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Recovery of *Arapaima* sp. populations by community-based management in floodplains of the Purus River, Amazon

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In the present study a unique dataset on population abundance in various community-based management (CBM) and non-CBM areas is analysed to address the question of whether CBM can recover overexploited populations of *Arapaima* sp. in river-floodplain ecosystems. All non-CBM areas possessed depleted *Arapaima* sp. populations with a mean density of 0·01 individuals ha^{-1}. *Arapaima* sp. population densities in all CBM areas changed over time from depleted to overexploited or well managed status, with a mean rate of increase of 77% year^{-1}. Rates of *Arapaima* sp. population recovery in CBM areas differed, probably reflecting differences in ecosystem productivity and compliance with management regulations. These results indicate that CBM schemes can be effective tools for the recovery and conservation of fish populations with non-migratory life cycles in tropical river-floodplain ecosystems.

Key words: Brazil; conservation; local knowledge; participation; pirarucu.

INTRODUCTION

Many of the world's fish populations are overexploited (Pauly *et al.*, 2002). The situation is worse in tropical multispecies fisheries, where there are additional limitations imposed by lack of information and management capacity (Allan *et al.*, 2005; Castello *et al.*, 2009). Community-based management (CBM) of fisheries has been shown to reverse resource-declining trends by involving local users in collecting information and applying them in management decisions (Johannes *et al.*, 2000; Berkes, 2004). Whereas evidence on the effectiveness of CBM in fisheries is mounting, most of it stems from studies in coastal ecosystems (Foale, 1998; Martin-Smith *et al.*, 2004; Wilson *et al.*, 2006). Few studies have documented the effectiveness of CBM in fisheries of river-floodplain ecosystems, where seasonal flooding causes fish dispersion events by connecting managed with un-managed lakes.

The river-floodplains of the Amazon basin sustain large fisheries, encompassing over 100 fish species, providing food, income and livelihood services to an estimated

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30 million people (Isaac & Almeida, 2011). Fishing has, however, been progressively impacting the structure of the Amazonian fish communities *via* the fishing-down process of Welcomme (1999), by which historical increases in fishing effort reduce the mean body size of harvested species through the gradual replacement of depleted large-bodied species with small-bodied ones. In the Amazon, fishing-down has shrunk the mean maximum total length (L_T) of harvested species from 206 cm in the early 1900s to 79 cm today (Castello *et al.*, 2013*a*). Conventional top-down management structures in the Amazon, based on seasonal and size limits of catch, have been unable to reverse declining trends due to poor enforcement of regulations and the difficulties of monitoring fishing activities that are widely dispersed geographically (Castello *et al.*, 2013*b*; Brum *et al.*, 2015; Cavole *et al.*, 2015).

Local riverine communities have responded to this situation by developing CBM schemes for economically important fish resources whose small-scale home ranges are *a priori* susceptible to local management (McGrath *et al.*, 1993; Castro & McGrath, 2003; Castello *et al.*, 2009). Most CBM in the Amazon target *Arapaima* sp. (Teleostei, Osteoglossidae), in a system in which fishers implement protected areas, patrol the area to curb poaching, and count the fishes at the moment of the fish's obligate air-breathing; the count data is then used to determine fishing quotas (Castello *et al.*, 2009; Amaral *et al.*, 2014). *Arapaima* sp. are the Amazon's most historically important and overexploited fish (Castello & Stewart, 2010). They sustained the largest fishery in the region, but landings and the average size of captured individuals started to decrease drastically by the 1950s (Verissimo, 1895; Isaac & Almeida, 2011; Antunes *et al.*, 2014). Today, *Arapaima gigas* (Schinz 1822) is listed in Appendix II of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (Castello & Stewart, 2010). *Arapaima* sp. were not included in the national list of endangered species owing to lack of data, but *A. gigas* is listed in the IUCN Red List of Threatened Species as 'Data Deficient' (Groombridge & Jenkins, 1996). Local extinctions of arapaima have been reported in several regions (Castello *et al.*, 2014).

The occurrence of CBM for *Arapaima* sp. in several Amazonian communities makes them a candidate for further scrutiny to assess the potential of CBM to conserve fisheries in floodplain ecosystems. Here, information from CBM schemes for *Arapaima* sp. in the Purus River is used to address the following overarching research question: Do Arapaima sp. populations in river-floodplain ecosystems recover from overexploitation as a result of CBM?

MATERIALS AND METHODS

STUDY AREA

The study area comprises the várzea floodplains of the Purus River of the Amazon basin, State of Amazonas, Brazil (Fig. 1), which are generally influenced by white-waters rich in sediments and nutrients from the Andes Mountains (Junk *et al.*, 2015). Seasonal river water level fluctuations in the study area are *c.* 10 m, flooding the entire area during high water levels and leaving most dry during low water levels. Várzea floodplains are a complex mosaic of lakes, flooded forests and floating vegetation that are highly productive and diverse (Haugaasen & Peres, 2006).

