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Behavioral and environmental influences on fishing rewards and the outcomes of alternative management scenarios for large tropical rivers

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ABSTRACT

Identifying the factors that influence the amount of fish caught, and thus the fishers' income, is important for proposing or improving management plans. Some of these factors influencing fishing rewards may be related to fishers' behavior, which is driven by economic motivations. Therefore, those management rules that have less of an impact on fishers' income could achieve better acceptance and compliance from fishers. We analyzed the relative influence of environmental and socioeconomic factors on fish catches (biomass) in fishing communities of a large tropical river. We then used the results from this analysis to propose alternative management scenarios in which we predicted potential fishers' compliance (high, moderate and low) based on the extent to which management proposals would affect fish catches and fishers' income. We used a General Linear Model (GLM) to analyze the influence of environmental (fishing community, season and habitat) and socioeconomic factors (number of fishers in the crew, time spent fishing, fishing gear used, type of canoe, distance traveled to fishing grounds) on fish catches (dependent variable) in 572 fishing trips by small-scale fishers in the Lower Tocantins River, Brazilian Amazon. According to the GLM, all factors together accounted for 43% of the variation in the biomass of the fish that were caught. The behaviors of fishers' that are linked to fishing effort, such as time spent fishing (42% of the total explained by GLM), distance traveled to the fishing ground (12%) and number of fishers (10%), were all positively related to the biomass of fish caught and could explain most of the variation on it. The environmental factor of the fishing habitat accounted for 10% of the variation in fish caught. These results, when applied to management scenarios, indicated that some combinations of the management measures, such as selected lakes as no-take areas, restrictions on the use of gillnets (especially during the high-water season) and individual quotas larger than fishers' usual catches, would most likely have less impact on fishers' income. The proposed scenarios help to identify feasible management options, which could promote the conservation of fish, potentially achieving higher fishers' compliance.

1. Introduction

Fisheries use diversified gear, target different species and perform at different scales, each of which requiring specific management measures (van Oostenbrugge et al., 2002; Castilla and Defeo, 2005; Anticamara et al., 2011). Typical management measures tend to disregard small-scale fisheries characteristics and focus on the conservation of stocks through effort limitation, gear control, seasonal fishing closures and no-take areas (Gewin, 2004; MacCord et al., 2007; Muallil et al., 2011). However, many fishery managers lack information about fishing effort (Anticamara et al., 2011), a case most common in small-scale fisheries (Salas and Gaertner, 2004; Hallwass et al., 2011).

Management plans aimed at regulating the use of natural resources, such as in fisheries, should consider the interaction between social and economic factors (Cinner and Aswani, 2007; Hilborn, 2007; McClanahan et al., 2009), as it has already been demonstrated that these are key factors in management success (Salas and Gaertner, 2004). Fishers' behaviors, which are motivated

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by a number of drivers including economic incentives (Begossi et al., 2011; Kawata, 2012), may be a major source of uncertainty regarding the outcome of fisheries management (Fulton et al., 2011). Although fisheries management could provide long-term economic benefits to fishers through the recovery of fish stocks, fishers usually behave in ways to maximize short-term gains and may not be willing to, or simply cannot, postpone economic benefits (Cinner and Aswani, 2007; Begossi et al., 2011; Kawata, 2012). Therefore, fisheries management should be sensitive to fishers' immediate economic and social needs, and by knowing the factors that most affect fishers' income it is possible to better evaluate the impact, effectiveness and acceptance by fishers of current and planned management measures (Johnston et al., 2012).

Inland fisheries in the Brazilian Amazon are mostly small-scale (Bayley and Petrere, 1989) and are usually performed with small canoes exploring a wide variety of species and habitats, using multiple types of gear and landing catches sparsely in several small ports (Cerdeira et al., 2000; Hallwass et al., 2011). These characteristics, combined with logistical restrictions, make difficult the monitoring and enforcement of management rules. Although we lack long-term fisheries statistics for most of the Amazonian regions, there is evidence that fishing effort has increased and that some preferred commercial fish species have decreased in abundance and size; also, some fishes have been caught at sizes smaller than the first maturity (Petrere et al., 2004; Castello et al., 2011), which indicates the need for fisheries management. In addition to overfishing, hydroelectric dams in large Amazonian rivers may also decrease fish production and threaten fish stocks, causing local extinction of commercial fish species (Hallwass et al., 2013). The fisheries management rules in the Brazilian Amazon tend to be imposed top-down from the government. These rules, such as a closed season with individual quotas, a prohibition of specific fishing gear and a minimum size for some fish species, are too general and usually disregard the heterogeneity and particularities of the all the considered fishing communities (Castello et al., 2013). Some recent initiatives of participatory management (co-management) adopted locally devised management rules and have better considered fishers' concerns (Almeida et al., 2009; Castello et al., 2009; Lopes et al., 2011). Nevertheless, most of the current fisheries management rules imposed from the government in the Brazilian Amazon have not been based on fishers' behavior, and the efficacy of these regulations has not been sufficiently monitored. Although there is limited evidence that lakes closed to fishing (with fishers' consent) and fishing quotas of highly valued fish species have increased the abundance of commercial fishes (Almeida et al., 2009; Castello et al., 2009), some management measures, such as gear restrictions or closed seasons, have not been evaluated. Thus few studies exist that explicitly link fisheries management measures, fishing rewards and fishers' behavior in the Brazilian Amazon, as management measures have usually been evaluated on the basis of the status of fish stocks (Petrere et al., 2004).

