborative solutions to understand inland fishers dynamic. A fundamental aspect of the study is hinged on good monitoring and evaluation systems that were in place. It is, however, important to note the geographic isolation of the communities and the low-tech fishing operations, characteristics described by Ostrom (2009) that allow the successful Socio-Ecological Systems, and makes management of local resources easier (i.e., fewer fishers and lower overall fisheries efforts). Overall, it was possible to achieve the study objectives with satisfactory results, while fulfilling the lack of capacity of institutional agencies for biological and fishing monitoring. This makes sustainable management difficult given the integrated nature of the assessment-

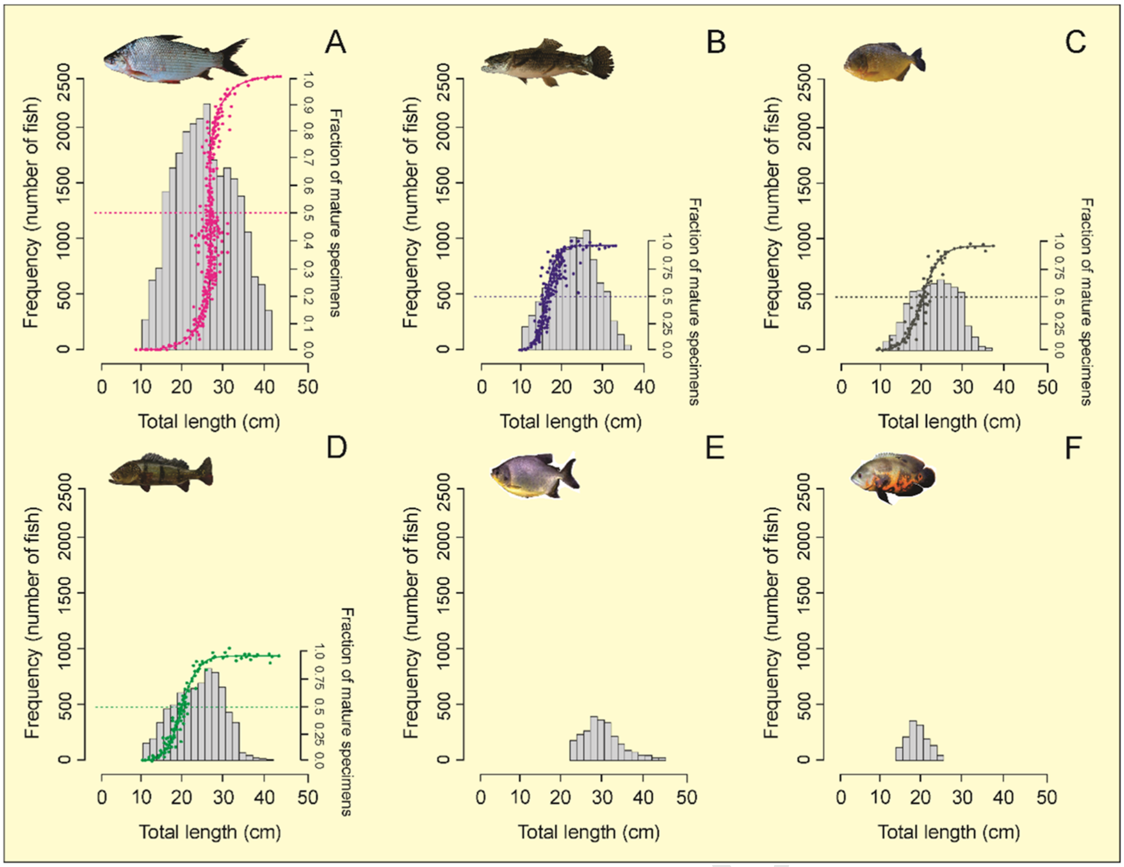

Fig. 10 Frequency of the size classes (total length) of the species caught most frequently in the floodplain lakes of the São Francisco basin. The logistic curves of the relative frequency of reproductive females are shown in the first four species. Target resources: *Prochilodus argenteus* (**A**), *Hoplias malabaricus* (**B**), and *Pygocentrus pyraia* (**C**). Complementary resources: *Cichla kelberi* (**D**), *Piaractus mesopotamicus* (**E**), and *Astronotus ocellatus* (**F**)

management cycle, once often management occurs in the absence of data (Cooke et al. 2016).

Most of the challenges for the monitoring of fisheries and the collection of data are not unique to inland systems but are common to fisheries in general, in particular, the less visible aspects of the operations, and the compilation of general knowledge (Elliott et al. 2019). In the present study, it is clear that self-monitoring by the fishers themselves – with adequate technical supervision – can generate a useful set of fish biological data (e.g., CPUE estimates, size frequencies and reproductive status), which are suitable for the implementation of effective conservation and management measures. Engaged fishers can play a role as intermediaries of knowledge between the community and natural resource managers. However, strategies to collaborate horizontally (i.e., fishers and communities) and vertically (i.e., enforcement officers) need tailored to highlight for positive changes. Inland bodies of water, like the floodplain lakes monitored here, may often be large, geographicallydispersed, and located in areas of difficult access (Welcomme 2008). Our results show that the implementation of a multi-method (i.e., fishing area preference mapping to generate scores of importance),participatory approach can gain insights into important but often neglected component of SSIF. In this case, participatory fishing monitoring can help to overcome many of these intrinsic challenges to provide relatively accurate catch data, by enlisting the help of the stakeholders, i.e., the fishers that should be most interested in the management of the local fishery resources (Fairclough et al. 2014).

