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Effects of fisheries management on fish communities in the floodplain lakes of a Brazilian Amazonian Reserve

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Abstract – We compared fish abundance, diversity and species composition between lakes open (fished) and closed (no-take) to fishing activities in Mamirauá Sustainable Development Reserve in the Central Brazilian Amazon, in order to investigate potential influences of the common-based management. We sampled 1483 fishes from 70 species through gillnet fishing during the low-water season, in seven fished and seven no-take lakes. Contrary to expected, the mean values for abundance, size, diversity and species-richness of fish did not differ between fished and no-take lakes. There was no difference between fished and no-take lakes considering only the abundance of the 14 fish species more intensely targeted by fishermen. However, the abundance of an important commercial fish, the tambaqui (*Colossoma macropomum*) was higher in no-take lakes. Such data from a rapid assessment may be useful to monitor this and other fishery co-management schemes.

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Key words: co-management; reserves; tropical freshwater fish; ecology of fish communities; fish conservation; fisheries management

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Introduction

Even the small-scale artesanal fishing may exert considerable pressure on exploited fish, especially on those that do not migrate over long distances and that live in more restricted environments, such as tropical lakes or marine reefs. Indeed, in marine reefs, several studies have been showing that fishing effects may go beyond the more noticeable effects on exploited fish populations, affecting the structure, composition and functioning of the entire fish community and aquatic ecosystem (Jennings & Polunin 1996; McManus et al. 2000; Bellwood et al. 2003). Reserves or no-take areas have been proposed as a useful management tool to protect marine fishes, as higher fish abundance and diversity have been reported inside reserves compared with areas subjected to fishing activities (Lubchenco et al. 2003). Effects of fishing pressure on fish communities have been far less studied on tropical freshwater lakes, but there is evidence that fishing has reduced the abundance and diversity of exploited fish in Southeast Asia (Lorenzen et al. 1998) and in the Peruvian Amazon (Gerstner et al. 2006). In an African lake, fishing gear used by fishers affect the composition of the fish community, because of changes in abundance of an introduced piscivorous fish (Schindler et al. 1998). Comparative studies addressing fish abundance and diversity in areas open and closed to fishing are crucial to monitor the efficacy of protected areas under the framework of adaptive management (Hilborn et al. 2004). More of these studies are required in freshwater's ecosystems, for example investigating the ecological effects of the common-based fisheries management systems adopted in the Brazilian Amazon.

The high fish diversity of the Amazon Basin sustains several small-scale artisanal fisheries, which are the main economic activity of Amazonian riverine populations (Bayley & Petrere 1989; Batista et al. 1998). However, fishing pressure has been increasing in Amazon, and there is evidence of over-fishing of some important commercial fish, such as the tambaqui

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(*Colossoma macroporum*) (Costa et al. 1999; Reinert & Winter 2002; Sánchez-Botero et al. 2005), pirarucu (*Arapaima gigas*) (Arantes et al. 2005) and large catfishes (Pimelodidae) (Petrere et al. 2004).

In the Brazilian Amazon, most of the fishing occurs along the white-water (higher organic matter) rivers, where the floodplain *várzea* lakes are regularly exploited by local fishing communities. These floodplains are nutrient-rich and hold high fish abundance and diversity (Junk et al. 1983; Lowe-McConnell 1987; Henderson & Crampton 1997; Crampton 1999; Saint-Paul et al. 2000; Silvano et al. 2000). Albeit the composition of fish landings at Amazonas and Solimões Rivers usually includes about 30–40 species, most of the catch often consists of 5–10 fish species, including large catfish (Pimelodidae) caught in the river channel and fish caught mainly in lakes, such as the tambaqui, pirarucu, tucunaré (*Cichla* spp.), aruanã (*Osteoglossum bicirhosum*) and pacus (*Myleus* spp. and *Mylossoma* spp.) (Petrere 1985; McGrath et al. 1993; Isaac et al. 1996; Batista et al. 1998; Almeida et al. 2001; Ruffino 2002; Viana 2004; MacCord et al. 2007). Therefore, these lakes may be viable environmental units to fishery management because they have well-defined boundaries during the low-water season and hold sedentary populations of target fish, such as the tambaqui, pirarucu, tucunaré and aruanã (McGrath et al. 1999).

As a result of personnel and funding limitations to run monitoring and enforcement programs, conservation initiatives in remote regions, such as the Brazilian Amazon, would greatly benefit by including local people. Indeed, one of the most recent and promising approaches aimed to locally protect and manage Amazonian fish is a kind of co-management where local fishermen participate in management decisions, preventing outsiders from fishing in selected lakes (McGrath et al. 1993; McDaniel 1997; Queiroz & Crampton 1999; Castro & McGrath 2003). The Mamirauá Sustainable Development Reserve was created in 1990 to protect the biodiversity of a large floodplain area in the Central Brazilian Amazon, actively recruiting local communities in natural resources conservation (Ayres 1993; Queiroz 2005). One of the main co-management measures adopted there since 1995 consists of a zoning system of lakes, which establishes two categories: lakes closed to fishing (hereafter denominated as no-take) and lakes open to fishing by local people only (hereafter denominated as fished) (Queiroz & Crampton 1999).