We analyzed the relative effect of fishers' behavior (effort and fishing gear used) and environmental variables (season and habitat) on immediate rewards (biomass of fish caught) of small-scale fishers in the Lower Tocantins River, Brazilian Amazon. Based on these results, we provide practical suggestions to managers about fishers' potential compliance using scenarios based on combinations of management measures.

2. Methods

2.1. Study area

The Tocantins River is a clear water river located on the eastern portion of the Brazilian Amazon Basin. In 1984, the construction of the Tucuruí dam and the Hydroelectric Power Plant flooded an area of 2830 km^2, possibly effecting the livelihood of people living downstream from the dam (Ribeiro et al., 1995; Hallwass et al., 2013).

We studied small-scale fishers from five rural fishing villages (Açaizal, Calados, Ituquara, Joana Peres and Umarizal) in the Lower Tocantins River (municipality of Baião, Pará State), approximately 100 km downstream from the Tucuruí dam (Fig. 1). These villages are spread through an area encompassing different habitats (lakes, tributaries, main river channel and flooded forest), and some fishers there are also dedicated to small-scale agriculture. We chose these villages because they are the main fishing villages in the area (see Hallwass et al., 2011 for more information).

2.2. Sampling of fish landings

We sampled 572 fish landings from all canoes that arrived during the day (7:30 to 18:00, approximately) for 11 days in the flooded season (December 2006, $n = 50$ landings), 26 days in the high-water season (March 2007 and February 2008, $n = 260$), 14 days in the receding-water (June 2007, $n = 125$), and 16 days during the low-water season (August and September 2007, $n = 137$), for two to five consecutive days in each village and season (total of 67 sampling days). For each fish landing, we recorded the biomass (kg) of each fish species caught. Fish were identified by their local

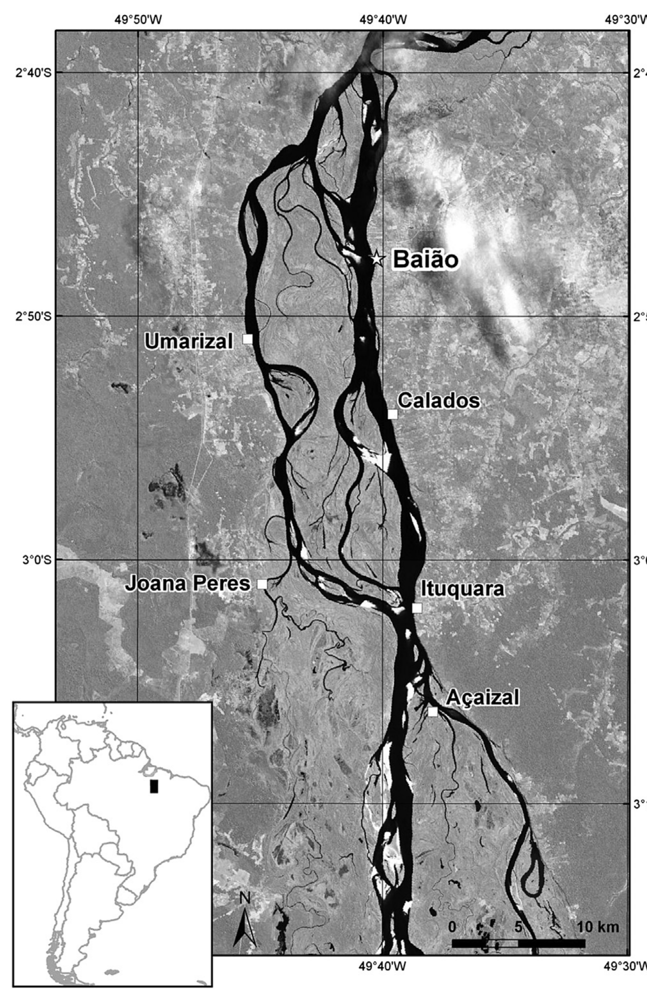

Fig. 1. Map showing the location of the five studied fishing villages (Açaizal, Calados, Ituquara, Joana Peres and Umarizal) and Baião city in the Lower Tocantins River, Brazilian Amazon.

names, which sometimes corresponded to groups of biological species (Hallwass et al., 2011). We also interviewed fishers about the gear they used, the fishing spot and habitats visited, the total duration of their fishing trip, the distance (time spent traveling) from home/port to the fishing spot and crew size.

2.3. The fisheries' economic yield and productivity

We aimed to analyze the influence of management measures on fishing rewards, but unfortunately, we could not directly measure fishers' monetary income earned by each fishing trip. Therefore, we calculated the financial revenue (in US$) per fishing trip using the average sale price per species (or group of species) landed and sold in 2007 at the public Market of Baião municipality (Hallwass et al., 2011), the nearest town to the studied fishing villages. The mean sales price for all species was $1.14/kg: cheaper species, such as traíra (*Hoplias malabaricus*), cost $0.47/kg on average, and the more expensive species, such as dourada (*Brachyplatystoma rousseauxii*), cost $2.31/kg. We made a linear regression analysis that showed that the money obtained from selling the fish (ln US$) at the market was positively and significantly related to the biomass of fish caught (ln kg fish) per fishing trip ($r^2 = 0.97$, $F = 18940$, $n = 572$, $p < 0.0001$). Therefore, we can argue that, in the studied region, 'fish is money': the biomass of fish caught (the variable that we analyzed in this study) can be considered a valid proxy of financial revenue of fishing trips. We transformed the data into natural logarithms (ln) to homogenize the residue variance.

