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When predators become prey: Community-based monitoring of caiman and dolphin hunting for the catfish fishery and the broader implications on Amazonian human-natural systems

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ABSTRACT

Wildlife hunting for commercial products has been responsible for decline of many large vertebrates around the globe. An Amazonian example of this worldwide trend is the use of caiman and dolphins as bait for the piracatinga catfish fishery. While it is a controversial issue in Amazonia conservation, there is no data on key biological aspects, such as age and sex, of those animals illegally hunted for bait. This lack of data complicates understanding of the true impact of bait-hunting on the targeted species. In this study, we present results of one year of participatory monitoring of bait-hunting in 12 communities in the Mamirauá Sustainable Development Reserve (MSDR), Brazilian Amazonia, during which participants recorded aspects of hunting activity and biometric data of animals used as piracatinga bait. The piracatinga fishery at MSDR has distinct spatial and seasonal patterns, being concentrated close to distribution centers and intensifying during the dry season. Adult male black caiman is the main bait used by fishermen, but viscera of commercial fish provide a potential alternative bait source for the piracatinga fishery. All recorded bait hunting was for caiman, none for dolphins. Despite the predominant use of caiman as bait, MSDR caiman populations remain the largest within the species' distribution. We suggest that informal management of caiman conducted by MSDR residents has guaranteed regional sustainability of the piracatinga fishery. In a broader context, the current study highlights the potential for participatory research with local populations in formulating well-informed decisions for the conservation of natural resources and economic alternatives focused on the conservation of human-natural systems.

1. Introduction

The international trade in wildlife products has been promoting massive population collapses and range reductions of large vertebrates around the world (Antunes et al., 2016; Ripple et al., 2015). In the late 19th century, the high European demand for hides nearly wiped-out the American bison in North America (Taylor, 2011). Later, a new international demand for pelts and hides was responsible for population collapses in several aquatic species in Amazonia, including manatee, caiman, capybaras and otters (Pimenta et al., 2018; Antunes et al., 2016; Smith, 1981). Currently, the international trade in wildlife

products continues to cause severe decline of Asian and African fauna populations, such as elephants, rhinos and tigers, threatening their continued wild existence and ecological function (Ripple et al., 2016, 2015). However, wildlife hunting for food or medicine has been part of the subsistence practices of many societies worldwide for millennia, since bushmeat is a major protein source for forest people (Bailey et al., 1989). Although local game harvest may also have negative impacts on wildlife populations (Bodmer et al., 1994), traditional beliefs and cultural hunting practices usually provide the local community hunting sustainability for most game species (Levi et al., 2011; Shepard et al., 2012; Vieira et al., 2015). However, studying the ecological and socio-

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economic complexity of modern commercial hunting activity is complicated by the recent illegal nature of this activity. As a result, many aspects of wildlife hunting remain poorly known, including in the Brazilian Amazon.

The social and environmental consequences of the Brazilian “piracatinga” (*Calophysus macropterus*) fishery is also a controversial issue among environmentalists and researchers. This commercial fishery has been expanding in the Amazon region since the early 2000s (Alves et al., 2012; Estupiñán et al., 2003; Gómez et al., 2008; Salinas et al., 2014), reflecting an increasing demand from the Colombian market, which saw the piracatinga as a substitute for “capaz” (*Pimelodus grosskopfii*), a popular fish in Colombia which has undergone a severe population decline due to overexploitation (Trujillo et al., 2010). Despite a widespread distribution within the Amazon's white water river systems (Barthem and Goulding, 2007), exploitation of piracatinga has been particularly strong on the middle and upper Solimões river. This is largely due to the proximity of the Colombian consumer market and the local logistic wherewithal to reach it (da Silveira, 2003; Estupiñán et al., 2003). Although the piracatinga itself has never been a significant part of the diet of the local Western Brazilian Amazonian population, in the early 2000s fishing became an important alternative income source for the human riverine dwellers on the Solimões (Franco et al., 2016), where artisanal fishing is the main regional source of animal protein, employment and income generation (Almeida, 2006; Peralta and Lima, 2013; Ruffino, 2004).