The monitoring of tropical inland fisheries faces specific challenges, related to the fact that they are often located in developing countries with limited governance and a lack of financial resources for systematic monitoring (Allison and Mills 2018) (Pauly et al. 2002). A monitoring scheme with a complementary system of tools and approaches based on the participation of the fishers may not only be extremely cost-effective, but may also be the most effective way of providing an adequate database for the establishment of sustainable fisheries (Elliott et al. 2019). The monitoring scheme presented here illustrates how the engagement of the fishers can produce reliable and valuable fishery data, as well as further stimulating self-perception to future sustainable management of resources. Prior to the

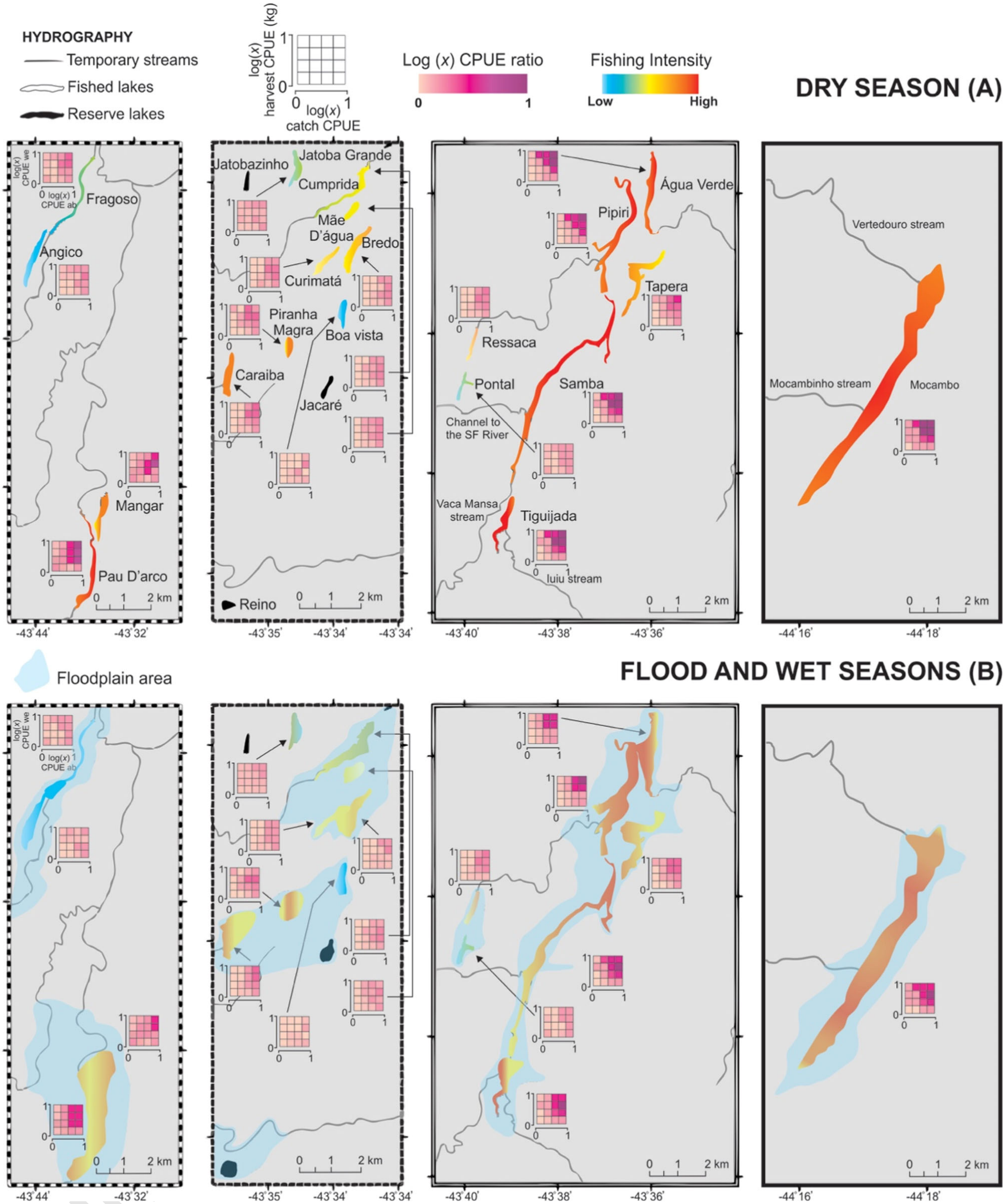

Fig. 11 Maps of fishing intensity in the floodplain lakes of the São Francisco basin during the different seasons: (**A**) dry season, and (**B**) flood and wet seasons. The log (*x*) CPUE ratio between the catches and harvests are presented using a mosaic analysis

implementation of the activities, it was essential to determine what to monitor and how to do this, considering, for example, the status of the environment, the assessment of productivity, and the identification of the drivers of the spatiotemporal variation in the fishing activities. We achieved this by involving the fishers in early debates, training, and self-perception about monitoring purposes (see Fig. 2A-D), so that the turnout rate (Fig. 5) was high along the study period. This was important to determine the reporting needs of the fishing communities, the target audience, and how the results could support policy-making decisions and management planning in the near future (Pope et al. 2010).