We also ran a Shapiro–Wilk normality test (W) to analyze the distribution of fishing productivity data (biomass of fish caught per fishing trip). The frequency of the biomass of fish caught per fishing trip was plotted to verify which measure of fishing productivity (mean or median) would better show the central tendency of the sample.

2.4. Influences of behavioral and environmental factors on fishing reward

We used General Linear Models (GLM) to analyze how total fish biomass (ln kg, a proxy for fishing reward) per fishing trip was affected by eight independent variables (continuous variables were transformed in ln): 1) number of fishers in the crew; 2) travel time to the fishing spot (minutes); 3) total duration of the fishing trip (minutes), excluding travel time; 4) village where the fishing trip was sampled; 5) hydrological season; 6) habitat; 7) gear; and 8) type of canoe (paddled or motorized) (Table 1). We did not observe any multicollinearity effect among the independent variables (all the correlations <0.35). We ran two GLM models, one that considers all the fish landings from all types of canoes and another for fish landings from paddled canoes, which represented most of the fishing trips ($n = 462$ or 80%).

We ran two Kruskal–Wallis (H) analyses, with an a posteriori Dunn test, to compare the median values of the Catch per Unit of Effort (CPUE, kg/fisher/hour) and the total fish biomass caught per fishing trip for the independent variables that were significant in the GLM and that explained at least 10% of the variance in the biomass of fish caught (Table 2). We used both CPUE and total fish biomass per trip because these variables provided complementary ecological and managerial information. Total biomass per trip can indicate where (habitat and village) and how (fishing gear) fishers catch more fish, while the CPUE represents the fisher's productivity along a certain period of time, considering the fishing effort variables analyzed in the GLM (number of fishers and fishing time, in this case including travel time). This information was used to elaborate the various management scenarios.

Finally, to verify whether the frequency of trips varied according to the gear used and seasonally, a chi-square test for heterogeneity of proportions for fishing trips with paddled canoes were performed. All the analyses were performed using R software (R Development Core Team, 2009).

2.5. Management scenarios

We proposed fisheries management scenarios based on some management measures that are already in place in the studied region and on the environmental and behavioral factors that influenced most of the fish catches, according to the GLM analyses. The official fisheries management regulations issued by the Brazilian environmental agency are: a) beach seines of any type and gillnets with mesh sizes smaller than 70 mm are forbidden on continental waters (Normative Instruction $n°$ 43, July 23rd, 2004); b) a closed period (locally called *defeso*), occurring annually during the high-water season, allowing the catch of 5 kg plus 1 individual fish per fisher, forbidding fisheries in marginal lakes and allowing only fishing performed with hook and line (Normative Instruction $n°$ 46, October 27th, 2005). We also based our recommendations on common management measures applied to small-scale fisheries worldwide, such as spatial, temporal, gear and catch restrictions (Cinner and Aswani, 2007).

The outcome of each scenario predicted the relative loss in total catch resulting from these management restrictions. The potential impact of a management measure on total catch was estimated by excluding those fishing trips that would not have been allowed by

Table 1
Description of the variables used in the General Linear Model (GLM) (Table 2), for the fish landings ($n = 572$) sampled in the Lower Tocantins River, Brazilian Amazon.

Variables	Factor levels	Type of fishing influence
Kg per trip	Continuous variable: biomass of fish caught per fishing trip	Dependent variable
Number of fishers	Continuous variable: number of fishers in the crew who participate in the fishing trip	Behavioral: decision about amount of fishers that participate on fishing; related to fishing effort
Community	Açaizal, Calados, Ituquara, Joana Peres and Umarizal	Socio-environmental: five communities sampled, which can differ in some aspects, such as proximity of fishing spot, economic activities available, and specific management initiatives
Season	Flooding, high-water, receding-water and low-water	Environmental: four distinct hydrological seasons related to level of water in the river
Distance	Continuous variable: travel time from community to the fishing spot	Behavioral: fisher's decision on how long to travel to a fishing spot; related to fishing effort
Fishing time	Continuous variable: total duration of the fishing trip, excluding travel time	Behavioral: fisher's decision on how much time to spend fishing; related to fishing effort
Habitat	Lake, backwater, Tocantins River, tributary and floodplain	Environmental: habitat where fishing was performed
Gear	Hook and line, harpoon and gillnet	Behavioral: fisher's decision on the type of gear used in fishing
Canoe	Paddled or motorized canoe	Socioeconomic: type of canoe owned is related to the financial position of the fisher

Table 2
Variables used and results of the General Linear Model (GLM) considering fish catch biomass (ln kg) per fishing trip ($n = 572$) as the dependent variable, for the fish landings sampled in the Lower Tocantins River, Brazilian Amazon.

Independent variables[a]	Factor	Degrees of freedom	Sum of squares	% of the variation explained	Average sum of squares	*F*	*P*
ln number of fishers	Continuous	1	14.3	10.2	14.3	23.4	<0.001
Community	Categorical	4	8.4	6.0	2.1	3.4	0.008
Season	Categorical	3	10.7	7.7	3.6	5.9	<0.001
ln distance (min)	Continuous	1	16.6	11.9	16.6	27.3	<0.001
ln fishing time (min)	Continuous	1	59.4	42.4	59.4	97.6	<0.001
Habitat	Categorical	4	13.6	9.7	3.4	5.6	<0.001
Gear	Categorical	2	6.0	4.3	3.0	4.9	0.007
Canoe	Categorical	1	11.2	8.0	11.2	18.4	<0.001
Residues		555	337.9		0.6		

[a] These independent variables are described in the Table 1.

that management measure. For example, if a measure includes the total closure of lakes in the high-water season, we subtracted all fishing trips performed in lakes in this season from the total fish caught. To avoid over- or underestimating losses due to differences in sampling effort among seasons, we weighted the excluded fishing trips by sampling days.

