Fisheries Research 110 (2011) 356–364

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Resource sustainability in small-scale fisheries in the Lower Amazon floodplains

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ARTICLE INFO

Article history:
Received 8 October 2010
Received in revised form 20 April 2011
Accepted 5 May 2011

Keywords:
Community
Floodplain
Management
Multispecies
Overfishing
Sigmoid model

ABSTRACT

Resource assessments of small-scale fisheries in the Amazon are rare, making it difficult to improve fisheries management. This study assessed the sustainability of small-scale fishery resources in the Lower Amazon region using data from over 20,000 interviews collected in three floodplain fishing communities between 1992 and 2007. The data were analyzed with respect to theoretical maxima of catches and historical trends of (i) catch per unit effort (CPUE), (ii) species composition of the catch, and (iii) mean body length of the most-caught species. The most important results were: First, observed catches have been about 54–58% of theoretical maxima in all communities. Second, CPUE has remained stable over time in all communities. Third, there has been no substitution of fish species in the catch. Fourth, mean body lengths of five of the nine most-caught species were below length-at-first-reproduction, and the body lengths of some have increased overtime while that of others have remained stable or decreased. Overall, fishery resources in the region appear to be moderately exploited, with some key species showing typical signs of overexploitation. This would indicate that the principal threat to the sustainability of fishery resources is excessive concentration of fishing effort on a few target species combined with unsustainable fishing practices. Management and research recommendations are proposed.

1. Introduction

Small-scale fisheries employ most fishers of the world and produce between a third and half of the global catch, but they remain poorly regulated and poorly studied quantitatively (Berkes et al., 2001; Castello et al., 2007; Chuenpagdee and Pauly, 2008; Mahon, 1997; Pauly, 1997). The situation is the same in the Amazon where small-scale fisheries produce about 60% of the total catch (Bayley and Petrere, 1989). Most of the few existing assessments of the status of Amazon fishery resources have focused on a few key species and were done in different regions. Such assessments have found overexploitation of pirarucu (*Arapaima* spp.), tambaqui (*Collossoma macropomun*), acará-disco (*Symphysodum aequifasciatus*), surubim (*Pseudoplatystoma tigrinum*), filhote (*Brachyplatystoma filamentosum*), piramutaba (*Brachyplatystoma vailanti*), and likely overexploitation of dourada (*Brachyplatytoma rousseauxii*) (Alonso and Pirker, 2005; Costa et al., 1999; Crampton, 1999; Isaac and Ruffino, 1996, 1999; Petrere et al., 2004; Queiroz and Sardinha, 1999). These studies are useful, but additional studies are needed, because a key characteristic of Amazonian fisheries is that they are multispecies, simultaneously involving various fish species.

Amazonian fisheries have historically been characterized by the overexploitation and subsequent extirpation of generally large-bodied, high-value fishery resources. This process started with the manatees (*Trichechus inunguis*) and Giant River turtles (*Podocnemis expansa*) one century ago, and it is now occurring with the pirarucu and tambaqui (Crampton et al., 2004; Castello and Stewart, 2010; Sousa and Freitas, 2011). Consequently, management of Amazon fisheries in Brazil has been increasingly based on the sharing of responsibility between fishing communities and government agencies (McGrath et al., 1993, 2008). Previous studies have shown that this 'co-management' has promoted recoveries of overexploited pirarucu populations and increases of multispecies catch per unit of effort (CPUE; Almeida et al., 2009; Castello et al., 2009). Aside from a few other studies, however, there are no quantitative assessments of the effectiveness of co-management and more generally of the sustainability of multispecies fishery resources exploited by subsistence, small-scale fisheries in the Amazon.

Assessing the impacts of fishing on Amazonian fished resources is difficult, however, because of data scarcity and our limited understanding of the dynamics of tropical multispecies fisheries (Chuenpagdee and Pauly, 2008; Mahon, 1997; Welcomme, 1999). Multispecies fisheries do not react to fishing pressure as regular unimodal stock-production models, which typically show increasing yields with increasing effort up to a point at which maximum yields are realized and after which increasing effort brings declining yields (Schaefer, 1954). In multispecies fisheries, catch levels

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doi:10.1016/j.fishres.2011.05.002

rise with increasing effort, then stabilize and do not decline even at very high effort levels (Laë, 1997; Lorenzen et al., 2006). Catch levels remain constant at high effort levels through the "fishing down" process—a process in which collapsed fish populations (usually large predators) are replaced with other (usually smaller) species (Welcomme, 1999). Also, CPUE, which in single-species fisheries generally shows linear and proportional declines with increasing effort, behaves non-linearly in multispecies fisheries. CPUE declines sharply in the initial phase when multispecies fisheries are exploited lightly; it remains stable or even increases to a maximum when the fisheries are exploited moderately; and it declines again when the fisheries are exploited very heavily (Lorenzen et al., 2006). Through consideration of the difficulties involved in assessing tropical multispecies fisheries, this study assessed the sustainability of fishery resources in small-scale fisheries in the Lower Amazon region using a multi-criteria approach.

2. Methods

To assess the sustainability of small-scale fishery resources in the Lower Amazon, four hypotheses were tested:

1. Observed catches are not maxima.
2. CPUE has not changed over time.
3. Species composition of the catch has not changed over time.
4. Body lengths of the five most caught species have not changed over time.

The combined strengths of this multi-criteria approach allowed for a relatively reliable assessment, as follows. The theoretical maxima of catches allow assessing the sustainability of observed yields. Historical trends in CPUE permit assessment of trends in resource biomass (e.g., Myers and Worm, 2003). Some potential biases in CPUE trend analyses (Richards and Schnute, 1986) as well as the fishing down process of multispecies fisheries can be detected via analyses of species composition of the catch (Pauly et al., 1998; Welcomme, 1999). Historical analyses of mean body length of the most fished species complement the foregoing analyses, because body lengths generally are positively related to population abundance, with small body lengths generally being correlated with overfishing (Froese, 2004).