The main concern among environmentalists is not the fishery, but the bait used for catching the fish. The piracatinga is a medium size (up to 40 cm) migratory catfish that inhabits rivers and floodplains in the Amazon and Orinoco river basins (Pérez and Fabr e, 2009) and, like capaz, is a scavenging catfish of the family Pimelodidae (Order Siluriformes). The species is also known as “mota” (Spanish) or “urubu d’ gua” (water vulture, in Brazilian Portuguese), due to its preference for dead and oil-rich animal flesh. This diet led to caiman and pink river dolphin carcasses becoming baits used by piracatinga fishermen (Botero-Arias et al., 2014; Brum et al., 2015; Franco et al., 2016), creating a hunting pressure on these predators' populations, especially on the Solimões River (da Silveira, 2003; Franco et al., 2016; Mintzer et al., 2013).

The pink river dolphin (*Inia geoffrensis*), also known as “boto”, and the black (*Melanosuchus niger*) and spectacled (*Caiman crocodilus*) caiman were reported as the main species used as bait for piracatinga fishery (Brum et al., 2015; Franco et al., 2016). These species are also considered apex predators, essential for ecosystem regulation, and highly sensitive to hunting and to any human impact on their habitat (Gittleman et al., 2001; Treves and Karanth, 2003). Dolphins and caiman have been legally protected in Brazil since 1967 (Federal Law 5197), but they continue to be illegally hunted due to a widespread failure in effective surveillance (Brum et al., 2015; da Silveira, 2003; da Silveira and Thorbjarnarson, 1999; Iriarte and Marmontel, 2013a; Loch et al., 2009; Rebelo and Magnusson, 1983). Faced with the threat to dolphins and caiman survival posed by the piracatinga fishery (Thorbjarnarson, 2010; Trujillo et al., 2010), the Brazilian government issued Normative Instruction No. 6 in 2014, which prohibited the fishing and trade of piracatinga within Brazil. The implicit intention of this legislation was to reduce, indirectly, the hunting pressure on dolphins and caiman.

The piracatinga moratorium, in force until 2019, has also eliminated an alternative source of legal income for river-dwelling human populations in the Brazilian Amazon (Franco et al., 2016), and may have strong local socioeconomic implications. However, the impact of bait hunting for the piracatinga fishery is still poorly studied; no data on the extent of pink dolphin and caiman use as bait have been published (though see an indirect estimation for caiman in da Silveira, 2003, and for dolphin in da Silva et al., 2011), nor have biases in age and sex of exploited animals been investigated. Harvest of yet non-reproductive animals, or females in full breeding condition, could have severe

consequences on species recruitment rates (Bodmer et al., 1994). Lack of data on extraction rates and key biological characteristics of the exploited animals have made it difficult to achieve accurate estimates of the true impact of bait-hunting on the targeted species (McCullough, 2013; Milner-Gulland and Ak akaya, 2001). Furthermore, the main social actor in this scenario, the hunter-fisherman, is rarely involved in the research process, making it difficult to both formulate truly efficient and well-informed decisions for the conservation of these species, and to guarantee the well-being of river-dwelling human inhabitants.