We thus estimated the degree of fishers' compliance with each management scenario as being inversely proportional to catch decline (the lower the loss, the higher the compliance). We assumed high compliance if losses were less than 20%, moderate compliance if losses were between 21 and 40% and low compliance if losses were above 40% of the total catch. Although arbitrary, these percentages are supported by a study performed in Tanzania where fishers stated that they would not change their fishing effort even if there were a decline of approximately 20% in their catches (Cinner et al., 2011).

3. Results

3.1. Measures of fishing productivity

The median of the biomass of fish caught was 5.3 kg per fishing trip (quartiles 25% and 75%: 2.4 and 11.6), while the mean of the biomass of fish caught was 11.1 kg per fishing trip (±16.5 kg per fishing trip). A histogram of the non-normal distribution ($W = 0.7$, $p < 0.0001$) and the fishing productivity (Fig. 2) indicated that the median better represented the usual or average biomass of fish caught per fishing trip in the Lower Tocantins River, and this value was considered when proposing management scenarios.

3.2. Which factors affected fishing rewards?

The eight behavioral and environmental factors were significant in the GLM analysis and explained 43% of the variance of the biomass of fish caught per fishing trip (Table 2, $r^2 = 0.43$, $F_{17,555} = 26.2$, $p < 0.001$). Three behavioral factors related to fishing effort influenced most the biomass of fish caught: duration of a fishing trip (explained 42.4% of the total variance), distance traveled to the fishing spot (11.9%) and crew size (10.2%) (Table 2). Habitat was the main environmental variable that influenced the biomass of fish caught (9.7%, Table 2): fishers caught more fish in lakes compared to other habitats ($H = 57.6$, $p < 0.0001$, Fig. 3). However, the CPUE (kg/fisher/hour) did not differ among habitats ($H = 9.3$, $p = 0.05$). All other variables accounted for less than 9% of the variance in the biomass of fish caught.

The second model (using only paddled canoes) was also significant ($r^2 = 0.27$, $F_{16,446} = 11.9$, $p < 0.001$) (Appendix A), and the behavioral factors related to fishing effort were again those that

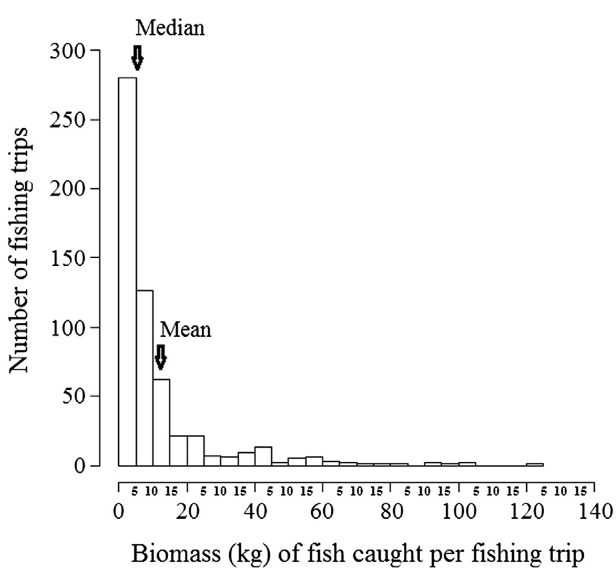

Fig. 2. Frequency distribution of the biomass (kg) of fish caught per fishing trip calculated based on 572 fishing trips sampled in five fishing villages in the Lower Tocantins River, Brazilian Amazon. Values of median and mean are indicated in the figure.

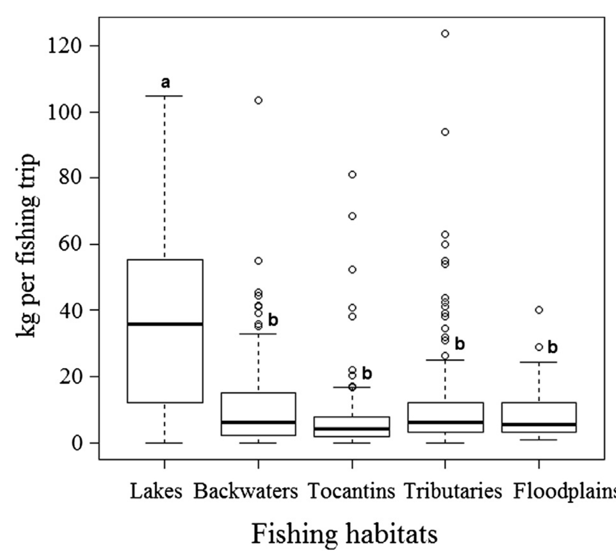

Fig. 3. Comparison among the habitats exploited by fishers in the Lower Tocantins River (Brazilian Amazon) ($n = 572$ fishing trips), considering the biomass of fish caught (kg) per fishing trip. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%), Dunn test: $a > b$, $p < 0.05$. Circles are outliers.

influenced most the biomass of fish caught: time spent fishing (40.8%), distance traveled to the fishing spot (16.5%) and crew size (10.2%). However, when considering only paddled canoes, season was the most important environmental factor influencing fish catches (14.4%), while habitat was not significant (Appendix A).