2.1. Study area

The study area is near the city of Santarém, an important fishing ground (Isaac et al., 2004) (State of Pará, Brazil; Fig. 1). Here, as in the rest of the Amazon, fish is a major source of animal protein for local populations, which are growing rapidly and increasing their demand for fish, and therefore promoting increasing pressures over fish resources (Cerdeira et al., 1997, 2000). The main area supplying Santarém with fish protein are the floodplains of the Amazon river, called *várzea*, which are a mosaic of seasonally flooded forests, lakes, and channels that border the river channel, and that in the study area have a unimodal flood regime with a mean amplitude of six meters (Irion et al., 1997).

Fishes in the várzea have adopted three main migratory patterns (Goulding et al., 1996). 'Resident' várzea fishes, including many cichlids, spend their entire life cycle inside the várzea forests, lakes, and channels. The 'migratory characiforms' grow in the várzea, and undertake annual upstream migrations of up to several hundred kilometers in distance when they reach maturity, spawning in the river as water levels rise, and then reentering the varzea to feed during the flood season. The 'migratory catfishes' do like the migratory characiforms, with the difference that they can migrate thousands

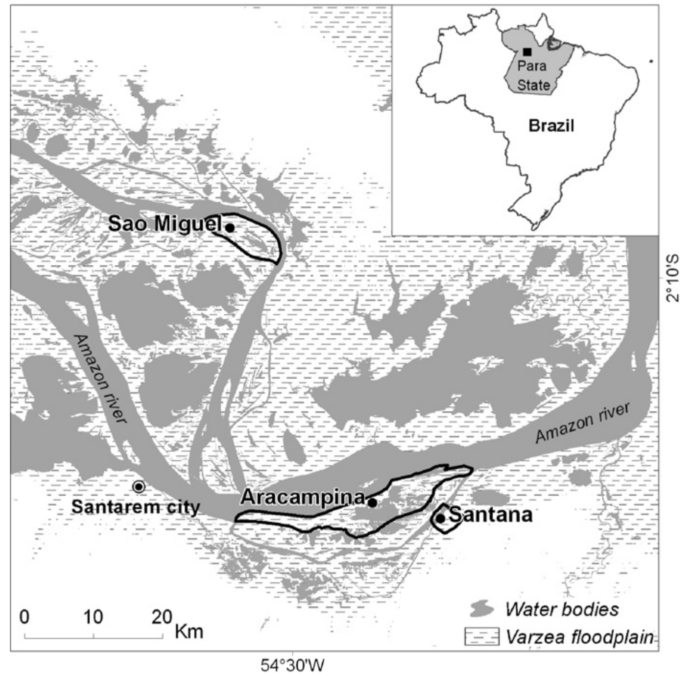

Fig. 1. The study area. Boundaries of community areas are in black, and the main Amazon river and various floodplain lakes and channels are in white. Grey areas immediately adjacent to lakes and river channels are forested or open fields of floodplains.

of kilometers upstream to spawn and use the floodplains and/or estuary area as a nursery (Barthem and Goulding, 1997).

Subsistence, small-scale fisheries in the study area generally operate as follows (following McGrath et al., 1998; Isaac et al., 2004). Fishing trips usually last a couple to a few hours long in total, are done by one or two fishers, using a small wooden canoe that is run by paddle or small outboard engine (i.e., <10 horsepower). Fishers use various types of gear, but gill nets are the most common gear, usually accounting for most of the catch, followed by castnets, long-lines, fishing poles, and harpoons. Some forty different fish species are exploited, but five account for most of the catch.

2.2. Fishing communities

We studied the sustainability of fishery resources in three typical fishing communities that are part of the Santarém municipal co-management system, which is one of the Amazon's most advanced institutional structures for fisheries management. The communities, Aracampina, Santana, and São Miguel (Fig. 1), represent a spectrum in the quality of community-based management, from limited- to well-developed. Santana is located on the uplands adjacent to the varzea, and is characterized by a high level of fishing effort and a low level of compliance with local management rules. Aracampina, located on the floodplain facing the main river channel, has a fishing territory of roughly 9039 ha, and it has a moderate level of compliance with management rules. São Miguel, located on a floodplain island of 3194 ha, has a well-developed management system with a high degree of compliance. Even though community-based, subsistence fishers fish in both floodplain habitats and main river channel, these estimates of community areas include only floodplains, which have well-delimited community boundaries, and they exclude main river channel areas, which are shared, often in conflict, by (community-based) floodplain fishers and urban-based fishers who use much larger boats and different gears.