Our major goal was to compare fish abundance, diversity and species composition between fished and no-take lakes of the Mamirauá Reserve in the Brazilian Amazon, in order to investigate the potential influences of the common-based management on fish communities. We expect that all these parameters would show higher mean values in no-take compared with fished lakes, as observed in previous surveys (Lorenzen et al. 1998; Gerstner et al. 2006). We also expected that fish community structure would differ between these two lake categories, no-take lakes showing higher abundance of large-sized and commercial fishes, in particular those more intensely exploited by fishers. Besides being one of the first studies investigating both the efficacy of freshwater reserves to protect food fishes and the ecological consequences of common-based fisheries management, this study will compliment the available surveys of fish populations in the Mamirauá Reserve (Costa et al. 1999; Castello 2004; Arantes et al. 2005; http://www.mamiraua.org.br). We thus provide baseline data to improve both ongoing and planned fisheries management approaches in Amazon (McGrath et al. 1993; McDaniel 1997; Queiroz & Crampton 1999; Reinert & Winter 2002), as well as in other tropical freshwater fisheries.

Study area

The Mamirauá Sustainable Reserve, located on the confluence of Solimões and Japurá Rivers, has a total area of 1.124.000 ha and is subdivided into nine sectors with about 60 small human settlements and 527 resident families living along the margins of main rivers (http://www.mamiraua.org.br; Queiroz & Crampton 1999). The two main rivers (Solimões and Japurá) draining the reserve have predominant white-water properties (Henderson & Robertson 1999). We sampled fish communities of fished and no-take lakes located between the coordinates of 02°45′–02°50′S and 64°58′–65°05′W in the Jarauá sector, which is bordered by the confluence of the Jarauá and Japura rivers and is located in the core management area of the Mamirauá reserve (Queiroz & Crampton 1999), where the fishing village of São Raimundo do Jarauá (hereafter denoted Jarauá) is located (02°51′849 S, 64°55′750 W) (Fig. S1).

The Mamirauá reserve and its management system could benefit the middle Solimões River region, where fishery is one of the main economic activities and fish is the main animal protein consumed (Barthem 1999; Ruffino 2002; Viana 2004). The most exploited fish in the middle Solimões region are the jaraqui (*Semaprochilodus* spp.), curimatã, aruanã, tucunaré, pacu, bodó, pirapitinga (*Piaractus brachypomus*) tambaqui and pirarucu; with the exception of jaraqui all others are caught in lakes (Barthem 1999; Viana 2004) and would thus be subjected to more intense regional fishing pressure. The main fishing gear used by fishers from Tefé (the major city in the region) are the seine nets and gillnets, which account for about 80% of total fish caught, gillnets being used mainly to catch fish in floodplain lakes during the low-water season (Barthem 1999; Ruffino 2002; Viana 2004). Some studies show that the fishing-management measures (including the zoning systems of lakes) adopted in Mamirauá have been successful to enhance the populations of pirarucu (Arantes et al. 2005) and tambaqui (Costa et al. 1999), but possible management effects on the whole fish community are not yet well known.

Considering the fishing intensity in the Mamirauá reserve, during 1993–1995, Jarauá fishermen made a total of 261 fishing trips, 205 of which (78%) happened in lakes and 176 (86%) in fished lakes. These fishermen marketed a total of 13.8 t of fish from February 1994 to January 1995 (Barthem 1999). More recently, in 2003, Jarauá fishermen caught a total of 2.3 and 17.1 t of fish during the high- and low-water seasons respectively (MacCord et al. 2007). According to these studies, the main lake fishes regularly caught, marketed and eaten by people from Jarauá are pirarucu, tambaqui, aruanã, pacu, tucunaré, bodó, curimatã and pirapitinga (Queiroz 1999; MacCord et al. 2007), the same fishes also exploited by regional fisheries from Tefé and other nearby cities (Barthem 1999; Viana 2004). Besides the local fishery, lakes in the Mamirauá Reserve, including those in Jarauá, have been regularly exploited by outside fishers, but such invasions decreased in recent years as a result of a more stringent control of lakes by the reserve fishers (Barthem 1999; Queiroz 1999; Viana 2004). Jarauá lakes have thus been subjected to considerable fishing pressure along the last 15 years, directed mostly to the fished lakes and during the low-water season.

Materials and methods

Fish sampling

The Jarauá sector of the Mamirauá Reserve has about 33 no-take and 49 fished lakes. We selected 14 of these lakes (seven fished and seven no-take) after a preliminary survey and advice of local fishermen. We chose lakes that could be easily located and reached during the dry season, thus being logistically feasible to daily samples. We collected fish in the selected lakes during the low-water season, in October and November of 2003. Although we also sampled lakes during the high-water season (June and July of 2003), we excluded these data from this survey because of the low amount of fish sampled (R.A.M. Silvano, P.F.M. Lopes, M.R. Souza, M. Clauzet, A. Begossi, J.A.S. Zuanon, unpublished abstract).

We made one sample per lake during 14 days (one lake per day), collecting fish with two sets of seven monofilament gillnets. Each gillnet had a length of 10 m, with heights varying between 1.5 and 2.5 m, and with varied mesh sizes (pairs of nets with 15, 25, 35, 50, 60, 70 and 80 mm between opposite knots). We also used two multifilament gillnets with larger mesh sizes of 110 and 120 mm respectively between opposite knots, with 70 m length and about 3.5 m height to sample large commercial fishes. In all samplings, we placed four sets of nets (two larger nets and two sets of attached gillnets) in distinct and suitable places in the lake, attaching an end of each set of nets to the marginal vegetation and lying the nets perpendicular to the marginal vegetation and crossing the lake. We left gillnets in the water during the morning (8:00–12:00 h) and afternoon (14:00–16:00 h), for total periods ranging from 5 to 8 h (mean 6.3 h). We checked the nets at regular 30-min intervals, to avoid damage to the nets and fish by aquatic predators (e.g., caimans, piscivorous fishes and river dolphins).