Fishers using paddled canoes caught more fish in the high-water season than in the low-water season ($H = 9.8$, $p = 0.02$) and their CPUE was the lowest in the low-water season ($H = 23.8$, $p < 0.0001$) (Fig. 4a, b). Although the frequency of gear used by fishers with paddled varied seasonally in general ($\chi^2 = 283.4$, $gl = 2$, $p < 0.0001$), the frequency in their use of gillnets, the most used gear ($n = 261$ of 462 fishing landings with paddled canoes), did not differ among seasons ($\chi^2 = 3.8$, $gl = 3$, $p = 0.28$). Similarly, the frequency in use of harpoons, the least used gear ($n = 23$), did not differ among seasons ($\chi^2 = 7.6$, $gl = 3$, $p = 0.05$). Compared with the low-water season, however, hook and line fishing ($n = 178$) was more often used in the high-water ($n = 93$) and flooding ($n = 23$) seasons ($\chi^2 = 9.1$, $gl = 3$, $p = 0.02$), as was catching more fish ($H = 25.3$, $p < 0.0001$) and showing a higher CPUE ($H = 21.1$, $p = 0.0001$) per fishing trip in the high-water season (Fig. 5a, b).

3.3. Management scenarios

The results of the GLM analyses either based on all fish landings or on fish landings of paddled canoes, indicated that behavioral factors related to fishing effort (time spent, distance and crew size), in addition to environmental factors (habitat and season), influenced most the fish catches (Table 2). Based on these results, we estimated potential fishers' responses to alternative scenarios combining management measures. The scenarios included no-take areas (in floodplain lakes – the most productive habitats) and fishing quotas (due to the strong influence of fishing effort on catches), as well as restrictions on fishing gears and closed seasons, which have been commonly applied as governmental management

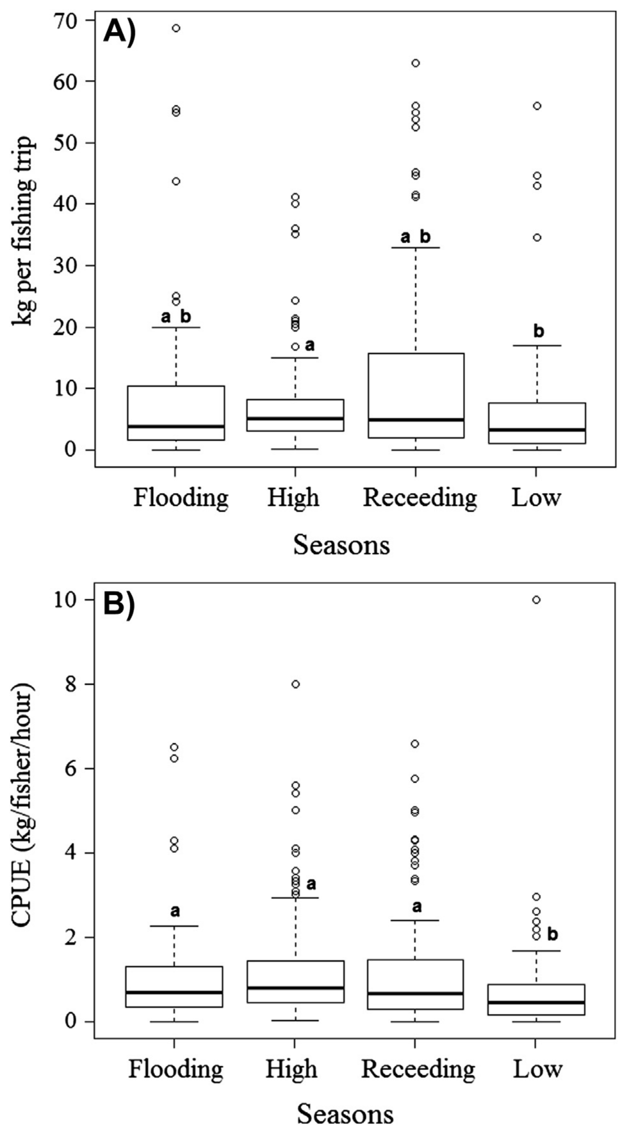

Fig. 4. Comparison of fishing trips that used paddled canoe ($n = 462$) among the four hydrological seasons in the Lower Tocantins River, Brazilian Amazon, considering: A) biomass (kg) of fish caught; and B) CPUE (kg/fisher/hour) per fishing trip. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%), Dunn test: $a > b$, $p < 0.05$. Circles are outliers.