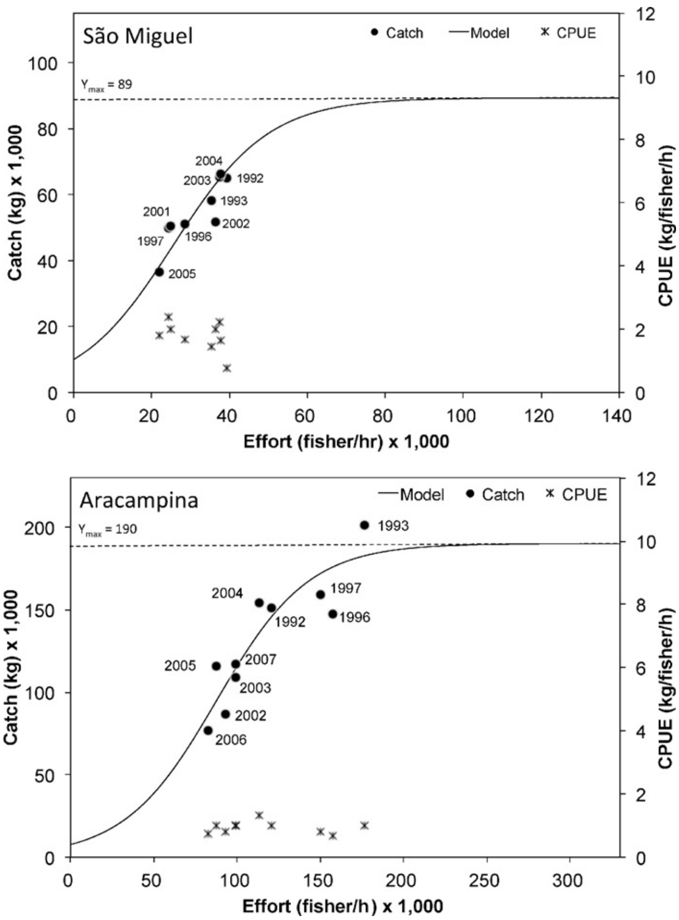

Fig. 2. Catch and effort relations showing fits of sigmoid production model, and mean annual CPUE in two of the communities. Catch and effort values are annual estimates calculated through extrapolation for the whole community (see Section 2.3 for details). Also indicated are the year of observations and the estimate of Y_{max}.

The principal management rules in place by local communities are gear restrictions, with 85% of the communities having bans on gillnets during one or more months during low water levels when fish are more vulnerable to fishing (Castro and McGrath, 2003). Other gears such as poison, explosives, and lantern (for night fishing) also are banned. Some communities set aside some lakes as reserves where commercial fishing is prohibited (Castro and McGrath, 2003). São Miguel is unique in having a full ban on gillnets, and local fishers rely primarily on cast nets, hook and line and harpoons. The present analysis will seek to identify general relations between management restrictions and resource status.

2.3. Sampling

Catch and effort data were collected through household interviews based on daily recall of catches by the fishers themselves. Household interviews are widely used in small-scale fisheries where diffuse landings make the use of conventional port-based catch assessments impossible (Bayley, 1988; Bayley and Petrere, 1989). Recall of catches by fishers has been shown to be reasonably accurate provided recall periods are less than one week (Carvalho et al., 2008; Lorenzen et al., 2006). In this study, household interviews were done within 24 h of the fishing trip, so recalls of catches were as accurate as possible. Daily interviews were conducted during the last seven days of every month. In general, fishers from about 20% of the houses in each community were interviewed each month. A total of 20,098 interviews were conducted, 7795 in Aracampina, 4988 in São Miguel, and 5120 in Santana. The data collected included: total weight and number of individuals caught of each species, number of fishers involved in the catch, and amount of time the fisher(s) spent fishing (including time spent traveling to and from the fishing spot).

2.4. Data analysis

Interview data were analyzed as follows. *Catch levels* for every community were assessed by comparison to theoretical estimates of maximum catches. Fishing effort and catch data for each community were extrapolated to the whole community for every month by accounting for the number of fishing days and number of households sampled each month. Annual estimates of fishing effort and catch for Aracampina and São Miguel communities were used to fit a sigmoid (yield-effort) production model, of the same form as that previously developed for these fisheries (Lorenzen et al., 2006; Welcomme, 1985, 1999). The model was not fit to the data from Santana because of the short time series available. Model choice was based on the poorer fits of the asymptotic and Fox models, which also were proposed for these fisheries (Halls et al., 2006; Laë, 1997). The sigmoid model used was forced through the origin, and is of the form $Y = (Y_{max}/1 + \exp(-(x - x_0)/b)) + \varepsilon$ where, Y is aggregated yield at aggregated fishing effort x, Y_{max} is maximum yield (i.e., catch), b and x_0 are parameters of the model, and ε is random error. The model was fitted using the least squares method based on the Marquardt–Levenberg algorithm (Marquardt, 1963).

CPUE was estimated considering the weight of the catch, number of fishers involved, and time spent fishing. CPUE was measured as kg/fisher/h, as in other Amazonian studies. Petrere (1978) proposed the use fisher/days to measure of CPUE in Amazon fisheries, but most fishing trips in the study last only a few hours (McGrath et al., 1998). Our CPUE analysis was done in conjunction with a historical analysis of trends of catch and effort. These analyses were done using ordinary least square linear regression models that were chosen after careful consideration of the data and check of the assumptions (i.e., residuals showing constant variance and fitting a normal distribution). We tested the CPUE hypothesis using an ordinary least squares linear regression model in which the year of observation served as the predictor variable. Raw CPUE data were aggregated on a yearly basis and the aggregates were weighted in the regression model by the associated total annual effort. To analyze trends in catch and effort, the regression models estimated mean monthly catch and effort for every year.

Because of the non-linearity exhibited by CPUE in tropical multispecies fisheries, these assessments were complemented with investigations of CPUE and effort relations. These relations allowed to identify the three effort regions (lightly, moderately, or heavily exploited) proposed by Lorenzen et al. (2006), and hence the reliability with which historical analyses of CPUE can be made.

Species composition of the catch was computed for every year for the species contributing to 50% or more of the catch in weight (referred to as 'most caught species') to assess if there has been substitution of any of those species throughout the time period studied.

Mean body length of the five most caught species was calculated for every catch event. To do this, we estimated the mean weights of the fished individuals by dividing the total species-specific weight of the catch by the respective number of individuals. The estimates of mean body weights were then transformed into mean body length estimates using published total length-weight relationships, as summarized at Fishbase.org (Table 1). This was done to allow comparisons with best-available data on length-

Table 1
Most caught species, life history strategies, their contribution to catch (in weight), their mean length in the last observed two years in the communities, and best available information on length-at-first-reproduction (L_r). Parameters of the length-weight relations used to estimate their mean lengths also are shown.