Each fish collected was measured to standard length (SL, in cm), weighed (g), preserved in a 10% formalin solution and identified to species level by one of the authors [Zuanon – Instituto Nacional de Pesquisas da Amazônia (INPA)] in the INPA where we deposited voucher specimens. Due to logistical constraints, when many individuals of the same species in a sample were caught, we collected some and released or discarded the others. Although such a procedure did work for the majority of fish, we encountered difficulty when trying to discern those nonretained specimens belonging to very similar species, such as *Serrasalmus altispinis* and *Serrasalmus eigenmanni* (piranha branca). We dealt with this problem by assigning all the noncollected individuals to the most common species collected at a given lake, which was *S. altispinis* in three lakes and *S. eigenmanni* in one lake. We also followed this procedure for two similar species of sardinhas (*Triportheus angulatus* and *Triportheus elongates*) in five of the sampled lakes. We applied this procedure to assign species for a total of 138 individuals (9.3% of all fishes collected): 115 individuals of *S. altispinis*, 20 of *T. angulatus* and three *T. elongates*. Therefore, albeit this procedure possibly overestimated the relative abundance of some species (for example, *S. altispinis*), we believe this did not alter our major results and conclusions.

Simultaneous to fish sampling, we measured the temperature, pH and dissolved oxygen levels at each lake, at the same spots where we set gillnets. We measured water temperature (early morning and late afternoon), pH (only in the morning) and dissolved oxygen (morning and afternoon) near the water surface (up to a depth of 50 cm) and averaged these data in a single daily measure for each variable.

Data analysis

We standardised fish abundance data as kilograms per hour and number of individuals per hour, in order to account for slight differences in sampling duration among lakes. We compared fish abundance, biomass, mean fish size (SL) and environmental parameters between fished and no-take lakes using *t*-tests. We also used Pearson linear correlation analysis to check for relationships among fish community variables and environmental variables, such as oxygen levels and distance (in km) of the lake from the Jarauá River mouth (estimated through the CartaLinx software, using Global Positioning System coordinates of sampled lakes). Besides indicating the distance of lakes from the Jarauá River, such measurements might reflect the accessibility of lakes to fishermen, as the main fishing village of the region, São Raimundo do Jarauá, is located at the mouth of this river. We used the *F*-test (variance ratio; Fowler & Cohen 1990) to check for homogeneity of variances of samples and the Shapiro–Wilk test (Ayres et al. 2000) to check for data normality. We log-transformed data to achieve normal distribution and homogeneous variances; when these was not achieved, we then used the nonparametric Mann–Whitney test (*U*) and Spearman rank correlation coefficient. Due to differences in the number of individuals and species collected between the two lake categories, we compared fish diversity between fished and no-take lakes through rarefaction curves, as adopted in other surveys of fish communities (Silvano et al. 2000).

Besides comparing the abundance (in number and biomass) of total fish caught between fished and no-take lakes, we also made a separate analysis comparing the abundance of 14 fish species more intensely targeted by local and regional fishermen respectively from the Jarauá community in Mamirauá Reserve and Tefé, the largest city in the region (Appendix S1). For such analysis, we considered as commercial or targeted fish species those that corresponded to 5% or more of biomass of fish caught, consumed or sold, according to the literature (Queiroz 1999; Ruffino 2002; Viana 2004; MacCord et al. 2007). The piranhas included several fish species, some of which are small size and seldom caught. We thus considered as target fish only the two largest and commonest piranha species, *Pygocentrus nattereri* and *Serrasalmus rhombeus* (Appendix S1). However, considering that such piranha species were abundant in our samples and usually not intensely caught by fishermen, we also analysed data for the remaining commercial fishes, but excluding piranhas.

We made a principal components analysis (PCA) ordination to analyse fish species composition in sampled lakes, considering both number and biomass of the fish caught. We also made a PCA ordination of lakes according to environmental parameters: temperature, pH, oxygen levels and distance from the confluence between the Jarauá and Japurá rivers. We made Spearman correlations between the scores of lakes in the two first-ordination axes generated by the first PCA analysis and some of the environmental variables (distance from the main river and oxygen levels) to check for influences of these variables on fish species composition.

Results

Environmental variables

The mean values of dissolved oxygen, temperature, pH and distance from the Jarauá Rivers' mouth did not differ between fished and no-take lakes (Fig. 1). Of these parameters, dissolved oxygen and distance showed a higher variability among lakes, the former ranging from 2.8 to 16.1 mg·l^{-1} and the second ranging from 3.5 to 50.4 km (Fig. 1). However, considering the 14 sampled lakes, dissolved oxygen was not related to the number of specimens ($r = 0.46$, d.f. = 12, $P = 0.098$), biomass ($r = 0.48$, d.f. = 12, $P = 0.08$), species-richness ($r = 0.39$, d.f. = 12, $P = 0.17$) and species diversity (H′; $r = 0.13$, d.f. = 12, $P = 0.65$) of fish. Lakes' distance was neither related to the number of specimens (rs = 0.17, $N = 14$, $P = 0.55$), fish biomass (rs = 0.5, $N = 14$, $P = 0.07$), species-richness (rs = −0.07 $N = 14$, $P = 0.8$) nor species diversity