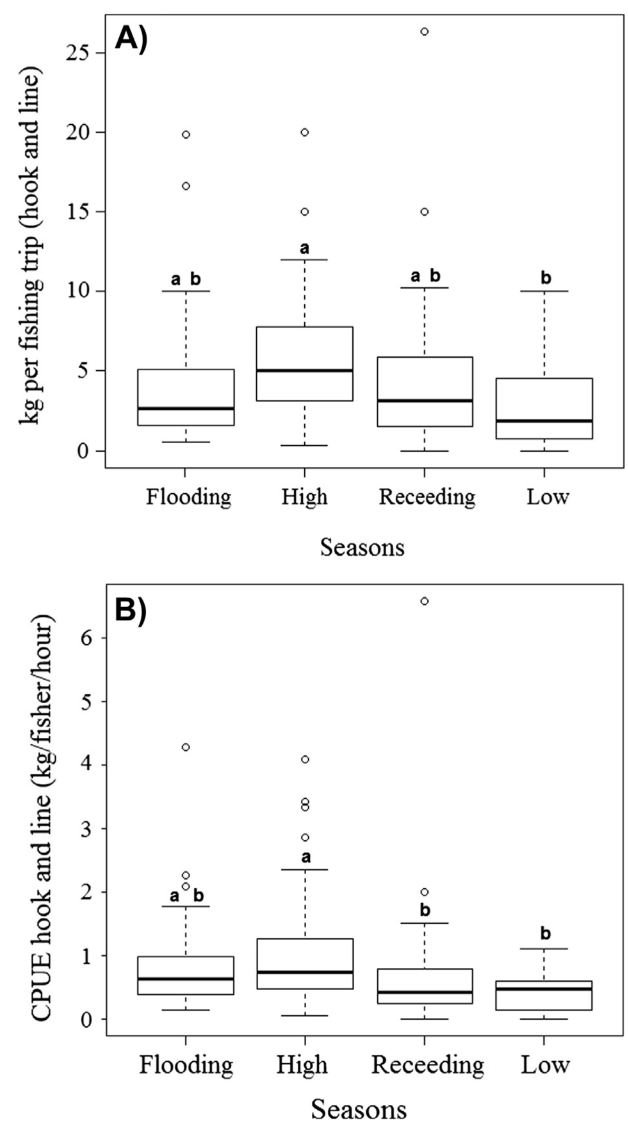

Fig. 5. Comparison of fishing trips that used paddled canoe and only hook and line ($n = 178$) among the four hydrological seasons in the Lower Tocantins River, Brazilian Amazon, considering: A) biomass (kg) of fish caught; and B) CPUE (kg/fisher/hour) per fishing trip. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%), Dunn test: $a > b$, $p < 0.05$. Circles are outliers.

measures in Brazil (Table 3). The scenarios proposed with only one management measure would have moderate (floodplain lakes and seasonal closures) to low (permanent fishing quotas and gillnets banning) acceptance by fishers (Table 3). The combination of management measures, such as seasonal banning of gillnets, seasonal fishing quotas, using both restrictions during the high-water season or the combining these three measures (fishing gear, quota and season), as well as establishing no-take areas in selected lakes (all the time or during the high-water season), was estimated to have high acceptance and compliance by fishers (Table 3).

4. Discussion

4.1. Fishing rewards and productivity

The non-normal and skewed distribution toward small catches (less than 6 kg of fish per fishing trip) indicated that the median would be more appropriate as a measure of the average fishing productivity in the Lower Tocantins River, as observed in other tropical small-scale fisheries (Daw et al., 2011). Therefore, estimates and comparisons of fishers' economic yields based on mean catch might overestimate average fishers' income; thus, we suggest that researchers check the fisheries data distribution and choose the better metric (mean or median) for determining fisheries productivity.

The fishing reward (fish biomass) of small-scale fishers in the Lower Tocantins River was mainly affected by variables related to fishers' behavior and fishing effort: time spent fishing, traveling time to the fishing spot and crew size. Fishing gear and effort (e.g., fleet size and capacity, engine power and amount of ice) are also positively related to the amount of fish caught in other commercial fisheries (Maynou et al., 2003), including those in the Brazilian Amazon (Almeida et al., 2003; Isaac et al., 2008). Fishing effort, which directly affects fish catches, is a daily behavioral decision made by fishers that should thus be included in management plans more suitable to local realities, to enhance compliance with proposed regulations (Fulton et al., 2011).

4.2. Fisheries management scenarios

Increases in the fishing effort may initially lead to larger catches, which may increase the risks of overexploitation in the Lower Tocantins River, as well as in other Amazonian fisheries. However, any management measure that restricts fishing efforts can raise opposition by fishers, leading to low compliance (Table 3). Here, we discuss the possible effectiveness of the proposed scenarios, considering that even those management measures that are already in place (e.g., fishing restrictions during high-water season) have been loosely enforced and that fishers' compliance has not been evaluated.

A potential limitation of our analyses, and consequently of the management scenarios proposed, is the limited sample: 67 days, which would correspond to nearly 25% of effective fishing days (269 days), considering that fishers do not fish, or at least reduce fishing activity, during weekends. Nevertheless, we consider that this would be a reasonable sample, as we obtained 572 fish

Table 3
Potential fishers' response (level of compliance) to proposed scenarios (combinations of management measures) in the Lower Tocantins River region (Brazilian Amazon), considering available data on fishing rewards.