Prior to the implementation of a participatory monitoring scheme, a cost-benefit analysis is needed (Elliott et al. 2019). This should normally be followed by a pre-implementation pilot phase for testing of the various components of the scheme and review the data to ensure that the approach is adequate for the intended purpose (Cotter and Pilling 2007). In the second year of the present study, the engagement of the fishers increased (Fig. 5), indicating that the standards of the on-going monitoring system were maintained. Even though the first year can be considered to have been a pilot phase, the early training of the fishers to ensure their rapid engagement, together with the continuous reinforcement from the technical team, this process guaranteed the data necessary to evaluate spatiotemporal components of the fisheries. However, the data-collecting activities must be relatively easy to carry out and not too time-consuming, to ensure that the participants will be willing to collect data while they are doing their jobs. This will ensure the recruitment of the broadest possible body of human resources, and will ensure continuity and the minimization of potential information gaps (Bieluch et al. 2017) (Tredick et al. 2017). Adequate technical assistance is nevertheless crucial, in particular during the pilot phase, in order to ensure that the fishers are able to conduct the monitoring correctly. This horizontal network makes it possible for fishers can sustain the monitoring program in the future, connecting the communities with government policy and policy makers as well as supporting the data gathering activities in scientific assumptions.

Historically, participatory approaches have been adopted for the monitoring of fish stocks and fisheries in inland systems, and continue to be an important and cost-effective approach used around the world (e.g., the Mekong basin – Halls et al. 2013) (Patricio et al. 2012). Recently, Silvano and Hallwass (2020) presented a successful case of participatory monitoring in the Brazilian Amazon, in which the data were collected entirely by the fishers themselves, under the close supervision of scientists. In this case, the participating fishers and their communities not only participated in the definition of the research goals and methods, but also had the autonomy to collect and discuss their data. We argue a more inclusive community engagement in the whole research process, like that applied in our study would allow a better standardization of data collection and sample design over a large and fragmented fishing area. The local presence of a strong organizational structure, i.e., fishing cooperatives, was also a fundamental factor influencing the willingness of the communities to engage in the participatory monitoring. Although we have not properly evaluated the role of local fisheries cooperative and how they may energize their communities, they seem to be one of the key factors contributing to the successful participatory monitoring program. Most of the fishers engaged in the project are members of fisher folk organizations, which were willing to build local capacity (or catalystic) to make changes or transformations, and accept novels initiatives in their communities (Abdurrahim et al. 2022). In the fisheries cooperative, the fishers self-reported share and promote their ideas, visions, wisdom, and innovation to encourage other parties to be involved in the PFM process and stages of achieving goals.

In the present study, the examination of the mature gonads by participating fishers provided additional data on the size distribution of the fish and the reproductive patterns of the target species, which are often poorly-known. These data can be especially important when detailed biological studies are lacking, and even when they are available, the participatory data can provide an important complementary perspective (Schemmel et al. 2016) (Elliott et al. 2017) (Harper et al. 2021) (Hugues et al., 2021). Even so, it is important to note that the biological information obtained through this approach is limited, and is subject to the same general challenges of self-reporting, in most cases. Although the present study was not designed to obtain specific details of fish biology, the knowledge of the fishers on breeding patterns has the added advantage of providing more specific and targeted information, and should be considered for future initiatives. However, obtaining more specific life-history characteristics, such as spawning seasons and the identification of breeding grounds through participatory monitoring will require additional technical supervision and may not be cost-effective (Sato et al. 2017). Silvano and Hallwass (2020) nevertheless concluded that this task could be improved in the future by training fishers to collect and weigh the fish gonads or use field microscopes to check for the presence of mature eggs. Conversely, while highlighting the relevance this participatory monitoring case for large-scale survey, Brenier et al. (2013) argues that lesser interest for regular data gathering on long-time scales may be a negative result of discontinuance of coordination and supervision by scientists and/or governmental agencies.

It is crucial that the data obtained from participatory fishing monitoring should not only be reliable, but also comparable. This requires the standardization of specific elements of the approach and to ensure be replicable and feasible (Brookes and Sieu 2016) (Elliott et al., 2019). The research here reported in the floodplain lakes can be view as beyond a more basic stage in which fishers actively collect

Table 2 Studies of inland systems in which the fisheries were monitored by a technical team in comparison with the present study (community-based monitoring)

Country	Basin	Environment	Area (ha)	Tons/ month (mean)	Reference
Brazil	Amazon	Madeira River	8500	16.6	Cardoso and Freitas (2008)
Brazil	Amazon	Medium Madeira River	6320	21.3	Cardoso and Freitas (2007)
Brazil	Amazon	Lower Amazon River	60,500	60.3	Lopes et al. 2016
Brazil	Amazon	Madeira River	4790	5.5	Lopes et al. 2017
Brazil	Amazon	Purus River	12,600	8.5	Lopes et al. 2018
Brazil	Amazon	Juruá River	10,500	5.5	Lopes et al. 2019
Brazil	Amazon	Upper Solimões River	26,900	8.5	Lopes et al. 2020
Niger	Niger	Niger River floodplain	9560	5.3	Bayley, 1988
Albania	Vurgo and Vrina	Albanian lagoons	3050.9	1.5	Peja et al. 1996
Egypt	Nile	Inland lakes	8945.2	6.8	Samy-Kamal, 2015
Sri Lanka	Kirindi Oya	Lagoons	5060.2	4.9	Nguyen-Khoa et al. 2005
Laos	Huay Thouat	Lagoons	4580.5	2.6	Nguyen-Khoa et al. 2006
Mexico	Usumainta and Grijalva	Floodplain lakes and wetlands	4800.7	4.4	Mendoza-Carranza et al. 2013
Ghana	Volta	Natural lakes	2589.5	16.7	Béné and Russell, 2007
Brazil	Lagoa Mirim	Lagoon	3890.8	21.5	Morato-Fernandes et al. 2008
Brazil	São Francisco	Floodplain lakes	1264.5	5.7	present study