In part, the lack of hunting-related data stems from the difficulty in addressing sensitive and illegal issues with interviewees (Nuno and John, 2014). In this context, participatory research emerges as a promising tool for hunting studies, since informants take an active role in research, strengthening the bond of trust between researchers and community (Castello et al., 2009; Franco, 2004). Data collection by hunters themselves can also extend the spatial and temporal sampling scale, unfeasible if carried out only by the researcher (Constantino et al., 2008; Luzar et al., 2011; Noss et al., 2004; Shepard et al., 2012). This method allows immediate recording of hunting, minimizing the loss of information common in recall-based methods (Dufour and Teufel, 1995). Participatory approaches have been used to gain understanding of hunting patterns (Souza-Mazurek et al., 2000; Valsecchi, 2012; Vieira et al., 2015), and evaluate hunting sustainability (Levi et al., 2009, 2011; Ohl-Schacherer et al., 2007; Shepard et al., 2012). Moreover, this approach enables decision-making and promotes local autonomy in resource management in regions with low investment in research and low enforcement capacities (Constantino et al., 2012; Funder et al., 2013; Townsend et al., 2005; Vieira et al., 2015; Yu et al., 2010). In this study we present the results of one year of participatory monitoring by fishermen from the Mamirau  Sustainable Development Reserve (MSDR), western Brazilian Amazonia, on the baits used in the piracatinga fishery, before the moratorium. Our goals were to: (I) ascertain which species, ages and sexes of caiman and dolphins were exploited for use as bait; (II) characterize hunting sites and the seasonality of piracatinga bait-hunting; (III) identify possible alternative baits for the piracatinga fishery. These results may allow a better understanding of the impact of hunting on the species used as bait, as well as a reconsideration of the viability of the piracatinga fishing activity as carried out by the riverine communities from the Brazilian Amazon. Beyond the regional perspective, the situation is notable as an example of a stakeholder group exploiting a newly-arisen economic opportunity, and their first experience of participatory research in this functionally illegal activity. In this context, the sociological implications of this fishery is an example of the need for flexibility in long-term conservation planning that may have a global relevance, as an example of mediation between the needs of conservation and desires of the local human population.

2. Methods

2.1. Study area

Sustainable Development Reserves (SDR) belong to a protected area category of the Brazilian National System of Protected Areas (SNUC Law N  9.985) which aims to marry wildlife conservation with standard-of-living improvement for the rural population inhabiting the reserve in question. Following this ideal, the 1,124,000 ha MSDR was established in 1990, in the middle Solimões river, State of Amazonas, Brazil (Fig. 1). The reserve is located between the Solimões, Japur  and Auati-Paran  rivers. Major vegetation types include floodplain habitats (“v rzea”), and a system of lakes defined by the seasonal fluctuation in river level, which causes variations of up to 10 m between the flood and dry season (Jardim-Lima et al., 2005; Ramalho et al., 2009). The main vegetation types of seasonally-inundated v rzea (high v rzea, low v rzea, chavascal and herbaceous vegetation) vary in botanical composition and duration of annual inundation (Ferreira-Ferreira et al.,