Fishing restrictions[a]				Fishers' compliance[d]	Outcomes and observations	% reduction in fishers' total fish production[e] (6378.8 kg)
Quotas	Fishing gear	No-take areas[b]	Season[c]			
None	None	All lakes	None	Moderate	Fishers caught more fish biomass in lakes compared to other habitats	21.5%
None	None	Selected lakes	None	High	Fishing effort could be displaced and increase in other habitats where fishing is permitted	10.8%[f]
Individual (5 kg of fish)	Gillnets	All lakes	High-water	High	Fishing effort is reduced, but fishers may use spare time to other economic activities	17.4%
None	Gillnets	None	High-water	High	Fishers can use hand lines with similar efficiency (CPUE) during this season, but effort is reduced and some fish may no longer be caught.	14.6%
Individual (5 kg of fish)	None	None	High-water	High	Fishers usually catch less than this suggested quota in the high-water season. Besides, registered fishers receive a wage from the Brazilian government during the high-water season due to the closed period	9.3%
None	None	All lakes	High-water	High	Few fishers fished in lakes during the high-water season	0.1%
None	None	None	High-water	Moderate	Fishing effort would be cut down during three months, reducing fishing yield and income	20.9%
Individual (5 kg of fish)	None	None	None	Low	Fishing effort is reduced. Although fishers may use spare time to perform other economic activities, they lose the opportunity of obtaining sporadic large catches.	41.4%
None	Gillnets	None	None	Low	Gillnets are the most common fishing gear and may be important to catch some fish in some habitats (e.g. lakes) during the low-water season	79.8%

[a] When more than one restriction is imposed in a given measure, we suppose they are combined: for example, in the third measure, fishers cannot fish in lakes with any fishing gear, they cannot use gillnets to fish anywhere nor can they catch more than 5 kg of fish during the high-water season, but they can use hook and line to fish in other habitats during this season, and use gillnets to fish in lakes during other seasons.

[b] Protected areas, where all forms of fishing are banned.

[c] Most of the current freshwater fishing regulations in Brazil focus on the high-water season, when many fish species are reproducing and young fish are growing in the floodplains. In the Lower Tocantins River, this season occurs from November to February (including the raising-water period).

[d] High (losses up to 20%): many fishers would possibly accept the proposed measure with little opposition, and there would be few motivations to break regulations; Moderate (losses between 21 and 40%): some fishers would accept the measure, while others would disagree, some fishers may be motivated to break regulations; Low (losses above 40%): many or most of the fishers would disagree with the proposed measure, there would be strong motivations to break regulations.

[e] Proportional amount that would be reduced from total catches if the corresponding management measure was effectively enforced and followed by fishers, which was calculated by subtracting from total catches those fishing trips that disagree with the respective measures. This calculation was weighed by day, as fishing trips were sampled for different number of days in each season. For example, in the high-water season we sampled landings along 26 days. The total production of this season was then divided by 26, while the total productivity was divided by 67 (total sampling days in all seasons). This average productivity per day allowed us to estimate more accurately how much fishers would lose with a specific management measure.

[f] Calculated by considering that 50% of the lakes would be set as no-take areas, thus this value corresponds to half of the total fish biomass caught in lakes.

landings, which provided sufficient data for the statistical analyses and included the necessary seasonal variation. Furthermore, this dataset is comparable to those of other studies on small-scale fisheries (Silvano and Begossi, 2001; MacCord et al., 2007) and should reveal at least the major trends of the biomass of fish caught. A more representative sample of fish landings could be achieved through other methods, such as interviews with fishers who mention their previous catches (Almeida et al., 2009; Castello et al., 2013) or through participatory research in which fishers record their catches themselves (Ticheler et al., 1998). However, in this survey, fish landing data were recorded by trained researchers, and logistic restrictions limited the sampling effort. The management proposals could be updated and reformulated if a more representative sample of fish landings was available, but unfortunately sampling of fish landings from scattered small-scale fishing villages are scarce in the Brazilian Amazon.

4.2.1. No-take areas in productive habitats

Although lakes were the most productive habitat (Fig. 3), only 6.5% of the 572 fish landings occurred there, possibly because most of the lakes are relatively far from the communities, demanding a higher investment of time or crew size, which could explain why the CPUE did not differ among habitats. Therefore, Lower Tocantins River fishers may show moderate acceptance of management measures, establishing all (or most) lakes as no-take areas, but fishers may show high compliance with no-take areas in selected lakes, such as the more distant ones or those that could be more easily enforced (Table 3). Despite their high fishing productivity, fish caught in lakes accounted for only 21.5% of total fish production and was not the main source of the fishers' income (Table 3). Indeed, some fishing communities have already closed selected lakes to fishing in the Lower Tocantins River (Lopes et al., 2011), and some of these no-take lakes have showed increased fish catches (CPUE) and fish abundance (Silvano et al., 2009a). No-take lakes in the Tocantins River and other large tropical floodplain rivers could also help protect biodiversity and, more specifically, fish stocks, which may disperse beyond the protected lakes and provide spill-over effects observed in marine protected areas (Gell and Roberts, 2003). Such spillover effects in Amazonian floodplains may occur during the high-water season, when rivers and lakes are connected (Fernandes, 1997; Silvano et al., 2009b).

4.2.2. Closed fishing season

Fishing productivity in the Brazilian Amazon is usually higher during the low-water season, when fish density increases in shrinking water bodies (Cerdeira et al., 2000; MacCord et al., 2007). However, those fishers with paddled canoes caught less fish per trip and had a lower CPUE during the low-water season in the Lower Tocantins River. This unusual pattern could be because fishing productivity is increased in the high-water season, when fishers used hook-based gear more often to catch pescada (*Plagioscion squamosissimus*). Hook-based gear is more selective (Wiyono et al., 2006) and may be less affected by fish density than gillnets (Silvano and Begossi, 2001).