The CBM schemes studied here comprise two Paumari Indigenous Lands and three sectors of the Piagaçu-Purus Sustainable Development Reserve (PPSDR). Three Paumari Indigenous Lands are upstream on the Purus River: Manissuã Lake and Paricá Lake (on the banks of Tapauá

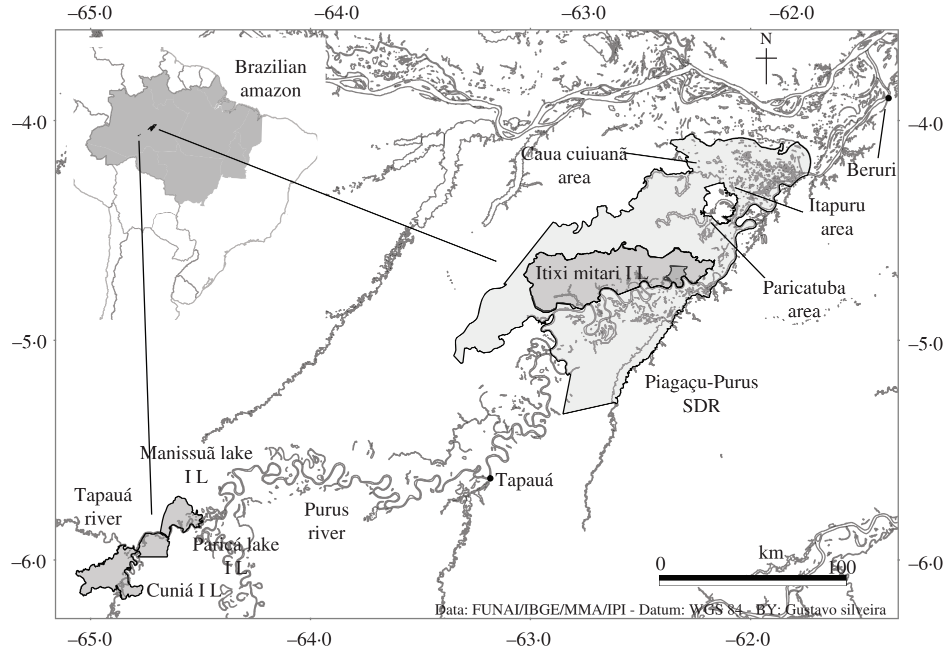

FIG. 1. The study area located in the margins of the Tapauá River and in the lower part of the Purus River, Amazon region, Brazil. Tapauá and Purus Rivers are identified in the figure. Tapauá and Beruri Cities are shown (●). In the Tapauá River margin: Paumari Indigenous Lands. In the Purus River margin: Piagaçu-Purus Sustainable Development Reserve (the three studied areas are identified with their respective names) and Itixi Mitari Indigenous Land.

River), and Cuniuá (at the confluence of the Cuniuá and Tapauá tributary ivers of the Purus River; Fig. 1). These comprise a protected area of 81 590 ha and possess a management system run as a communal area. Here, the ecosystem consists of large floodplain lake systems influenced by local blackwater igapó environments, which are generally less productive than whitewaters (Junk *et al.*, 2015). In the PPSDR, located on the lower portion of the Purus River, are the sectors Itapuru and Caua/Cuiuanã, which conduct *Arapaima* sp. CBM. The Paricatuba sector does not conduct any sort of fisheries management. Adjacent to the PPSDR is the Itixi Mitari Indigenous Land, which also does not conduct CBM (Fig. 1 and Table I). The studied areas were classified as: CBM (Itapuru, Caua and Cuiuanã and Paumari Indigenous Lands) and non-CBM (Paricatuba and Itixi Mitari Indigenous Land).

TABLE I. *Arapaima* sp. population densities in community based management (Itapuru, Caua and Cuiuanã and Paumari) and non-community based management (Paricatuba and Itixi Mitari) areas with their respective management area sizes

Area/year	Area (ha)	2008	2009	2010	2011	2012	2013	2014
Itapuru	48 516	455	2016	4700	6539	6800	8434	12 937
Caua and Cuiuanã	85 248	–	482	1445	2007	3090	4152	4503
Paumari	19 928	–	268	269	375	585	1135	2520
Paricatuba	32 600	–	–	–	–	–	–	257
Itixi Mitari	24 000	–	–	–	–	–	–	357