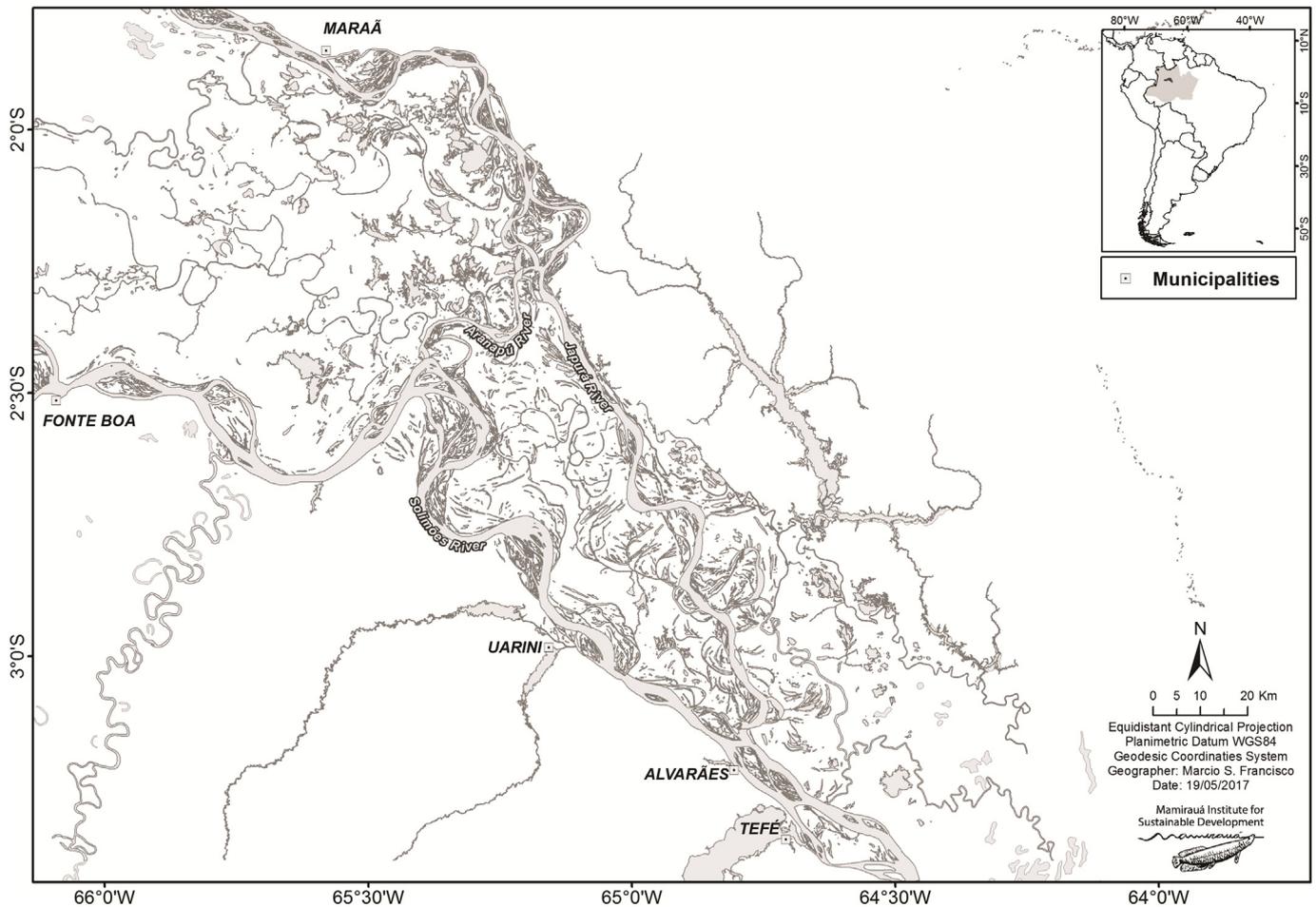


Fig. 1. Study area at Lower Mamirauá Reserve, Amazonas, Brazil.

2014). Together, these biotic and abiotic factors also influence resource-use by local human populations inhabiting MSDR. The 2011 Mamirauá Reserve Demographic Census recorded 200 human settlements, with a total of 10,867 people, when visiting users and full-time residents are included (Moura et al., 2016). The main income source for such families is a mixture of government social benefits and the use of natural resources, especially subsistence and commercial artisanal fishing, which is the largest extractive activity for the local population (Peralta and Lima, 2013). For ease of access and prior relations with the communities, we concentrated the current study in Lower Mamirauá, which has been focus of Mamirauá Institute activities due to its proximity to Tefé municipality, the main commercial center of the region. For almost 30 years the Mamirauá Institute has been working on the middle Solimões, co-managing the Mamirauá and Amaná Reserves with local communities to develop sustainable management systems. The actions of the Mamirauá Institute meet the economic, socio-political and environmental demands of the region, integrating the search for alternative sources of income with community involvement in the decision-making processes as a way to promote the conservation of renewable natural resources in the Amazon (Queiroz, 2005).