data themselves. We successfully developed a participatory approach that defined the profile of fishing activity by estimating fishing intensity, harvests, and was reasonably precise in comparison with studies in which the fisheries were monitored by a team of technicians (Table 2). Moving forward, acknowledging the complexities inherent in the relationships between inland fisheries and the implementation of participatory monitoring approaches will be crucial. We suggest that acknowledging the value of stakeholders' involvement is the first step in effectively balancing the information need of these social systems with supporting sustainable resources use. The positive effects of the co-assessment, evidenced by the comparison between studies dependent exclusively on technicians and our participatory approach can bring additional benefit of including local stakeholders in the research activities, thus increasing capacity building and raising awareness among rural communities regarding management needs.

As Brazilian fishery catch data are at best incomplete and the national monitoring collapsed in 2014 (Reis-Filho et al. 2021), a well-structured, participatory monitoring may be the only way to understand and manage the small-scale fishery sector. Unfortunately, estimating catches for many fisheries - especially in developing and poor nations - is not reported to any official body. Thus, we propose the monitoring model herein presented as a starting point to raise the profile of inland fish and fisheries to better incorporate them in indigenous and water resource planning. Furthermore, compiling these data into official statistics would allow managers and conservationists to better determine the status of stocks, determine exploitation levels, and develop specific recommendations for local areas. It will nevertheless be essential to engage the stakeholder community to ensure that it accepts the study and, ultimately, that it is conscious of the potential benefits of the monitoring (Aceves-Bueno et al. 2015) (WorldBank et al. 2012) (Brookes and Sieu 2016). One major problem in remote locations, such as the floodplain lakes monitored in the present study, is the existence of incentives to under-report catches (Beard et al. 2011). This problem can be mediated by continuous training and evaluation, to ensure that the data produced by fishery-dependent monitoring can be assimilated into the spheres of policy-making and governance.

Conclusion

In Brazil, where fisheries in the most vulnerable and isolated locations, such as the studied floodplain lakes receive little attention, and even fewer resources from government agencies, participatory monitoring can provide an optimal and cost-effective approach to the management of SSIF.

Participatory approaches, such as the one presented here, can also help to highlight inland fisheries in the cross-sectoral debate or even minimize the 'pandora-box' of fishery productivity in the small-scale sector in Brazil, given that national catch statistics are no longer compiled by the government, and even when the system was operational, remote floodplain lakes were almost certainly assessed inadequately. We advocate improvements in monitoring and catch statistics will highlight conservation concerns, while also reinforcing our understanding of the effectiveness of participatory methods supporting the development of more sustainable management approaches to SSIF. As such, the participatory monitoring in fishery areas where management policies are poorly implemented, may at the very least lead to an increase in community compliance and awareness. Therefore, we claim more comprehensive self-produced fishery data may also help communities to better engage in the dialog on management decisions, both internal and external. Similar benefits could be obtained elsewhere by adopting an inclusive approach to inland fishery monitoring.

Acknowledgements The authors thank the Associação de Pescadores e Pescadores da Ilha de Zezé and the Colônia de Pescadores Z-59 for technical and logistical support. Essential logistical and financial supports were provided by ICHTUS Environment and Society. We are also indebted with all fishers and traditional communities that volunteered their time to this project to ensure its success. Special thanks to the editor and reviewers for the constructive comments and recommendations, which improved quality of the paper.

Author Contributions J.A.R.-F.: Conceptualization, investigation, writing, review, editing, and supervision; F.R.-F. conceptualization and investigation; L.C. writing and review; T.G. writing and review.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

References

Abdurrahim AY, Adhuri DS, Ross H, Phelan A (2022) Community champions of ecosystem services: The role of local agency in protecting Indonesian coral reefs. Front Ecol Evol 10:868219. https://doi.org/10.3389/fevo.2022.868218

Aceves-Bueno E, Adeleye AS, Bradley D, Tyler Brandt W, Callery P, Feraud M, Tague C (2015) Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: Criteria and evidence. Ecosystems 18(3):493–506

Allison EH, Mills DJ (2018) Counting the fish eaten rather than the fish caught. Proc Natl Acad Sci 115(29):7459–7461

Asche F, Bellemare MF, Roheim C, Smith MD, Tveteras S (2015) Fair enough? Food security and the international trade of seafood. World Dev 65:151–160

Bartley DM, De Graaf GJ, Valbo-Jørgensen J, Marmulla G (2015) Inland capture fisheries: status and data issues. Fish Manag Ecol 22:71–77. https://doi.org/10.1111/fme.12104

Bastardie F, Nielsen JR, Ulrich C, Egekvist J, Degel H (2010) Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. Fish Res 106:41–53. https://doi.org/10.1016/j.fishres.2010.06.016

Bayley PB (1988) Accounting for effort when comparing tropical fisheries in lake, river-floodplains, and lagoons. Limnol Oceonagr 33:963–972