ARAPAIMA

The taxonomy of *Arapaima* sp. in the study area remains uncertain (Stewart, 2013), so here they are referred to at the generic level. *Arapaima* do not migrate long distances, conducting lateral migrations among eight of the recognized floodplain habitats, following seasonal water variations. They inhabit floodplain lakes during low water levels and migrate to flooded forests habitats during high water levels, and return to floodplain lakes when receding waters force all fish to seek refuge in remaining aquatic habitats (Castello, 2008*a*, *b*). They are fished in floodplain lakes when low water levels (September to January; Castello, 2008*a*) where they are particularly vulnerable to fishing as their obligate air-breathing behaviour exposes them to harpoon-specialist fishers every 5–15 min when they come out to gulp air. *Arapaima* grow fast in body size, reaching 88 cm L_T in 1 year and sexual maturity at 157–164 cm at 3–4 years of age (Arantes *et al*., 2010), allowing their populations to recover relatively fast from overexploitation when management practices let adult individuals reproduce (Castello *et al*., 2011*a*).

DATA SOURCES

Estimates of *Arapaima* population density in the studied areas were obtained using the method of Castello (2004) that allows expert fishers to count the fish at the moment of aerial breathing. Only individuals >1 m L_T are considered. The method establishes that fishers count the *Arapaima* during a period of 20 min in an area no greater than 2 ha. If the area of a lake is >2 ha, two or more fishers do the counts simultaneously. If the number of available fishers is insufficient to cover the entire area of the lake doing simultaneous counts, the fishers do successive counts until the entire area of the lake is covered. Counts of *Arapaima* were done in floodplain lakes during low water levels; counts done in multiple lakes produced population censuses (Arantes *et al.*, 2007). *Arapaima* density in each studied area was quantified per floodplain area (individuals ha^{-1}), excluding river channels, because such territories comprise different sets of lakes that together host local *Arapaima* populations (Castello *et al.*, 2011*a*). *Arapaima* density estimates for each area were obtained by local fishers under supervision of the Piagaçu Institute, which has been implementing CBM schemes in the region since 2001.

DATA ANALYSIS

Arapaima density estimates for each studied area and year were classified with respect to their population status using the population density range classes of Castello *et al.*, 2014): depleted (0–0·02 individuals ha^{-1}), overexploited (0·02–0·18 individuals ha^{-1}), well-managed (0·18–0·32 individuals ha^{-1}) and (near-) unfished (0·32 < individuals ha^{-1}) conditions. Data exhibiting non-normal or heterogeneous variance were ln-transformed and data that did not fit a normal distribution were analysed using non-parametric statistical tests. To investigate if CBM led to a recovery of *Arapaima* population densities, *t*-tests were applied to census data for all areas, including CBM and non-CBM areas, to investigate if the areas are comparable in terms of population densities. After that, a *t*-test was applied to two sets of data including the first 2 years and last 4 years to assess if population densities changed over time. Finally, a Kruskal–Wallis test was applied to population density estimates for CBM areas and years to investigate the potential existence of different population density patterns. Statistical analyses were based on Zar (1999) and performed in R software (www.r-project.org).

RESULTS

The results indicate that CBM schemes led *Arapaima* populations to recover from overexploitation. *Arapaima* population densities in the first year of census data were found to be no different between CBM (mean ± S.D. = 0·01 ± 0·00 individuals ha^{-1}; Table I and Fig. 2) and non-CBM (mean ± S.D. = 0·01 ± 0·00 individuals ha^{-1}; $t = -0{\cdot}58$, $n = 5$, $P > 0{\cdot}05$), indicating CBM and non-CBM areas are comparable in term of *Arapaima* density. In the non-CBM areas, depleted *Arapaima* populations

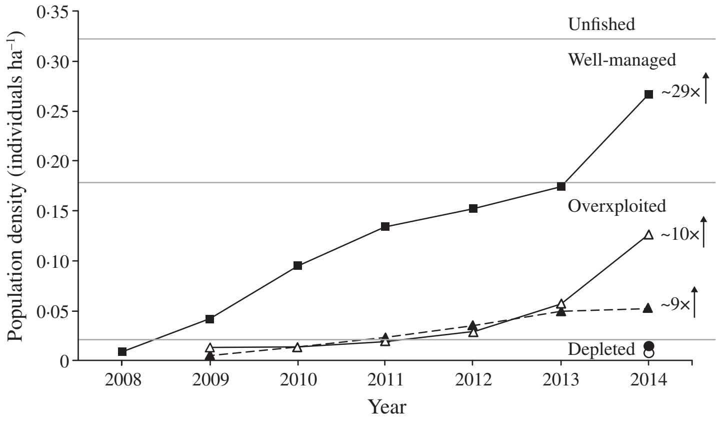

FIG. 2. *Arapaima* sp. population densities in community-based management (CBM) and non-CBM areas in the Purus River, Amazon Basin. Estimates for *Arapaima* >1 m total length. Data for CBM areas (—■—, Itapuru; —△—, Caua/Cuiuanã; —▲—, Paumari) include three sectors from Piagaçu-Purus Sustainable Development Reserve and two of Indigenous land (Fig. 1). Data for non-CBM areas (●, Paricatuba; ○, Itixi Mitari) are also given. ——, the limits of *Arapaima* sp. population status categories from Castello *et al.* (2014). The numbers on the right side indicate observed population increases during the study period.