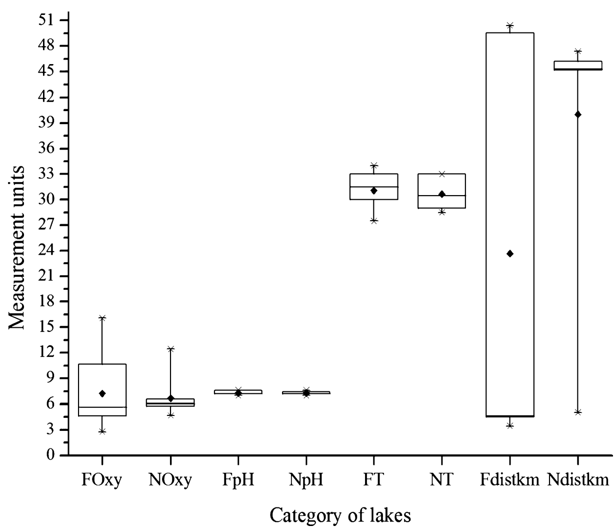

Fig. 1. Mean (diamond point), maximum and minimum values (top and bottom of lines) and 75 and 25 percentiles (the box areas respectively above and under the line) of environmental parameters of fished (F) and no-take lakes (N) of the Mamirauá Reserve: dissolved oxygen (mg·l^{-1}; Oxy; $U = 21$, $N = 14$, $P = 0.65$), pH, temperature (°C; T; $t = 0.39$, d.f. = 12, $P = 0.7$) and distance from Japurá River's mouth (km; distKm; $U = 21$, $N = 14$, $P = 0.65$).

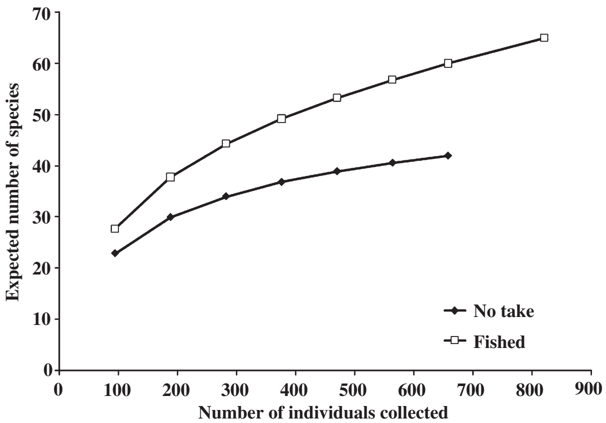

Fig. 2. Rarefaction curves for fish species-richness in fished and no-take lakes of the Mamirauá Reserve.

(H') (rs = 0.1, N = 14, P = 0.74). However, we observed nearly significant relationships (values close to P = 0.05) between distance and fish biomass and between dissolved oxygen and fish biomass.

Fish abundance and diversity

We collected a total of 1482 fish corresponding to 603.9 kg, from 70 species and 12 families, with a diversity of H' = 4.2 considering all the sampled lakes (Appendix S1). In fished lakes, we collected 821 fish with a biomass of 272.5 kg, from 65 species, 12 families and H' = 4.2. In no-take lakes, we collected 661 fishes with a biomass of 331.4 kg from 42 species, 12 families and H' = 3.8. The rarefaction curves indicated a higher fish species-richness in fished compared with no-take lakes (Fig. 2). Mean values for fish abundance (Fig. 3a,b) and fish sizes (Fig. 4) did not differ between fished and no-take lakes. The mean abundances of the target fish species in biomass (Fig. 3a) and number (Fig. 3b) also did not differ between the two lake categories, even after excluding the piranhas (Fig. 3a,b). It was not possible to compare the abundance of tambaqui between the two categories of lakes through statistical tests. The large variance (Fig. 5) and lakes with no tambaquis (zero data) rendered samples non- normal and with heterogeneous variances, even after log-transformation. The nonparametric Mann–Whitney test could not be applied due to overlap of observations: two fished and three no-take lakes had equal values (no tambaquis), thus resulting in rank overlaps and precluding the use of this test considering the sample size (seven lakes in each category) (Fowler & Cohen 1990). However, the mean number and biomass of tambaqui, a very important commercial fish, were respectively 10 and 90 times higher in no-take than in fished lakes (Fig. 5).