2.2. Data collection

We carried out research between March 2013 and February 2014. Initially, we focused on identifying communities that participated in the piracatinga fishery, and then selected communities for the study, followed by enlisting and training participating fishermen. To identify those communities active in the piracatinga fishery, we visited 65 human settlements located in the Lower Mamirauá area, along the

shores of the Solimões, Arapapu and Japurá rivers. We considered as “piracatinga fisher communities” those which had in their vicinity some “caixas” (box-like fish trap used for piracatinga fishery, see Fig. 2.A), and/or the presence of animal carcasses used for bait (Fig. 2.B). We also included the presence of residents who, during informal conversations, stated that they were in some way actively engaged in this activity, whether as a bait hunter, fisherman or catfish trader. We used the snowball sampling technique to select which fishermen would be the first contacts in each community. This method identifies stakeholders who perform an activity relevant to the research, then generating a network of informants based on that individual’s contacts (Bailey, 1994). Considering the illegal nature of piracatinga fishing, we opted to preserve the anonymity of all communities and individuals involved.

For participatory monitoring, we focused our efforts on the region with the highest concentration of piracatinga fisher communities. Within this area, 12 communities agreed to collaborate with the study, with a total of 33 fishermen directly involved in participatory monitoring. Participatory monitoring consisted of fishermen self-recording those hunts undertaken to obtain bait for the piracatinga fishery. Therefore, we trained participants (Fig. 1.C) to record the following information regarding hunting of caiman and dolphin: date, hunting site, species, sex and total length of animals used for bait. In case of alternative bait (i.e. not caiman or dolphin), participants recorded the bait type, amount of bait used and yield of piracatinga (in kilograms). We adapted the information usually collected in harvest self-monitoring studies (Noss et al., 2004; Souza-Mazurek et al., 2000; Vieira et al., 2015) to match the particular nature of the current research and to follow suggestions given by fishermen from Mamirauá Reserve.

Most of the participants had low levels of schooling, but in each



Fig. 2. Black caiman tail used as bait for piracatinga (A) and black caiman carcass found beside a piracatinga box fishing trap (B), both records found during study travel between communities. Training for self-monitoring (C) and data collection performed by Mamirauá Reserve residents (D).

community there was at least one literate fisherman who, voluntarily, took on responsibility for filling out monitoring forms. During the study period, we made monthly visits to all participating communities to monitor activities undertaken by the piracatinga fishermen (Fig. 1.D). As complementary data, we recorded all caiman and dolphin carcasses found in the area while traveling to and from communities. When such remains were encountered, we recorded their location, species, sex, biometrics and possible cause of death. We also recorded any signs that the carcass had been used for piracatinga fishing which, in the case of caiman, were considered the tail having been severed and the ventral region opened, as well the location of the carcass near a fish trap. The latter was also used to assign dolphin deaths to the piracatinga fishery. For further details of piracatinga fishery techniques, see Franco et al. (2016).

3. Results

3.1. Use of caiman and dolphins as bait

Matching carcass registration with participatory monitoring we obtained 152 records of caiman used as bait, 90.8% (138) of which were black caiman (the larger species) and 9.2% (14) spectacled caiman. During the research period, we recorded 14 caiman carcasses along the Lower MSDR, ten of which (71.4%) showed signs of having been used as piracatinga bait. It was only possible to determine the sex of five animals. In the other instances we either found only tails, the main part used for bait, or the animals were in possession of fishermen from whom we did not have permission to collect data. However, analysis of a tail is sufficient to identify the species and to estimate the total length of the animal, allowing us to suggest that all the animals we found with signs of piracatinga fishery use were black caiman, between

2.5 and 4.0 m in length.

Among the 12 communities participating in the research, ten effectively contributed to the monitoring with hunting records, and were responsible for 93.4% (142) of the hunting records (14 spectacled and 128 black caiman). Complete records, with hunt sites and biometrics, were recorded from 44 exploited animals. In other cases, according to participants, those responsible for recording the information were absent at the time. In total 86.4% (38) of the animals were hunted in “paranãs” (the local term for a main river channel), 9.1% (four) in the main river and 4.5% (two) in lakes, always near the home community. Of the 44 animals with biometric data, 86.4% (38) were black caiman (eight females and 30 males) and 13.6% (six) were spectacled caiman (five males and one female). All individuals hunted for bait were adults (for caiman growth rates, see Vanzolini and Gomes, 1979). Average total length was 283 cm (males 290 cm, females 257 cm) for black caiman, and 185 cm (males 196 cm, females 130 cm) for spectacled caiman. Our results show, unequivocally, that adult male black caiman is the most hunted animal for piracatinga bait by fishermen from Mamirauá Reserve (Fig. 3).