Species names		Life history strategy	Length-at-first reproduction (cm)	São Miguel		Aracampina		Santana		$W = a \times L^b$	
Local	Scientific			Catch (%)	Length (cm)	Catch (%)	Length (cm)	Catch (%)	Length (cm)	a	b
Acari	*Liposarcus* spp.	Sedentary	–	13	29			16	30	0.08	2.5
Curimatá	*Prochilodus nigricans*	Migratory charac.	26	7	32			14	37	0.01	3.179
Dourada[a]	*Brachyplatystoma rousseauxii*	Migratory catfish	76–107			15	70			0.01	3
Filhote	*Brachyplatystoma filamentosum*	Migratory catfish	95–130			7	89			0.01	3
Pescada	*Plagioscion* spp.	Sedentary	20			10	34	9	39	0.012	3.014
Pirarucu[b]	*Arapaima* spp.	Sedentary	160	18	115						
Surubim	*Pseudoplatystoma* spp.	Migratory catfish	80			8	69	8	65	0.011	3.004
Tambaqui	*Colossoma macropomum*	Migratory charac.	61	25	45	12	29	12	34	0.025	3.008
Tucunaré	Cichla sp.	Sedentary	25	6	34					0.024	2.985
Total contribution to catch in weight				69		52		54			

[a] Length-at-first-reproduction data for dourada and filhote are given in ranges due to differing estimates (see Petrere et al., 2004). Because of lack of length-weight data for filhote, we used values for *B. rousseauxii*.
[b] Because pirarucu traditionally are commercialized in the form of fillets, field data on fillet weights were transformed first to whole body weights and then total lengths using Martinelli and Petrere's (1999) body weight and length relations.

at-first-reproduction (L_r, Petrere et al., 2004; Santos et al., 2006; Table 1). We tested the hypothesis regarding changes in fish length using individual linear regression models for each species at each community with the year of harvest as a predictor variable. These regression models were chosen after consideration of the data and check of the assumptions, as done with the CPUE analyses. The migratory patterns of the most caught species were considered in the interpretation of the mean body length results.

3. Results

The most important results found were the following. First, catches at all three communities have been lower than theoretical maxima. Second, CPUE remained constant in all communities. Third, there has been no substitution of fish species in the catch. Fourth, mean body lengths of five out of the nine most caught species were below length-at-first-reproduction, and mean body lengths of the nine most caught species showed varied trends over time.

3.1. Catch levels

The sigmoid yield-effort model fitted the data from Aracampina and São Miguel well, as indicated by high coefficients of determination and *F*-values, and rather small *P*-values for both the model's fit and the Y_{max} parameter estimates (Fig. 2). For São Miguel, the main model results were: $R^2 = 0.92$, $Y_{max} = 89{,}297$ (S.E. ± 8505, $P_{Y_{\max}} = 0.0001$), $b = 12{,}281$ (S.E. ± 3,025), $x_0 = 25{,}570$ (S.E. ± 3026), $F = 46.5$, $P_{\text{regression}} = <0.0001$, D.F. = 9. For Aracampina, the main model results were: $R^2 = 0.87$, $Y_{max} = 190{,}093$ (S.E. ± 22,058, $P_{Y_{\max}} = 0.0001$), $b = 27{,}699$ (S.E. ± 12,246), $x_0 = 87{,}690$ (S.E. ± 7704), $F = 36.5$, $P_{\text{regression}} = 0.0001$, D.F. = 10. The visible linearity between catch and effort, and the good but no better fits of the linear model would suggest that annual catches in the two communities have not reached asymptotic levels and that the model under-estimated the predicted maximum (Fig. 2). Although catch and effort data for Aracampina in 1993 were greater than the predicted maximum, catches in the last three years of observations were 54% of the predicted maximum in Aracampina and 58% in São Miguel (Fig. 2).

CPUE did not change within the observed range of fishing effort values in these two communities, as indicated by the lack of fit of the linear model to annual fishing effort and median annual CPUE; coefficients of determination were very low ($r < 0.25$) and *P*-values high ($P > 0.5$; Fig. 2). Therefore, catch levels at Aracampina and São Miguel communities appear to be in the moderately exploited range of Lorenzen et al. (2006), and the historical trends of CPUE presented below may be hyperstable (i.e., CPUE is not affected by changes in effort).

3.2. CPUE

Under the range of values observed, the regression models showed no change in historical CPUE in the three communities (Table 2 and Fig. 3). However, catch and effort showed varied trends. Catch and effort have remained stable in São Miguel and have decreased in Aracampina. Catch has increased and effort remained stable in Santana (Table 2).

3.3. Species composition

In São Miguel, the mean annual contribution of the five most caught species to the total catch has been around 69% (Table 1), and the contribution of each species to catch has been relatively constant, except for acari which in 2006 decreased markedly while that of pirarucu and tambaqui increased (Fig. 4). In Aracampina,