Beard Jr TD, Douglas T, Arlinghaus R, Cooke SJ, McIntyre PB, De Silva S, Cowx IG (2011) Ecosystem approach to inland fisheries: Research needs and implementation strategies. Biol Lett 7:481

Béné C, Russell AJM (2007) Diagnostic study of the Volta Basin fisheries Part 2 – livelihoods and poverty analysis, current trends and projections. Report commissioned by the Focal Basin Project. WorldFish Center Regional Offices for Africa and West Asia, Volta. Cairo Egypt, p 66

Bernard RH (2006) Research methods in anthropology: qualitative and quantitative approaches, 4th ed. AltaMira Press, 821

Bieluch KH, Willis T, Smith J, Wilson KA (2017) The complexities of counting fish: Engaging citizen scientists in fish monitoring. Mar Pol Rev 26:9–18

Bond R, Mukerjhee N (2002) Livelihood asset status tracking: An impact monitoring tool? J Intern Develp 14:805–815

Brenier A, Mahafina J, Galzin R, Ferraris J (2013) Participatory approaches and reef fishing monitoring. Nat Sci Soc 21:293–306

Bunce L, Townsley P, Pomeroy R, Pollnac R (2000) Socioeconomic manual for coral reef management. Global Coral Reef Monitoring Network, Townsvile

Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre- Barbieri SK (2011) A standardized terminology for describing reproductive development in fishes. Mar Coast Fish 3(1):52–70. https://doi.org/10.1080/19425120.2011.555724

Brookes A, Sieu C (2016) The potential of community fish refuges (CFRs) in rice field agro-ecosystems for improving food and nutrition security in the Tonle Sap region. Worldfish. Program Report: 2016–10. WorldFish Center, Penang, Malaysia, https://www.worldfishcenter.org/content/potential-community-fish-refuges-cfrsrice-field-agro-ecosystems-improving-food-and-0

Cardoso RS, Freitas CEC (2008) A pesca de pequena escala no rio Madeira pelos desembarques ocorridos em Manicoré (Estado do Amazonas), Brasil. Acta Amazon 38:781–788

Cassels S, Curran SR, Kramer R (2005) Do migrants degrade coastal environments? Migration, natural resource extraction and poverty in North Sulawesi, Indonesia. Hum Ecol 33(3):329–363. https://doi.org/10.1007/s10745-005-4142-9

Castello L, Isaac VJ, Thapa R (2015) Flood pulse effects on multispecies fishery yields in the Lower Amazon. R Soc Open Sci 2:150299. https://doi.org/10.1098/rsos.150299

Cooke SJ, Arlinghaus R, Bartley DM, Beard TD, Cowx IG, Essington TE (2014) Where the Waters Meet: Sharing ideas and experiences between inland and marine realms to promote sustainable fisheries management. Cana J Fish Aqua Sci 71:1593–1601. https://doi.org/10.1139/CJFAS-2014-0176

Cooke SJ, Arthington AH, Bonar SA (2016) Assessment of inland fisheries: A vision for the future. In: Taylor WW, Bartley DM, Goddard CI, et al., (Eds.) Freshwater, fish and the future: Proceedings of the global cross-sectoral conference. Food and Agriculture Organization of the United Nations. FAO, Rome, Italy, www.fao.org/3/a-i5711e.pdf

Cooke SJ, Allison EH, Beard TD, Arlinghaus R, Arthington AH, Bartley DM (2016) On the sustainability of inland fisheries: Finding a future for the forgotten. Ambio 45:753–764. https://doi.org/10.1007/S13280-016-0787-4

Cooke SJ, Lapointe NWR, Martins EG, Thiem JD, Raby GD, Taylor MK, Beard Jr TD, Cowx IG (2013) Failure to engage the public in issues related to inland fishes and fisheries: strategies for building public and political will to promote meaningful conservation. J Fish Biol 83(4):997–1018

Cardoso RS, Freitas CEC (2007) Desembarque e esforço de pesca da frota pesqueira comercial de Manicoré (Médio rio Madeira), Brasil. Acta Amazonica 37(4):605–612

Cardoso RS, Freitas CEC (2008) A pesca de pequena escala no rio Madeira pelos desembarques ocorridos em Manicoré, Amazonas, Brasil. Acta Amazonica 38(4):781–788

Cota-Nieto JJ, Erisman B, Aburti-Oropeza O, Moreno-Báez M, Hinojosa-Arango G, Johnson AF (2018) Participatory management in a small-scale coastal fishery – Punta Abreojos, Pacific Coast in Baja California Sur, Mexico. Reg Stu Mar Sci. https://doi.org/10.1016/j.rsma.2017.12.014

Chuenpagdee R, Rochlin D, Hynes M, Greene R, Lorenzi M, Devillers R (2017) The global information systems on small-scale fisheries (ISSF): A crowdsource knowledge plataform. Marine Policy. 101. https://doi.org/10.1016/j.marpol.2017.06.018

Cotter AJR, Pilling GM (2007) Landings, logbooks and observer surveys: Improving the protocols for sampling commercial fisheries. Fish Fish 8(2):123–152

De Graaf G, Bartley D, Jorgensen J, Marmulla G (2015) The scale of inland fisheries, can we do better? Alternative approaches for assessment. Fish Manag Ecol 22:64–70