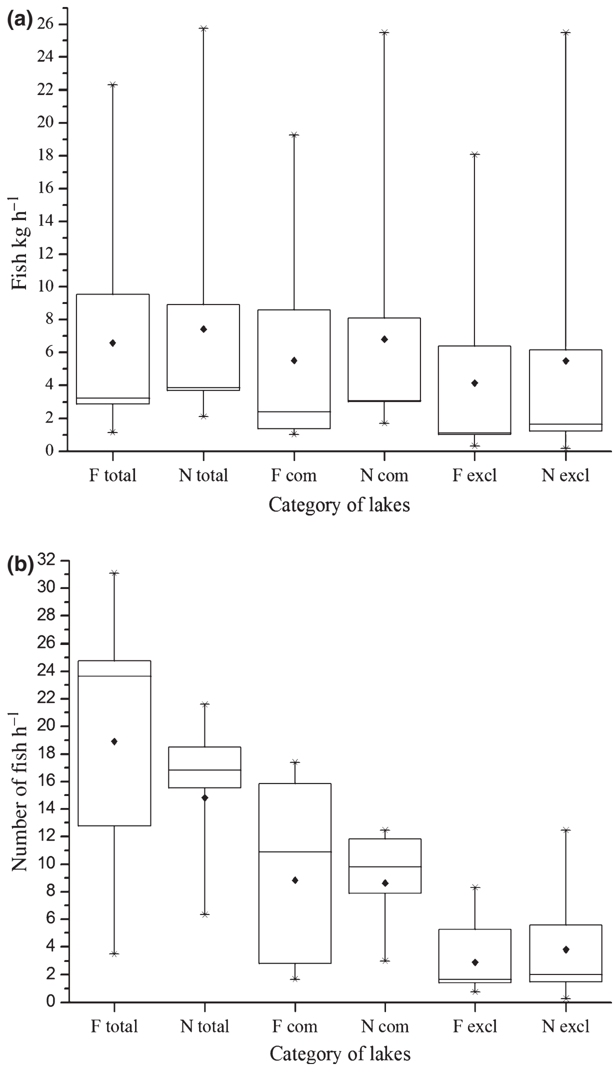

Fig. 3. Mean, maximum and minimum values and 75 and 25 percentiles (as in Fig. 1) of fish abundance per hour fishing at fished (F) and no-take lakes (N) of the Mamirauá Reserve: (a) biomass (kg) of total fish (t = 0.37, d.f. = 12, P = 0.71), only commercial (target) fish (com; t = −0.49, d.f. = 12, P = 0.63) and commercial fish excluding piranhas (excl; t = −0.313, d.f. = 12, P = 0.76); (b) number of individuals of total fish (t = 0.97, d.f. = 12, P = 0.351), only commercial (target) fish (com; t = 0.08, d.f. = 12, P = 0.94) and commercial fish excluding piranhas (excl; t = −0.25, d.f. = 12, P = 0.81).

Fish species composition

Considering the total number of specimens caught, the overall composition of fish communities was similar for fished and no-take lakes: the main fish species in both lakes categories were the piranhas (*Serrasalmus* spp. and *P. nattereri*), besides the commercial fish aruanã (*Osteoglossum bicirrhosum*), this same pattern being observed regarding biomass (Appendix S1).

The two first axes generated by the PCA analysis of lakes according to the number of fish showed eingenvalues of 12.33 and 11.46 respectively, accounting for

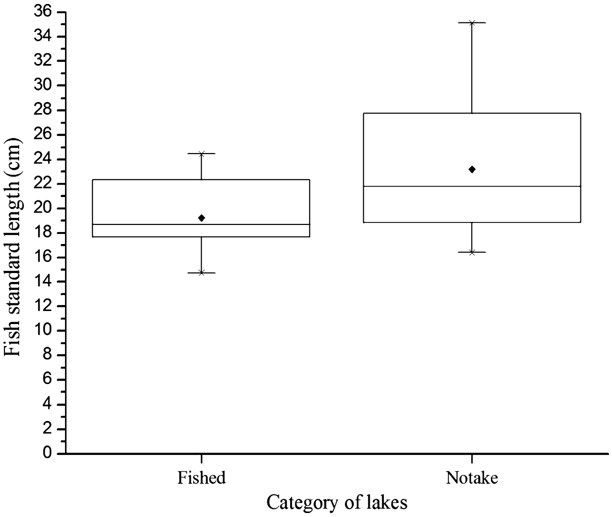

Fig. 4. Mean, maximum and minimum values and 75 and 25 percentiles (as in Fig. 1) of standard length of fish collected in fished and no-take lakes of the Mamirauá Reserve ($t = -1.42$, d.f. = 12, $P = 0.18$).

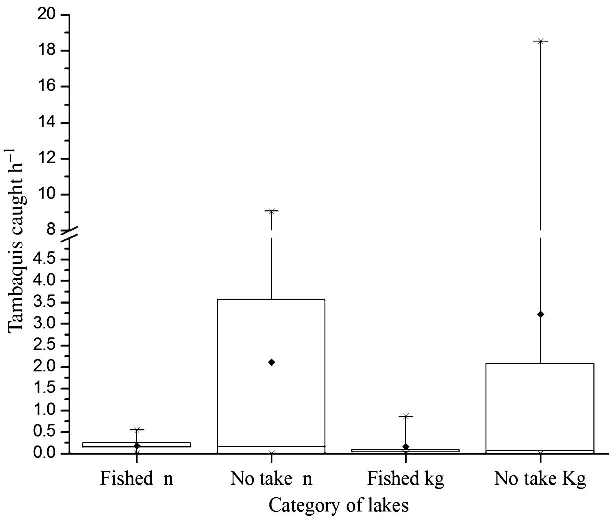

Fig. 5. Mean, maximum and minimum values and 75 and 25 percentiles (as in Fig. 1) of biomass (kg) and number of tambaqui caught per hour fishing at fished and no-take lakes of the Mamirauá Reserve. The *y*-axis was broken, due to large variability of data in no-take lakes.