During the entire research period, there was no record of hunting of either boto or tucuxi (*Sotalia fluviatilis*, the Amazon's other freshwater dolphin) for the piracatinga fishery, nor were any cetacean carcasses recorded, with or without evidence of use for piracatinga fishery. However, ten (30%) of the fishermen who participated in the survey said they had used pink dolphin carcass as bait when they started the activity. There was a reported preference for “purple” botos (i.e. adult females: Martin and da Silva, 2006), as these accumulate more fat and attract more piracatinga. Fishermen who have used both baits affirmed that the fishing for piracatinga with boto yields more than does caiman flesh. According to our informants, while a 3-m caiman yields approximately 500 kg of piracatinga, a single boto can yield up to three

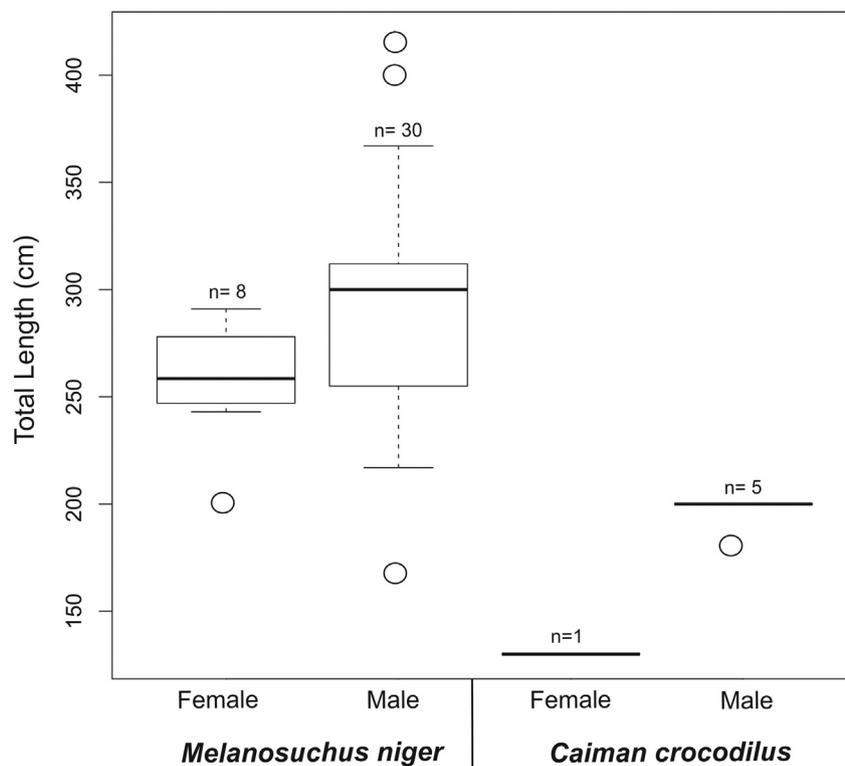


Fig. 3. Total length by sex of black caiman (*Melanosuchus niger*) and spectacled caiman (*Caiman crocodilus*) used as bait in the piracatinga fishery at Mamirauá Reserve.

times as much (from 1000 to 1500 kg of piracatinga). This corroborates information given by Botero-Arias et al. (2014), who also reported that using boto as bait gives a greater piracatinga yield than does caiman. However, these authors estimated a lower harvest, indicating that two black caiman yield 500 kg of piracatinga, similar to the amount obtained with a single boto. Fishing piracatinga using tucuxi as bait was not reported by any fisherman. Their smaller size, greater timidity and speed, plus lower body fat levels were all given as reasons for their non-use.