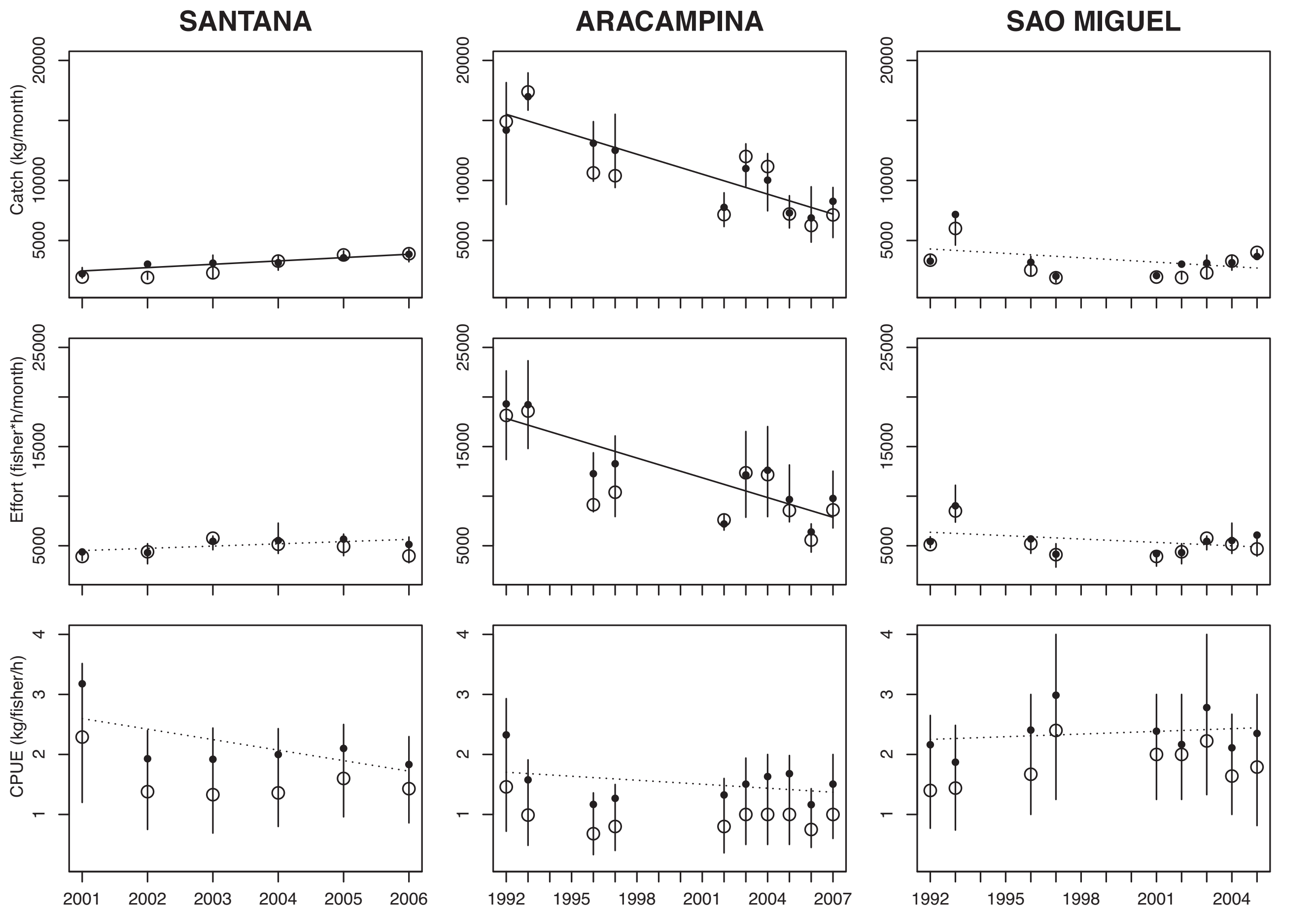

Fig. 3. Historical trends in monthly catch, monthly effort, and CPUE of daily fishing trips in the three communities. Solid lines denote statistically significant regression trends; dotted lines denote non-significant regressions. Black circles denote averages of observations, and empty circles denote the median. See Table 2 for associated statistics.

the mean annual contribution of the five most caught species to catch has been around 52% (Table 1), and the contribution of those five species remained relatively stable during the years, and even increased (Fig. 4). In Santana, the mean annual contribution of the five most caught species to the catch has been around 54%, and it decreased over the short period of observations, mainly due to decreases in the catch of surubim (Table 1 and Fig. 4).

3.4. Fish lengths

In Santana, mean lengths of curimatá and surubim increased, of acari and pescada decreased, and of tambaqui remained unchanged (Tables 1 and 3; Fig. 5). In Aracampina, the mean lengths of tambaqui, filhote, and pescada decreased, and of dourada and surubim remained unchanged (Tables 1 and 3; Fig. 5). In São Miguel, only the mean lengths of tambaqui increased; those of pirarucu and tucunaré remained stable, and that of acari and curimatá decreased (Tables 1 and 3; Fig. 5).

Table 2
Historical trend analyses of CPUE, catch, and effort in the three communities. Data shown include: parameter estimate (P.E.), standard error (S.E.), and *P*-value. The data stem from linear regressions with CPUE, catch, and effort as response variables and year of observation as explanatory variables. CPUE observations were aggregated on a yearly basis, and catch and effort were monthly means. See Fig. 3 plots of the data.

		P.E.	S.E.	*P*-value
Santana	Effort	226.10	112.30	0.114
	Catch	278.80	48.91	0.005
	CPUE	−0.18	0.10	0.165
Aracampina	Effort	−664.40	152.30	0.002
	Catch	−587.93	100.39	0.001
	CPUE	−0.02	0.02	0.307
São Miguel	Effort	−113.90	108.10	0.327
	Catch	−122.12	108.38	0.297
	CPUE	0.01	0.03	0.590

Table 3
Historical trend analyses of body lengths of the five most caught species. See Table 1 for respective scientific names and life history strategies, and Fig. 5 plots of the data. Data shown include: parameter estimate (P.E.), standard error (S.E.), *P*-value, and total body length changes observed during the study period. The data stem from linear regressions with mean body lengths as response variables and year of observation as explanatory variables.