Reducing fishing effort during the high-water season could benefit fish stocks in the Lower Tocantins River because several fish species reproduce at that time, especially in floodplain lakes (Silvano et al., 2009a). Fishers may accept fishing effort restrictions during the high-water season, especially if combined with lakes as no-take areas or banning of gillnets, but a total fishing closure in this season would negatively affect the productive hook and line fishery, having moderate acceptance by fishers (Table 3). However, as argued by Fulton et al. (2011), fishers may show unintended responses to management measures, for example an increased fishing effort with hook-based gear during the high-water season directed mostly toward a single fish species (*P. squamosissimus*).

Although the studied fishers in the Lower Tocantins River may comply with management rules that restrict gillnets during the high-water season, when fishers use mostly hook-based gear, a permanent ban of gillnets would result in low compliance by the fishers due to the large reduction in total catches and consequent financial loss (Table 3).

4.2.3. Fishing quotas

A permanent fishing quota of 5 kg would considerably reduce total fish production in the Lower Tocantins River (Table 3). Nevertheless, most of the studied fishers used paddled canoes and caught less than 5 kg of fish per fishing trip (Fig. 2) as observed in 69% of the fishing trips performed with paddled canoe and 37% of the fishing trips performed with motorized canoes. Therefore, the median of the fishing productivity of fishers with paddled canoes that we observed in the Lower Tocantins River (3.7 kg/fisher/day) was below the suggested quota (5 kg/fisher/day), especially during the high-water season, when this quota is imposed by law. Additionally, the median of the amount of fish caught was 3.9 kg/fisher/day, indicating that the proposed quota could be well accepted by most of the studied fishers, especially if established during the high-water season. Fishing quotas could be even extended for longer periods if fishers could use their spare time after reaching the quota to perform other economic activities, thus reducing fishing effort and consequently the pressure on fish stocks (Cinner and Bodin, 2010; Muallil et al., 2011). The allocation of fishers' time to other economic activities, such as agriculture and animal husbandry, is common among Amazonian small-scale fishers (Bayley and Petrere, 1989; Cerdeira et al., 2000; McGrath et al., 2008), and has been considered a positive outcome of fisheries management (Almeida et al., 2009).

4.3. Management scenarios of small-scale fisheries

Few studies have addressed management proposals based on empirical data from research on fish landings in the Brazilian small-scale fisheries, either inland or coastal. Fisheries management measures in Brazil have caused conflicts with local fishers and mostly lack scientific validation (Begossi et al., 2011). Castello et al. (2011) observed a high fishing pressure directed to some preferred fish species in the Brazilian Amazon and suggested a diversification of target fish in addition to better enforcing of fish size limits. This analysis of a temporal data series of fish landings from eight fishing villages in the Lower Amazon River indicates that fishing characteristics are stable temporally but are heterogeneous spatially (among fishing villages) and that this heterogeneity should be taken into consideration in management systems, which have typically been top-down and too general (Castello et al., 2013). Nevertheless, these previous surveys have not detailed management measures and their outcomes as we have done here, by proposing scenarios of potential fishers' compliance.

Devising scenarios is valid and applicable to other small-scale fisheries around the world, as management measures similar to those suggested in this study have been widely adopted (Gewin, 2004; Cinner and Aswani, 2007). Therefore, the fishers' compliance estimates proposed in this study could be similar in other areas, where similar scenarios could a) indicate which combinations of fishing gear and season would have less impact on Indonesian small-scale coastal fisheries (Wiyono et al., 2006); b) help in the analysis of trade-offs between the restrictions of fishing gear with high ecological impacts and losses of fishers' income in Mexico (Shester and Micheli, 2011); and c) suggest combinations of fishing gear, habitat and season with higher costs and lower reward to fishers in the Lower Mekong Basin (Cambodia) (Navy and Bhattarai, 2009).

A major limitation of using empirical support to build management scenarios is the need for detailed fishing data, which are not available for most tropical small-scale fisheries (Salas and Gaertner, 2004; Bene et al., 2009). An alternative to using quantitative data could be to use data from interviews with fishers about their fish catches (Cinner et al., 2011; Hallwass et al., 2013). For example, Cinner et al. (2011) analyzed the Tanzanian fishers' strategies regarding the decline in catches and concluded that fishers with diversification options, such as gear and economic activities, could afford to reduce their fishing effort. This finding agrees with our proposed scenarios in the Lower Tocantins River, where combinations of management measures have a smaller impact on fishers' income because they guarantee alternative fishing options (Table 3). Therefore, those small-scale fisheries with higher diversity of gear, habitats, target species and supplementary economic activities (van Oostenbrugge et al., 2002; Wiyono et al., 2006; Bene et al., 2009; Muallil et al., 2011) could accommodate a larger variety of management combinations, which may cause lower losses in fishers' income.

5. Conclusions

Here, we identified those combinations of management measures that would possibly have the smallest impact on fishers' immediate income. The mixing of different management measures (space, time and effort based) could minimize losses and be better accepted by the studied small-scale fishers, who use several types of fishing techniques, habitats and gear. The proposed scenarios could work either for the classical top-down fashion (i.e., imposed by the Brazilian government) or for the emerging co-management systems in the Brazilian Amazon, including the studied region (Lopes et al., 2011). These scenarios could also be reformulated when more fishing data are available, thus being the first step of an adaptive management approach. If some of the proposed combinations of management measures are implemented, future studies could test the validity of the proposed scenarios by evaluating management outcomes and fishers' compliance. Therefore, the management scenarios proposed here, which are based on empirical data, may be a valuable tool for estimating the potential acceptance and compliance of small-scale fishers with fisheries management measures in Brazil and elsewhere.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2013.05.037.

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