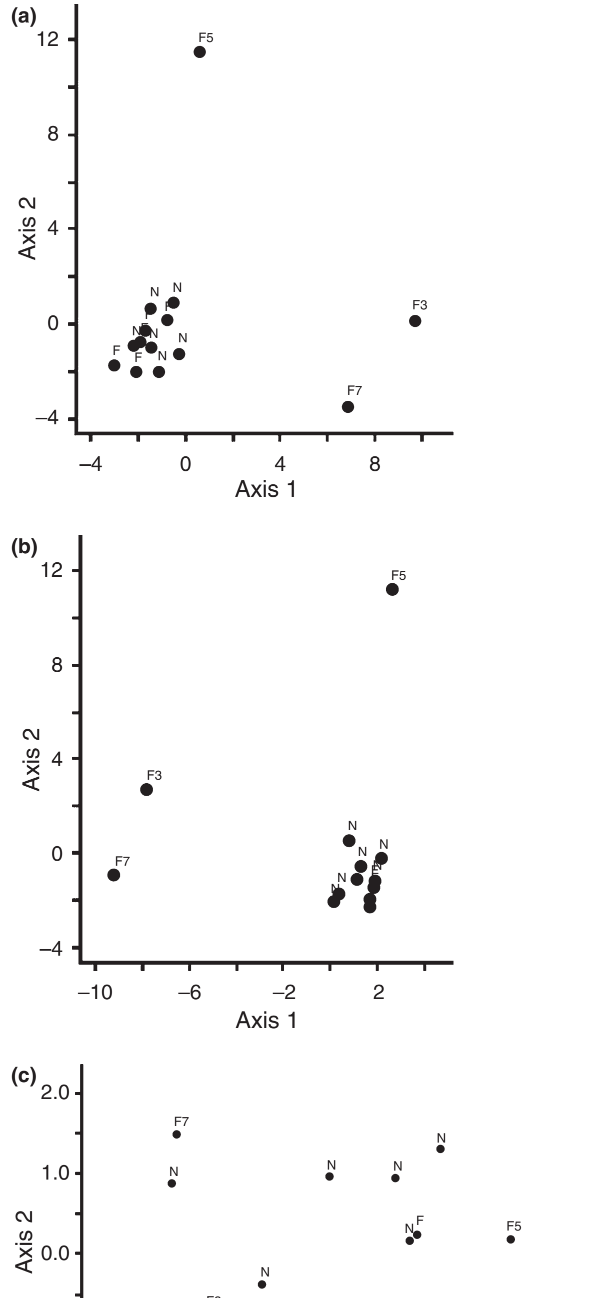

Fig. 6. Ordination of fished (F) and no-take (N) lakes along the first two axes of the PCA analyses based on (a) number of fishes, (b) fish biomass and (c) environmental characteristics (see Materials and methods). The three most distinct lakes are marked (F3, F5 and F7) on each figure.

17.6% and 16.4% of the variance respectively, thus explaining 34% of the total variance in the data set. This analysis did not provide any distinction among fish communities of no-take and fished lakes. However, two fished lakes showed higher scores along the first axis and another one showed a high score in the second axis, those three lakes being thus distinct from all others (Fig. 6a). The two first axes generated by the PCA based on fish biomass showed eingenvalues of 12.66 and 11.15 respectively, accounting together for 34% of the variance. The resulting ordination was almost identical to the previous analysis based on the number of fish caught, lacking any obvious patterns of segregation between fished and no-take lakes, the same three lakes being distinct from all others

(Fig. 6b). Fish species composition was more varied among fished than among no-take lakes (Fig. 6a,b). Those three (fished) lakes with distinctive fish assemblages (Fig. 6a,b) also showed a higher mean diversity ($H' = 3.8$) than the other 11 lakes ($H' = 2.6$) ($U = 0$, $N = 14$, $P = 0.01$) and a higher mean-richness (25.7 species vs. 15.4 species; $U = 0$, $N = 14$, $P = 0.01$).

The two first axes generated by the PCA analysis of lakes according to environmental variables (temperature, pH, dissolved oxygen and distance from the Jarauá River's mouth) had eingenvalues of 1.79 and 1.07 and accounted for 44.7% and 26.7% of the variance respectively (71.4% of the cumulative variance). The resulting ordination neither revealed a distinctive pattern of lakes with peculiar characteristics, nor differentiated between fished and no-take lakes (Fig. 6c). Furthermore, the three fished-lakes that were distinct from the other with respect to their fish species composition (Fig. 6a,b) were not segregated by the PCA based on environmental conditions (Fig. 6c).

Considering the influence of environmental variables on PCA analysis based on fish abundance in the lakes, the scores on the first axis were not related to dissolved oxygen (rs = 0.13, $N = 14$, $P = 0.67$), but were positively related to the lakes' distance (rs = 0.55, $N = 14$, $P = 0.04$). Lakes' scores on the second axis were not related to lakes' distances (rs = 0.07, $N = 14$, $P = 0.8$), nor to dissolved oxygen (rs = −0.14, $N = 14$, $P = 0.64$).

Discussion

Fish communities

We sampled fish communities through a set of gillnets with distinct mesh sizes, which are more suitable to catch open water and mobile fish in larger and deeper aquatic ecosystems (Ibanez et al. 2007), such as Amazonian lakes (Saint-Paul et al. 2000; Silvano et al. 2000). Indeed, most of the mobile open-water fish species are also those caught with gillnets by fishermen in the studied region (MacCord et al. 2007): nearly all the fish species more heavily exploited by local and regional fishermen were collected (Appendix S1). Therefore, our sampling method is coherent with fishing strategies, although fishermen may use different mesh sizes and employ a higher fishing effort.