Community	Fish species	P.E.	S.E.	*P*-value	cm/study period
Santana	Acari	−0.210	0.075	0.005	−1.26
	Curimatá	0.335	0.080	0.000	2.01
	Pescada	−0.318	0.115	0.006	−1.91
	Surubim	0.571	0.258	0.027	3.42
	Tambaqui	0.057	0.123	0.683	
Aracampina	Dourada	−0.094	0.063	0.140	−1.40
	Filhote	−0.656	0.275	0.018	−9.84
	Pescada	−0.212	0.037	0.000	−3.18
	Surubim	0.020	0.091	0.828	
	Tambaqui	−0.111	0.035	0.001	−1.66
Sao Miguel	Acari	−0.418	0.026	0.000	−5.43
	Curimatá	−0.243	0.050	0.000	−3.16
	Pirarucu	−0.046	0.337	0.892	
	Tambaqui	0.317	0.048	0.000	4.12
	Tucunare	0.038	0.057	0.505	

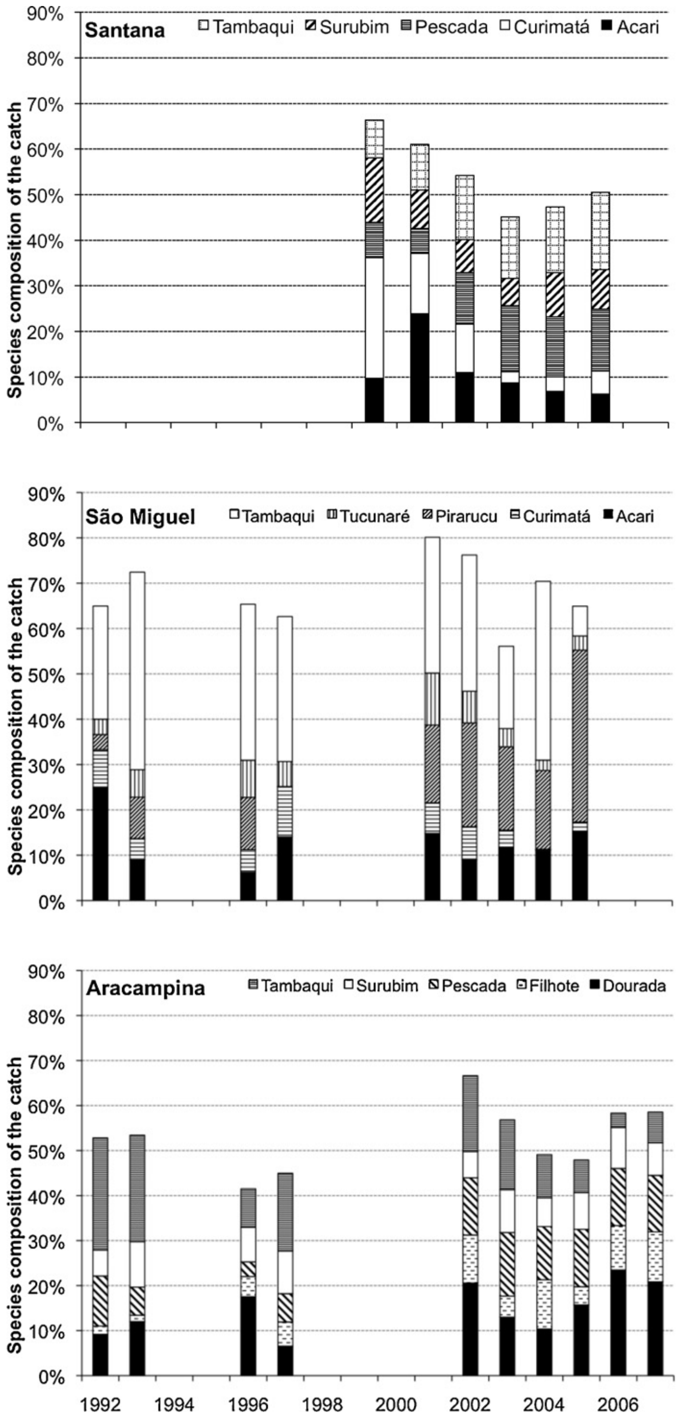

Fig. 4. Historical species composition of the catch (in weight) in the communities.

Comparing data in Fig. 5 and in Table 1, we find that the mean body length of five of the nine species during the last two years of observation were below the length-at-first-reproduction (L_r). Mean body lengths of tambaqui, and surubim in Santana and Aracampina, of dourada and filhote in Aracampina, and of tambaqui and pirarucu in São Miguel, all were below their length-at-first-reproduction (Table 1). Only the mean body lengths of curimatá and pescada in Santana, of pescada in Aracampina, and of curimatá and tucunaré in São Miguel were above their length-at-first-reproduction (Table 1). We found no data on length-at-first-reproduction for acari.

4. Discussion

4.1. Catch levels

Our finding that catch levels in the last three years of observations are only about 54–58% of the maximum appears to be sound and even conservative, as the sigmoid yield-effort model fitted very well to the data ($R^2 > 0.85$, $P < 0.001$) and the linearity of the data probably forced the model to underestimate maximum yields (Y_{max}). This result is in agreement with other studies. Both fishing effort and catch levels in the last three years of observations in the studied communities (10.9 and 20.9 kg/ha/year at fisher densities of about 0.008 and 0.014 fisher/ha, respectively, in São Miguel and Aracampina) were well below the estimated maximum sustainable catches for floodplain fisheries worldwide (141 kg/ha/year at fisher densities of 0.14 fishers/ha; Halls et al., 2006). Furthermore, Lorenzen and Almeida (in press) report that catch for floodplain lake fisheries near the study area is 28% of the predicted maximum. However, it is noted that our analysis does not consider urban-based fisheries, which exploit river channel resources.