possessed a mean density of 0·01 individuals ha^{-1} (Fig. 2). In the CBM areas, *Arapaima* population densities in the first 2 years of data (mean ± S.D. = 0·02 ± 0·02 individuals ha^{-1}) were lower than in the last 4 years of data (mean ± S.D. = 0·11 ± 0·07 individuals ha^{-1}; $t = -4{\cdot}83$, $n = 21$, $P < 0{\cdot}05$), indicating that *Arapaima* population densities increased over time. The *Arapaima* population density in all CBM areas changed over time from depleted to overexploited or well managed status, with a mean value of 0·08 individuals ha^{-1} and a mean positive rate of increase of 77% $year^{-1}$. Population densities, however, were different across the CBM areas of Itapuru and PIL ($H_{2,16} = 7{\cdot}35$, $P < 0{\cdot}05$). *Arapaima* population densities increased at a rate of 99% $year^{-1}$ in Itaipuru, leading to 29-fold population increase in 6 years, whereas they increased at a rate of 67% $year^{-1}$ in Caua/Cuiuanã and 62% $year^{-1}$ in PIL, leading to nine and 10-fold population increases, respectively (Fig. 2 and Table I).

DISCUSSION

The results found in this study, indicating that *Arapaima* populations in river-floodplain ecosystems recover from overexploitation as a result of CBM, provide additional support to previous studies. Arantes *et al.* (2006) studied CBM schemes for *Arapaima* with up to 8 years of management and found that the populations recovered from overexploitation at a mean rate of 25% in abundance per year. The population recovery rate found here of 77% $year^{-1}$is higher than that reported by Arantes *et al.* (2006), but that may be due to the shorter time series analysed here. Population growth rates in the CBM areas studied by Arantes *et al.* (2006) were higher in the first few years of management and tended to stabilize after 4–6 years. The 4-year time series analysed here may be capturing only the years of fast population growth. Data for additional years are necessary to better understand recovery rates.

Differences in population recovery rates found between CBM schemes in Paumari and Itaipuru areas (Fig. 2) are probably due to differences in ecosystem productivity. The white-water várzea areas in which Itaipuru is located are known for being highly productive biologically while Paumari are influenced by less productive blackwaters, rich in humic acids and poor in nutrients (Junk *et al.*, 2015). *Arapaima* populations, however, also recovered at different rates even inside várzea environments. Present experience working with these areas suggests that these differences are explained by the performance of CBM schemes. The Caua and Cuiuanã area allows for harvests of other fish species inside the managed area, whereas the Itapuru area allows harvests only of *Arapaima* in the managed area. The common use of gillnets in Caua and Cuiuanã, a feature that is widespread across Amazonian fishing communities, could impact *Arapaima* populations *via* incidental catch of small individuals (*i.e.* by-catch), a phenomenon that in certain areas has led *Arapaima* to local extinction (Castello *et al.*, 2014). The observed differences in *Arapaima* population recoveries under CBM may also be due to taxonomic uncertainties as well as compliance of regulations. Regulations that are implemented, but poorly followed by the fishers are largely ineffective.

Although the sample of CBM schemes analysed here is small, it is roughly representative of the poor level of *de facto* protection provided by protected areas in the Amazon. As much as 36% of the Amazon Basin area is now under some form of environmental protection (Castello *et al.*, 2013*a*). Yet, the results presented here indicate that fish populations in many of these areas may be in need of additional effective protection. *Arapaima* populations were depleted in all areas, inside and outside protected areas in the first year in which CBM schemes were implemented, representing the status of *Arapaima* populations in these areas. This poor state of affairs is largely due to illegal poaching brought about by near non-existent enforcement of protected area rules (Macedo & Castello, 2015). Involving local fishers in management decisions and actions provides a solution to the overfishing of non-migratory fish species such as *Arapaima*, alleviating biodiversity conservation and social well-being concerns, as documented for other resource systems elsewhere on the globe (Berkes, 2004; Castello *et al.*, 2011*b*).

It is evident that CBM schemes can be effective tools for the conservation of fish populations with non-migratory life cycles in tropical river-floodplain ecosystems. The degree of effectiveness depends, among other factors, on compliance with management regulations, the productivity of natural ecosystems, and the life cycles of the target fish species. CBM schemes appear to be one of several approaches that are required for biological conservation goals to be accomplished in river ecosystems (Ormerod, 2014).

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