The 70 fish species collected comprised only a fraction of the total fish assemblage from floodplain lakes, corresponding to 24% of all 291 fish species estimated for the Mamirauá Reserve (Crampton 1999). However, 20 of the fish species collected in this study were not yet recorded for the Mamirauá Reserve (Appendix S1), albeit this could be at least partially attributed to changes in nomenclature. The observed species-richness in this study ranged from 50% to 80% of the richness recorded in other surveys of fish communities in Amazonian white-water floodplain lakes (Henderson & Crampton 1997; Tejerina-Garro et al. 1998; Saint-Paul et al. 2000; Silvano et al. 2000; Petry et al. 2003).

There are usually complex relationships between environmental factors and Amazon fish communities (Junk et al. 1983, 1989; Henderson & Crampton 1997; Tejerina-Garro et al. 1998; Crampton 1999; Petry et al. 2003), and environmental parameters related to aquatic habitats may vary alongside to the management interventions (Gerstner et al. 2006). The environmental parameters that we measured did not differ between fished and no-take lakes, thus not biasing our comparison between lake categories. Furthermore, fish composition was not related to those measured environmental characteristics of sampled lakes.

Management implications

Contrary to other Amazonian regions in Brazil, the Mamirauá Reserve has not been subjected to environmental alterations such as deforestation, pollution or impoundments: small-scale local fisheries for food and income have been the sole source of impact on fish communities there. We made a rapid and cost-effective assessment of fish communities, to provide information potentially useful to managers. Contrarily to what we expected, in spite of the zoning system of lakes in Mamirauá, fish communities were not more diverse and abundant in no-take compared with fished lakes, even when comparing only the target commercial fish species. Also, the composition of fish communities did not differ between the two lake categories. We also observed a higher variability in fish species composition among fished lakes, which might be partially due to the higher variability among these lakes regarding their distance from the Jarauá River mouth. The greater distance from the Jarauá River mouth may have reduced the access of fishermen to those lakes, therefore alleviating fishing pressure compared with lakes closer to the fishing community. Fisheries management plans for Amazonian's floodplains should consider such a geographic characteristic. Moreover, populations of caimans in the Mamiraua Reserve have been partially protected from overexploitation due to the inaccessibility of lakes (Silveira & Thorbjarnarson 1999). The fished lakes, including those more distinct lakes, also showed a higher fish diversity (Fig. 2), which might be partially due to the presence of exclusive fish species.

The observed lack of effects of fisheries closure on fish communities in Mamirauá might not necessarily mean that such management actions have been ineffective, as they might take a longer time to generate measurable results. The zoning system of lakes in Mamirauá was formally implemented in 1994 (Queiroz & Crampton 1999), 9 years before our survey. In Peruvian Amazon, the abundance, diversity and biomass of ornamental fishes (targeted for the aquarium trade) are lower in a more intensively exploited river compared with a river located inside a no-take reserve established about 19 years prior to the study (Gerstner et al. 2006) .

Actual management categories of lakes in the Mamirauá Reserve may not be as distinguishable as stated by managers. The zoning system of lakes emerged from already existing conservation concepts among fishing communities who were influenced by Catholic missionaries (Queiroz & Crampton 1999). Some lakes may thus have been less-intensively exploited well before 1994. On the other hand, there is evidence that some fishermen, who do not fully agree with the zoning system, occasionally exploit no-take lakes (Costa et al. 1999; Arantes et al. 2005). However, Queiroz (1999) observed in 1994 that only 14% of 205 fish landings by Jarauá fishermen are from no-take lakes. Therefore, although occasional poaching of no-take lakes might occur in Mamirauá, we may arguably assume that no-take lakes have been less-intensively exploited than fished lakes and the degree of poaching probably did not influence our comparison of fished and no-take lakes.

Albeit several fish species move among Amazonian floodplain lakes during the high-water season, either as migrating adults (Junk et al. 1989; Henderson & Robertson 1999) or as dispersed larvae (Araújo-Lima & Oliveira 1998), we consider that such fish migrations did not obscure the comparison of the studied lakes. Some fish may not migrate nor disperse over large distances. For example, in a floodplain lake in the Amazon River, only 20 fish species out of 87 undergo lateral migrations between the river and the lake (Fernandes 1997). We also sampled lakes during the low-water season, when fish are usually not moving and when fishing pressure is most intense (Queiroz 1999; MacCord et al. 2007). Considering the above-mentioned migrations and larval dispersion of some Amazon fish species, including some commercial ones, such as the tambaqui (Lima & Goulding 1998), no-take lakes in Mamirauá may have been exporting fish to fished lakes and the similarities in fish abundance may not be indicating a management failure at the fish community level. Such process has been well documented for marine tropical reefs, where migration of adult fish (spillover) or larval dispersal (recruitment subsidy) may enhance fish populations in fished areas adjacent to reserves (Gell & Roberts 2003; Sale et al. 2005; Abesamis et al. 2006). However, fish populations could also be depleted in reserves if they are too small or fishing around them is too intense (Crowder et al. 2000). Therefore, our results could also be indicating that both lake categories in the Mamirauá Reserve had similar and reduced fish abundance, due to an overall fish depletion. It is hard to distinguish between these two scenarios (high or low overall fish abundance in Mamirauá Reserve), due to the limited understanding about the fish-movement patterns in Amazonian floodplain lakes. We thus compared fish abundance in Mamirauá Reserve to other fish surveys from the literature for Amazonian white-water or clear-water lakes and rivers, sampled during the dry season with the same kind of gear (Table 1). The mean catch per unit of effort (CPUE) observed in Mamirauá showed the third largest value for fish biomass. However, after excluding the data from the larger nets, which had not been employed in other studies, the CPUE in Mamirauá was the largest one regarding biomass and number of fishes (Table 1). Furthermore, our CPUE data was similar to values obtained during gillnet experimental fishing in other Mamirauá lakes 8 years before our survey (Henderson & Crampton 1997), indicating stable average fish

Table 1. Mean fish abundance expressed as CPUE values (g or number of fish * m^{-2} * h^{-1}) from this study and from other studies in Brazilian Amazon.