4.2. CPUE

The constant CPUE trends found in the three communities would suggest a stable resource biomass (Table 2 and Fig. 3). This result too is in line with the studies by Isaac et al. (2008) and Lorenzen and Almeida (in press), which analyzed historical trends in CPUE of fishery landings in the Santarém city for roughly the same study period. Whereas Lorenzen and Almeida (in press) found that CPUE did not change overtime, Isaac et al. (2008) found that CPUE has increased slightly overtime but they attributed that increase to technological improvements of the fishing fleet and suggested the fish biomass has remained roughly stable. However, these CPUE results have to be interpreted with caution, as CPUE may be hyperstable within the range of observations. This potential hyperstability was indicated by the lack of relation between effort and CPUE (Fig. 2), and by the fact that CPUE remained stable in Aracampina even though catch and effort decreased by ~30% (Table 2 and Fig. 3).

4.3. Species composition

The lack of species substitution in the catch (Fig. 4) is a positive sign of the state of fishery resource (Fig. 2; Pauly et al., 1998; Welcomme, 1999). However, species substitutions already occurred in the study area before our data collection. The pirarucu, for example, was once a major species in the regional catch, but their wild populations have decreased to an estimated ~13% of their un-exploited abundance (Castello et al., 2011; Veríssimo, 1895), tending to now exist only in communities involved in management (e.g., São Miguel; Fig. 4).

4.4. Fish lengths

The nine most caught species can be organized in three distinct groups. We note, however, that the following interpretation merely relates observed body length criteria with previously published stock assessment data, and it does not constitute a formal stock assessment, which would require detailed population dynamics studies using appropriate methods (e.g., yield-per-recruit analysis).

Among the most seemingly “healthy” species are tucunaré and curimatá, which are being fished on average at lengths greater than their length-at-first-reproduction (Table 1), are not known to be overexploited in the literature, and did not shown consistent decreases in body length (Table 3 and Fig. 5).

Acari and pescada appear to deserve some management attention, even though they are not known to be overexploited in

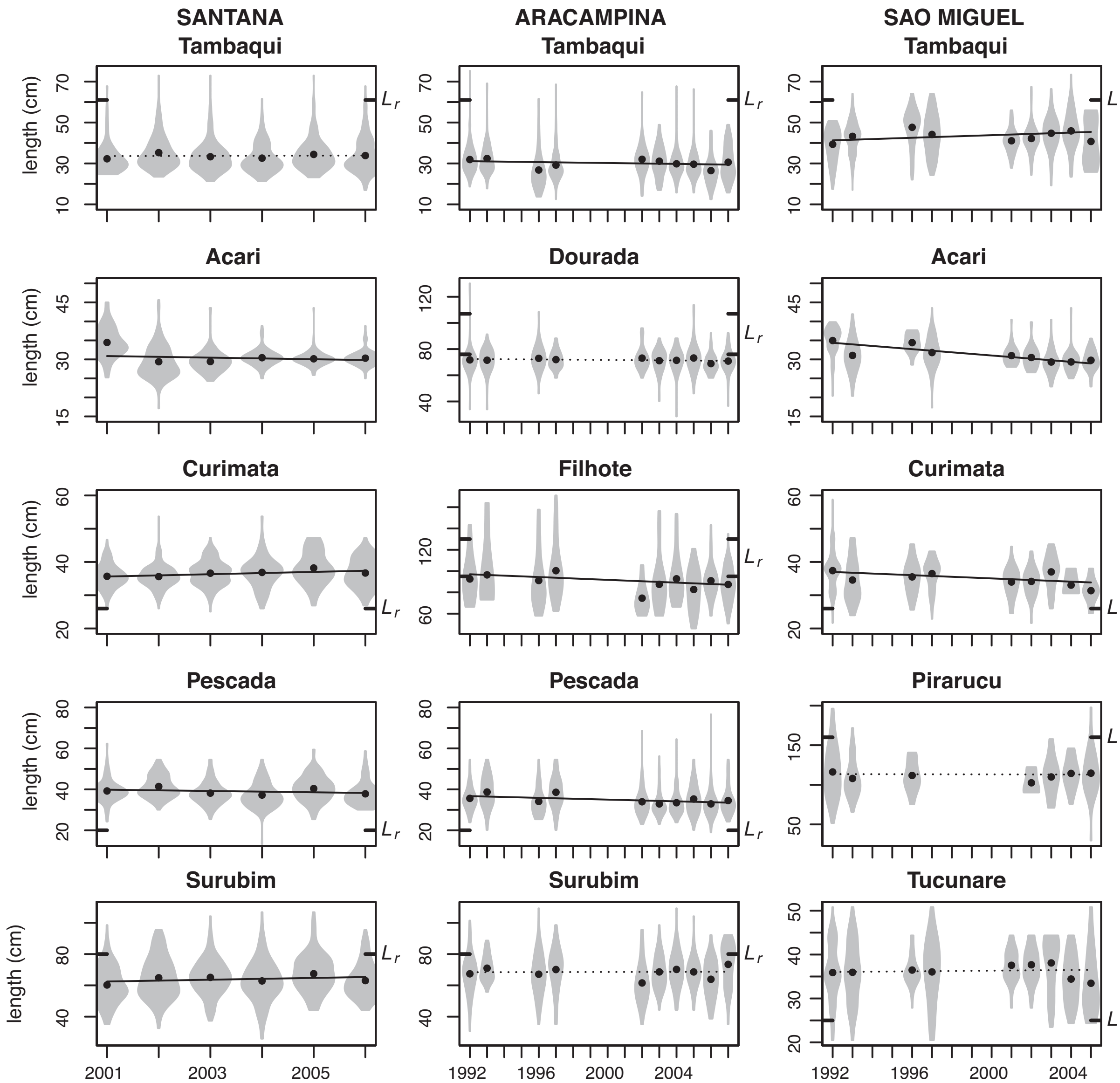

Fig. 5. Historical trends in mean body length of the five most caught species in the communities in relation to best available information on length-at-first-reproduction (L_r), which is indicated on the vertical axis. Solid lines denote statistically significant regression trends; dotted lines denote non-significant regressions. Grey areas are distribution plots of the data. Table 3 provides details of the regression analyses shown here.

the literature. Pescada is being fished at mean body lengths greater than its length-at-first-reproduction, and the length-at-first-reproduction of acari is unknown, but their mean body lengths have decreased in all communities where they are one of the most caught species (Tables 1 and 3; Fig. 5).