Deines AM, Bunnell DB, Rogers MW, Bennion D, Woelmer W, Sayers MJ (2017) The contribution of lakes to global inland fisheries harvest. Front Ecol Environ 15(6):293–298

Elliott VL, Chheng P, Uy S, Holtgrieve GW (2019) Monitoring of tropical freshwater fish resources for sustainable use. J Fish Biol 94:1019–1025

Elliott V, Chheng P (2017) Analysis of trammel net surveys for evaluation of conservation areas. A report prepared for the Fisheries Research and Development Institute (IFReDI), Fisheries Administration, Ministry of Agriculture, Forestry and Fisheries, Royal Government of Cambodia

Elliott VL, Uy S, Chhouy S, Thhanch P, Chheng P (2017) Mekong Fish Biodiversity: From barcodes to genomics. Book of abstracts, Global Biodiversity Genomics Conference 2017. Smithsonian Institution, Washington, DC

Elliot VL, Lynch AJ, Phang SC, Cooke SJ, Cowx IG, Claussen JE, Dalton J, Harrison I, Murchie KJ, Ashley Steel E, Stokes GL (2022) A Future for the inland fish and fisheries hidden within the sustainable development goals. Front Environ Sci. https://doi.org/10.3389/fenvs.2022.756045

Fairclough DV, Brown JI, Carlish BJ, Crisafulli BM, Keay IS (2014) Breathing life into fisheries stock assessments with citizen science. Sci Rep. 4:7249

FAO (2017) Workshop on improving our knowledge on small-scale fisheries: Data needs and methodologies. Workshop proceedings, 27–29 June 2017. FAO Fisheries and Aquaculture Proceedings No. 55, Rome, Italy. Rome, Italy

Fisher J, Jorgensen J, Josupeit H (2015) Fishers' knowledge and the ecosystem approach to fisheries.: Application, experiences and lessons in Latin America. Food and Agriculture Organization of the United Nations. Report 591. 294

Fluet-Chouinard E, Funge-Smith S, McIntyre PB (2018) Global hidden harvest of freshwater fish revealed by household surveys. Proc Nat Acad Sci 115(29):7623–7628

Forcada A, Valle C, Sánchez-Lizaso JL, Bayle-Sempere JT, Corsi F (2010) Structure and spatio-temporal dynamics of artisanal fisheries around a Mediterranean marine protected area. ICES J Mar Sci 67(2):191–203. https://doi.org/10.1093/icesjms/fsp234

Fournier DA, Skaug HJ, Ancheta J, Ianelli J, Magnusson A, Maunder M, Nielsen M, Sibert J (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim Meth Soft 27:233–249

Furletti B, Cintia P, Renso C, Spinsanti L (2013) Inferring human activities from GPS tracks. Paper presented at the 2nd ACM SIGKDD International Workshop on Urban Computing

Garaway C, Arthur R (2019) Measuring fish catch and consumption: Practical methods for small-scale fisheries based on length as an alternative to weight-based approaches. Fish Manag Ecol. https://doi.org/10.1111/fme.12409

Geijzendorffer IR, Beltrame C, Chazee L, Gaget E, Galewski T, Guelmami A, Perennou C, Popoff N, Guerra CA, Leberger R, Jalbert J, Grillas P (2019) A More Effective Ramsar Convention for the Conservation of Mediterranean Wetlands. Front Ecol Evol 7:21. https://doi.org/10.3389/fevo.2019.00021

Godinho AL, Godinho HP (2003) Breve visão do São Francisco. In: Godinho HP;, Godinho AL ed. Águas, peixes e pescadores do São Francisco das Minas Gerais. PUC Minas, Belo Horizonte, p 15–25

Gonçalves Neto JB, Goyanna FA, Feitosa CV, Soares MO (2021) A sleeping Giant: the historically neglected Brazilian fishing sector. Ocean Coast Manag 209:105699

Halls AS, Paxton BR, Hall N, Hortle KG, So N, Chea T (2013) Integrated Analysis of Data from MRC Fisheries Monitoring Programmes in the Lower Mekong Basin. MRC Technical Paper No. 33, pp. 154. Available at http://www.mrcmekong.org/assets/Publications/technical/Tech-No33-Integreted-Analysis-of-Data.pdf

Harper M, Mejbel HS, Longert D, Abell R, Beard D, Bennett JR, Carlson SM, Dell A, Domisch S, Dudgeon D, Freyhof J, Harrison I, Hughes KA, Jähnig SC, Jeschke JM, Lansdown R, Lintermans M, Lynch AJ, Meredith HMR, Molur S, Olden JD, Ormerod SJ, Patricio H, Reid AJ, Schmidt-Kloiber A, Thieme M, Tickner D, Turak E, Weyl OLF, Cooke SJ (2021) Twenty-five essential research questions to inform the protection and restoration of freshwater biodiversity. Aquat Cons Mar Fresh Ecos 31(9):2632–2653

Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. Biometrical J 50:346–363

Hughes JM, Johnson DD, Murphy JJ, Ochwada-Doyle FA (2021) The NSW recreational fisheries monitoring program – Charter Fishery Monitoring 2017/18. Fisheries Final Report Series, No 159

Isaac VJ, Ruffino ML (2007) Evaluation of Fisheries in Middle Amazon. American Fisheries Society Symposium 49. 11

Islam MM, Herbeck J (2013) Migration and translocal livelihoods of coastal small-scale fishers in Bangladesh. J Dev Stud 49(6):832–845. https://doi.org/10.1080/00220388.2013.766719