According to fishermen, bait-flesh is most attractive to the piracatinga when it is well decomposed. The difficulty in hiding a boto carcass until rotten was one of the main reasons given by the fishermen for its abandonment as bait. Boto has a strong odor (regionally called “pitiu”), and the greater concentration of fat makes it difficult to successfully sink the carcass in the water while awaiting its decomposition. The result is that evidence of boto hunting is more easily detectable by environmental surveillance agents. Moreover, it was clear when talking to fishermen that many were reluctant to hunt boto, largely due to the image the species has in popular culture. Fishermen who had already used boto as bait claimed that it is difficult to catch, because besides being very agile, it possesses the power of enchantment (Dutra and Santos, 2014; Slater, 2001), so that they are capable of harming those who threaten them, or even the families of those who do so. In face of these practical and cultural considerations, fishermen chose to substitute this more profitable bait with caiman flesh, which was the predominant bait among the piracatinga fishermen of Mamirauá Reserve during this pre-moratorium study.

3.2. Use of alternative baits

We obtained data on the use of alternative baits for four fishing events. The baits used were viscera of fish common in the middle Solimões region, as “pirarara” (*Phractocephalus hemiliopterus*), “jaú” (*Zungaro zungaro* = *Paulicea luetkeni*) and “sardinhão” (*Pellona castelnaeana*). In case of sardinhão, the whole fish is used, since it has no

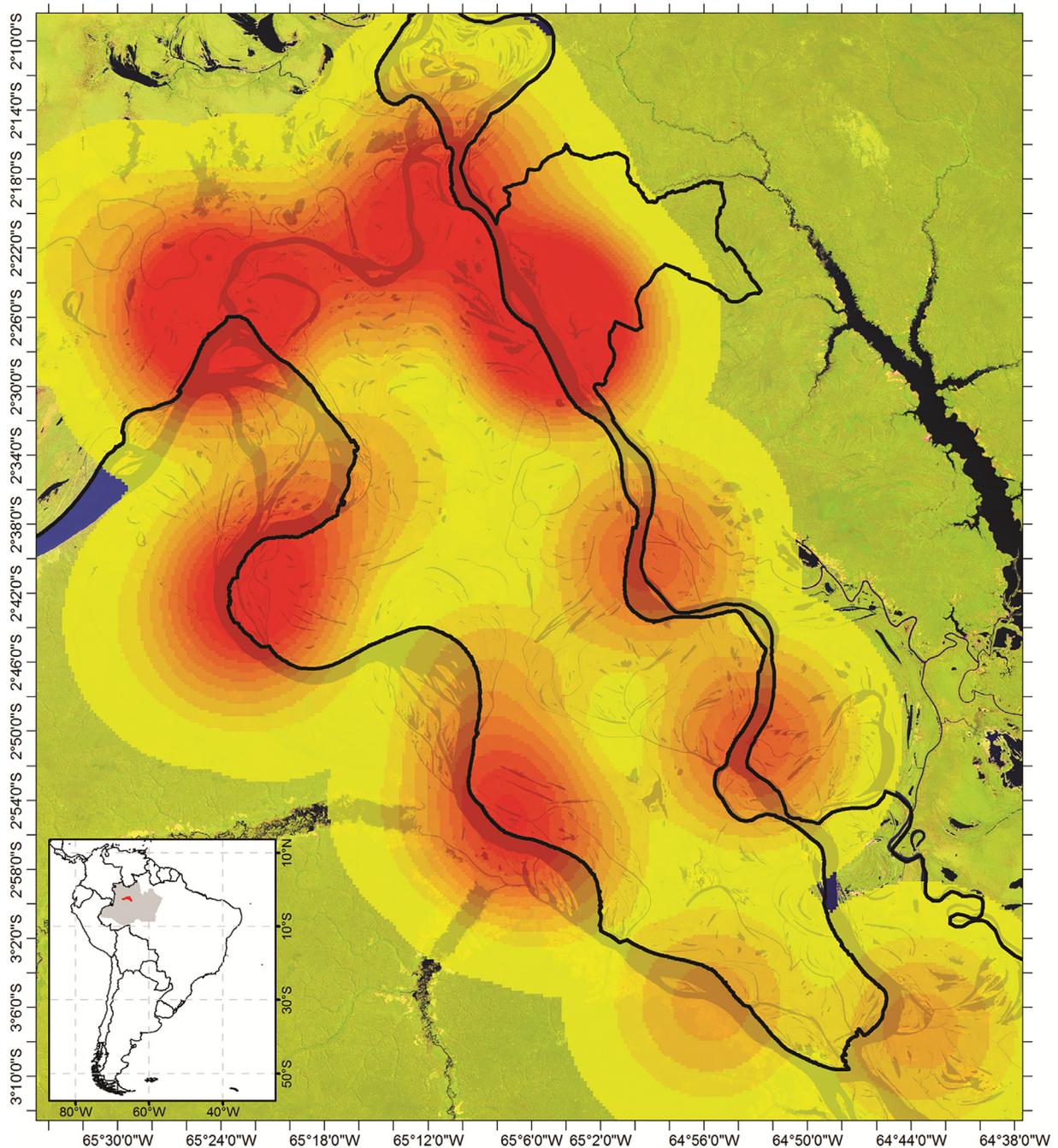
commercial value, and is not consumed by the local population, which considers it “reimoso” (unpalatable). Sardinhão is usually accidentally caught during fishing with large nets and is quickly attacked by scavenging fish, which encouraged fishermen to test the species as bait for the piracatinga fishery. The other species used as potential alternative baits are commercial fishes, sold to the middlemen after the complete removal of viscera. Thus, the viscera are available, and their deployment as bait was simply making profitable use of parts that would otherwise be discarded by the fishermen.