Five other species, pirarucu, surubim, dourada, tambaqui and filhote, have been previously reported to be overexploited (although the case of the dourada is unclear), and in this study they all showed mean body lengths below their length-at-first-reproduction (Alonso and Pirker, 2005; Isaac and Ruffino, 1999; Queiroz and Sardinha, 1999; Tables 1 and 3; Fig. 5). Of these, pirarucu, tambaqui, and surubim did not show consistent increasing or declining trends in their mean body lengths, a fact that suggests resource stability. The mean body lengths of dourada and filhote below their length-at-first-reproduction cannot be expected to imply overexploitation, because their adult populations concentrate in the headwaters of the basin, not in the study area. However, the declining trends in the mean body length of dourada and filhote, together with previous reports of overexploitation, can be expected to indicate continued resource decline. This seems worrisome for filhote, which already has been reported to be depleted in the headwaters, and in the study area has been shrinking by 0.6 cm in body length per year (Tables 1 and 3; Fig. 5; Petrere et al., 2004).

4.5. Co-management

In assessing the effectiveness of co-management, it must be considered that five of the nine most caught species cannot be expected to be managed by small-scale efforts, because they migrate long distances (Table 1). It also must be considered that only three communities were included in this study, making the following a preliminary assessment.

The principal effect of co-management appears to be higher efficiency of fishing (i.e., higher CPUE in São Miguel; Fig. 3) and preservation of higher-value species (Table 1). The most significant amounts of higher-value species (i.e., tambaqui, pirarucu and tucunaré) were caught in São Miguel, the community that has the most management restrictions and that enforces them the most rigorously.

However, the observed exploitation of fishery resources is not sustainable in any of the communities. The large proportion of the catch that is comprised of juveniles (Fig. 5) correlated well with previous reports of overexploitation (see Section 4.4). It is thus expected to undermine population recruitment, as it has been empirically shown for the pirarucu and tambaqui (Isaac and Ruffino, 1996; Castello et al., 2011). Furthermore, the decreasing body lengths of acari and pescada signal the potential need for all communities to develop additional restrictions, because both of these species are sedentary of the floodplains and amenable to small-scale management. Government fisheries regulations do include minimum size limits for most of these species, but co-management in the study area tends to focus on gear restrictions, probably because they are easier to monitor and enforce.

4.6. Conclusions

Our analysis indicates that fishery resources in the Lower Amazon appear to be exploited moderately, below the predicted maximum potential. However, five of the nine most caught species have been previously reported to be overexploited and even depleted, and in the study area they showed typical signs of overexploitation (e.g., length of catch below length-at-first-reproduction). This would indicate that the principal threat to the sustainability of fishery resources in the region is excessive concentration of fishing effort on the target species combined with unsustainable fishing practices such as the capture of sexually immature individuals.

Even though there was no substitution of species in the catch, probably because of the relatively short time series of data available, species substitution are known to have occurred before this study (e.g., pirarucu), and they may continue to occur with the overexploited species that in this study showed no signs of recovery. Tropical multispecies fisheries theory suggests that the potential decline of these species would not lower the total yield potential, but it would change the aquatic trophic structure. This seems un-necessary given that these fisheries are not fully exploited.

Co-management schemes that focus on high-value species, such as that in the São Miguel community, appear to be able to slow down, but not prevent, the fishing down process. Their management and conservation effectiveness can be improved, as suggested below.

4.7. Policy implications

There are four policy implications.

(1) It is possible to increase present yields. To some extent, this is feasible while avoiding the depletion of additional species, by effectively complying with minimum size and closed seasons and by diversifying the species composition of the catch.
(2) Enforcement of existing minimum size and closed season limits of catch would do much to increase the productivity of key fished populations while also addressing the overexploitation of some species. Protecting sexually immature individuals from fishing essentially eliminates the risk of resource collapse even if effort is uncontrolled (Myers and Mertz, 1998), and it increases fisheries productivity (e.g., Isaac and Ruffino, 1996; Castello et al., 2011). In contrast, limiting effort through gear restrictions, as is dominantly done in the study area, is expected to bring small increases in CPUE (Figs. 2 and 3).
(3) Diversifying the species composition of the catch could release pressure on overexploited species and lower dependency on a few fish species. This would be key to conserve the fished community. Ironically, the case of São Miguel, where five species contribute with 69% of the catch in weight, shows that existing co-management efforts tend to concentrate, not diversify, effort across species, probably because of market constrains.
(4) Management attention is needed on the migratory fish species. Four migratory fish species (i.e., filhote, dourada, surubim, and tambaqui; Table 1 and Fig. 5) are being captured below their size-at-first-reproduction, and have been previous reported to be overexploited. Their conservation requires management on the same geographical scale encompassed by their home ranges (Barthem and Goulding, 1997). There is thus a need to match the current shift towards community-based management with the development of larger-scale fisheries management frameworks.

Acknowledgements

Funding for data collection came from WWF-UK, INCRA-Brazil, IMAZON. Funding from the Gordon and Betty Moore Foundation allowed for preparation of this manuscript. Lourdes Pinto helped collect and store most of the data. Diego Pinheiro prepared the map and calculated community areas. Caroline C. Arantes assisted with data analysis, and she and two anonymous reviewers provided constructive criticisms.

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