River Basin	Source	Biomass	Number
Japurá and Solimões (Mamirauá Reserve), Central Amazon	This study	12.0	0.03
Japurá and Solimões (Mamirauá Reserve), Central Amazon	This study†	22.4	0.07
Manacapurú River, Central Amazon‡	Saint-Paul et al. 2000	14.5	
Mucajaí River, eastern Amazon§	Ferreira et al. 1988	3.7	0.02
Lower Tocantins River, western Amazon¶	De Merona 1986/87	5.0	
Trombetas River, western Amazon††	Ferreira 1993	10.2	0.03
Japurá and Solimões (Mamirauá Reserve), Central Amazon	Henderson & Crampton 1997	13.5	

Most other studies include fish samples through gillnet fishing, during the low-water season and mostly in white-water lakes, unless otherwise stated.
†Excluding data obtained through experimental fishing with multifilament gillnets of large mesh sizes (110 and 120 mm).
‡Data gathered both by fishing in lakes and in the flooded forest (Saint-Paul et al. 2000).
§Fish samples from several sites along the white-water Mucajaí River during various seasons, including sites upriver and downriver from a waterfall (Ferreira et al. 1988).
¶Data are the mean CPUE for fish samples in four clear water lakes (De Merona 1986/87).
††Data from the Caxipacoré River, which show the highest productivity in fish biomass for this clear water river system. Data are from fish samples in several habitats, such as lakes, river channels and streams (Ferreira 1993).

densities over time in the reserve. The above comparisons suggest that the studied region was probably not over-fished yet, and the management may have been contributing to this.

Although there is lack of observed effects on the whole fish community, the zoning system of lakes in Mamirauá positively affected the abundance of tambaqui, an important commercial fish species, which was more abundant in number and biomass in no-take lakes (Fig. 5). Notwithstanding the large variability on tambaqui abundance among sampled lakes, this species was the second most caught in no-take lakes (97 individuals), while only eight individuals were caught in fished lakes. Such difference in management outcomes regarding fish community and target fish species is also observed in coastal reefs of Kenya, where the common-based management system enhances fish landings in managed areas, without affecting fish species diversity and ecological integrity (Mcclanahan et al. 1997). This could be because of the prime goal of such co-management is to improve fisheries, not to conserve biodiversity (Mcclanahan et al. 1997). All tambaqui specimens that we caught in the Mamirauá Reserve were smaller than 55 cm SL (proposed size at first maturity), thus reinforcing previous observations that no-take lakes in Mamiraua Reserve have been protecting juveniles of this fish (Costa et al. 1999). Fish landings of pirarucu in the Jarauá sector of the Mamiruá Reserve have been increasing steadily since the establishment of the zoning system, suggesting a positive effect of this management measure (Queiroz & Crampton 1999; Arantes et al. 2005; Queiroz 2005). Such positive effects on the abundance of tambaqui and pirarucu may be also because of other fishery regulations adopted in the Mamirauá Reserve, such as the establishment of quotas, closed fishing seasons, restrictions to the use of gillnets in the floodplain lakes and exclusion of outside commercial fishermen (Queiroz & Crampton 1999; Castello 2004; MacCord et al. 2007).

Conclusion

Our results indicated that no-take lakes in the Mamirauá Reserve seem to have enhanced (or at least maintained) densities of an important commercial fish, but did not affect the whole fish community. We also suggest that the zoning system could be potentially improved by protecting more distant lakes. These results should be viewed as baseline ecological data, which may be useful to monitor and to improve current common-based fishery management in the Mamirauá Reserve. The rapid assessment approach adopted in the present study may also be applicable to other tropical freshwater fisheries elsewhere that already have or are in need of common-based management systems (Begossi et al. 1999; Silvano & Begossi 2001; Mann 1995; McDaniel 1997; Lorenzen et al. 1998; Mathooko 2005).

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Figure S1. Map of the Jarauá sector of the Mamirauá Reserve, indicating the overall placement of the studied lakes (F = fished and N = no-take) on the reserve. Source: detailed map of the Jarauá sector (http://www.mamiraua.org).

Appendix S1. Relative composition (%) in biomass of fish species collected in fished and no take lakes of the Mamirauá Reserve, compared to relative composition in biomass of the same fish species regarding fish landings and fish consumption in Mamiraua Reserve and in the region of the Middle Solimões River, based on literature data. Fish species considered as commercial, or subjected to more intense fishing pressure are in bold (see text for explanations). FLJ: fish landings Jarauá, during 2003; FCJ: fish consumed Jarauá, during 1991 and 1992; FSC: fish sold in four communities, during 1994 and 1995.

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