Irwin BJ, Wagner T, Bence JR, Kepler MV, Liu W, Hayes DB (2013) Estimating spatial and temporal components of variation for fisheries count data using negative binomial mixed models. Trans Am Fish Soc 142:171–183

Keppeler FW, Hallwass G, Santos F, da Silva LHT, Silvano R AM (2002) What makes a good catch? Effects of variables from individual to regional scales on tropical small-scale fisheries. Fisheries Research 229: https://doi.org/10.1016/j.fishres.2020.105571

Kimani P, Obura DO (2007) Participatory mapping of terrestrial fishery resources in Kwale District, Kenya. West Ind Ocean J Mar Sci 3(2):209–220. https://doi.org/10.4314/wiojms.v3i2.28462

Kolding J (2017) Data collection methods for small-scale fisheries in FAO (2017) Workshop on improving our knowledge on small-scale fisheries: data needs and methodologies. FAO Fisheries and Aquaculture Proceedings No. 55, Rome, Italy, p 14–15

Leith P, Jacobs BC, Brown P, Nelson R (2012) A participatory assessment of NRM capacity to inform policy and practice: Cross-scale evaluation of enabling and constraining factors. Soc Nat Resour 25(8):775–793

Lindseth M, Wiggins A, Swanson A, Simmons B (2016) Assessing data quality in citizen science. Front Econ Environ 14(10):551–560

Lokrantz J, Nyström M, Norström AV, Folke C, Cinner JE (2009) Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. Environ Conserv 36(04):327–337. https://doi.org/10.1017/S0376892910000147

Lopes GCS, Catarino MF, Lima AC, Freitas EEC (2016) Small-scale fisheries in the Amazon basin: General patterns and diversity of fish landings in five sub-basins. Bol Inst Pesca 42:889–900

Lopes GCS, Freitas CEC (2018) Avaliação da pesca comercial desembarca em duas cidades localizadas no rio Solimões – Amazonas. Biota Amazônia 8:36–41

Lopes GCS, Catarino MF, Castello L, Freitas CEC (2020) Amazon commercial fishing dynamics: a space macroscale analysis on fishing variables. Braz J Dev 6(2):6025–6044

Lynch AJ, Cooke SJ, Deines AM, Bower SD, Bunnell DB, Cowx IG, Nguyen VM, Nohner J, Phouthavong K, Riley B, Rogers MW, Taylor WW, Woeler W, So-Jung Y, Douglas Berd Jr T (2016) The social, economic, and environmental importance of inland fish and fisheries. Environ Rev 24:115–121

Malleret-King D, Manghubhai S, Tunje J, Muturi J, Mueni E, On'ganda H (2003) Understanding fisheries associated livelihoods and the constraints to their development in Kenya and Tanzania – Annex 4: Livelihood Appraisal (FANRM/MKK/MRAG), London, UK

Mangi S, Smith CS, Catchpole TL (2016) Assessing the capability and willingness of skippers towards fishing industry-led data collection. Ocean Coast Manag 134:11–19. https://doi.org/10.1016/j.ocecoaman.2016.09.027

McClanahan TR, Glaesel H, Rubens J, Kiambo R (1997) The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. Environ Conserv 24(2):105–120. https://doi.org/10.1017/S0376892997000179

McClanahan TR, Mangi SC (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. Fish Manag Ecol 11(1):51–60. https://doi.org/10.1111/j.1365-2400.2004.00358.x

Mendoza-Carranza M, Arévalo-Frías W, Inda-Díaz E (2013) Common pool resources dilemas in tropical inland small-scale fisheries. Ocean Coast Manag 82:119–126

Nguyen Khoa S, Lorenzen K, Garaway C, Chamsingh B, Siebert DJ, Randone M (2005) Impacts of irrigation on fisheries in rain-fed rice-farming landscapes. J Appl Ecol 42:892–900

Pauly D, Christensen V, Guénette S, Pitcher TJ, Sumaila UR, Walters CJ, Zeller D (2002) Towards sustainability in world fisheries. Nature 418:689–695

Patricio HC, Ainsley SM, Andersen ME, Beeman JW, Hewitt DA (2012) The Mekong Fish Network— Expanding the capacity of the people and institutions of the Mekong River Basin to share information and conduct standardized fisheries monitoring: U.S. Geological Survey Open-File Report 2012–1246; 36. Available at https://pubs.usgs.gov/of/2012/1246/

Peja N, Vaso A, Miho A, Rakaj N, Crivelli AJ (1996) Characteristics of Albanian lagoons and their fisheries. Fish Res 27:215–225

Pompeu PS, Godinho HP (2006) Effects of extended absence of flooding on the fish assemblages of three floodplain lagoons in the middle São Francisco River, Brazil. Neotrop Ichthyol 4(4):427–433

Pompeu PS, Godinho HP (2003) Ictiofauna de três lagoas marginais do médio São Francisco. In: Godinho HP, Godinho AL eds Águas, peixes e pescadores do São Francisco das Minas Gerais. PUC Minas Gerais, Belo Horizonte, p 167–181

Pope KL, Lochmann SE, Young MK (2010) Methods for assessing fish populations. In: W. A. Hubert & M.C. (Eds.) Quist Inland Fisheries Management in North America, 3rd edn (pp. 325–352). Bethesda, MA: American Fisheries Society

Porter-Bolland L, Ruiz-Mallén I, Camacho-Benavides C, McCandless SR (2013) Community action for conservation. Mexican Experiences. Springer, New York

Power JH, Moser EB (1999) Linear model analysis of net catch data using the negative binomial distribution. Canad J Fish Aqua Sci 56:191–200

Ostrom E (2009) A general framework for analyzing sustainability of Social-Ecological Systems. Science 325:419–422

Rago PJ, Wigley SE, Fogarty ML (2005) NEFSC bycatch estimation methodology: Allocation, precision and accuracy. Northeast Fisheries Science Center Reference Document. NOAA FINSS. Available at https://www.nefsc.noaa.gov/publications/crd/crd0509/crd0509.pdf

Reis-Filho JA, Leduc AOHC (2017) Management-Challenged Brazilian Governance and the Low Relevance of National Fishery Management Policy: Recommendations to Promote Viable Small-Scale Fisheries. Fish & Ocean Opj. https://doi.org/10.19080/OFOAJ.2017.02.555583

Reis-Filho JA (2020) Historical perspective of artisanal encircling gillnet use at the Brazilian coast: changes in fishing behaviour is mirrored by dwindling stocks. Fish Manag Ecol 27(2):155–166. https://doi.org/10.1111/fme.12393

Reis-Filho JA, Nunes JACC, Miranda RJ, Sampaio CLS, Leduc AOHC (2021) Web-based and logbook catch data of permits and pompanos by small-scale and recreation fishers: predictable spawning aggregation and exploitation pressure. Fisheries Research 243. https://doi.org/10.1016/j.fishres.2021.106064

Roop HJ, Poudyal NC, Jennings CA (2018) Assessing angler effort, catch, and harvest on a spatially complex, multi-lake fishery in middle Georgia. North Am J Fish Manag 38:833–841

Samy-Kamal M (2015) Status of fisheries in Egypt: reflection on past and management challenges. Rev Fish Biol Fish. https://doi.org/10.1007/s11160-015-9404-z.

Sato H, Sogo Y, Doi H, Yamanaka H (2017) Usefulness and limitations of sample pooling for environmental DNA metabarcoding of freshwater fish communities. Sci Rep. 7(1):14860

Schemmel E, Andrade P, Keakealani K, Wiggins C, Yasutake Y, Friedlander A, Castro LM, Wilcox BA, Kittinger JN (2016) The co-development of coastal fisheries monitoring methods to support local management. Ecol Soc 21:185–198

Silvano RA, Hallwass G (2020) Participatory research with fishers to improve knowledge on small-scale fisheries in tropical rivers. Sustainability 12:4487. https://doi.org/10.3390/su12114487

Strele M, Holtge K, Fiebeger M, Were J, Schulmeister A, Weingartner L (2006) Participatory livelihoods monitoring. Linking programmes and poor people's interests to policies experiences from Cambodia. FAO LSP WP 21. Participation, Policy and Local Governance Sub-Programme

TopoGrafix (2016) Easy GPS

Tredick CA, Lewison RL, Deutschman DH, Hunt TANN, Gordon KL, Von Hendy P (2017) A rubric to evaluate citizen science programs for long-term ecological monitoring. Bioscience 67(9):834–844

Wanyonyi IN, Macharia D, Heenan A, Mangi SC (2018) Using participatory methods to assess data poor migrant fisheries in Kenya. Hum Dimen Wild 23:569–586

Welcomme RL (2011) An overview of global catch statistics for inland fish. ICES J Mar Sci 68(8):1751–1756

Welcomme, R., 2008. Inland Fisheries: Ecology and Management. Oxford, UK: John Wiley & Sons FAO. Available at http://www.agrifs.ir/sites/default/files/Inland%20Fisheries.pdf.

WorldBank, FAO and WorldFish Center (2012) The hidden harvests: The global contribution of capture fisheries Agriculture and Rural Development Department Sustainable Development

Network. World Bank, Washington, DC, https://openknowledge.worldbank.org/handle/10986/11873

Yates KL, Schoeman DS (2013) Spatial Access Priority Mapping (SAPM) with fishers: A quantitative GIS method for participatory planning. PLoS ONE 8(7):1–14. https://doi.org/10.1371/journal.pone.0068424

Youn S, Taylor W, Lynch A, Cowx I, Beard D, Bartley D, Wu F (2014) Inland capture fishery contributions to global food security and threats to their future. Glob Food Sec 3:142–148

Journal : **267**
Article : **1819**

Springer
the language of science

Author Query Form

Please ensure you fill out your response to the queries raised below and return this form along with your corrections

Dear Author

During the process of typesetting your article, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the 'Author's response' area provided below

Queries	Details Required	Author's Response
AQ1	References Sato and Godinho 2003, Reis et al. 2003, R Core Team 2020, Nguyen-Khoa et al., 2006, Lopes et al., 2017, Morato-Fernandes et al., 2008 not listed into the reference list. Please add into the list else delete text citations.	
AQ2	Please provide complete details for reference TopoGrafix (2016).	
AQ3	References Elliott, Chheng (2017); Elliot et al., (2022); Hughes et al., (2021); Isaac, Ruffino (2007); Keppeler et al., (2002); Lopes, Freitas (2018) not cited into the reference list. Please cite else delete from reference list.	
AQ4	Please provide Place of publication in the reference Bernard 2006, Elliott and Chheng 2017, Fisher et al. 2015, Isaac and Ruffino 2017, Strele et al. 2006	