According to participating fishermen, the greatest difficulty in the piracatinga fishery with fish viscera is their short durability as bait, since, hand-held, they are lost quickly when submerged in the water. This results in the comparatively low profitability when this bait is used (see events 1–3, Table 1). However, small methodological modifications to fishing techniques can enhance the yield of such baits: viscera of jaú and pirarara catfish stored in old rice sacks show enhanced persistency and resulted in an increase in the piracatinga harvested (event 4, Table 1). Thus, the use of viscera from commercial fish has potential as an alternative bait for the piracatinga fishery.

Table 1

Alternative baits recorded in participatory monitoring by piracatinga fishermen from Mamirauá Reserve, and their respective yields.

Event	Source of bait	Bait amount	Yield of piracatinga (kg)
1	Pirarara (<i>P. hemiliopterus</i>)	95 kg	102
2	Pirarara (<i>P. hemiliopterus</i>)	64 kg	95
3	Sardinhão (<i>P. castelnaeana</i>)	42 un	84
4	Jaú (<i>Z. zungaro</i>) and pirarara (<i>P. hemiliopterus</i>)	60 kg	600



Legend

Community per Km²

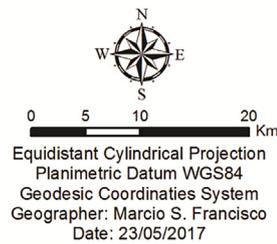
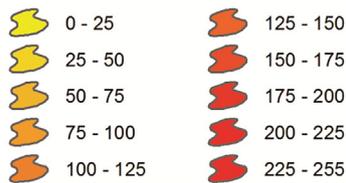


Fig. 4. Density of piracatinga fishing communities (number of communities per km²) in the Lower Mamirauá Reserve.

3.3. Geographical coverage and seasonality of the piracatinga fishery in Mamirauá Reserve

From 65 communities visited, we identified 31 (47.7%)

communities which, at the time, practiced some activity related to the piracatinga fishery, either via residents who were dedicated exclusively to the hunting of caiman to be sold as bait, or who were directly involved in fishing for piracatinga. Piracatinga fishing communities were

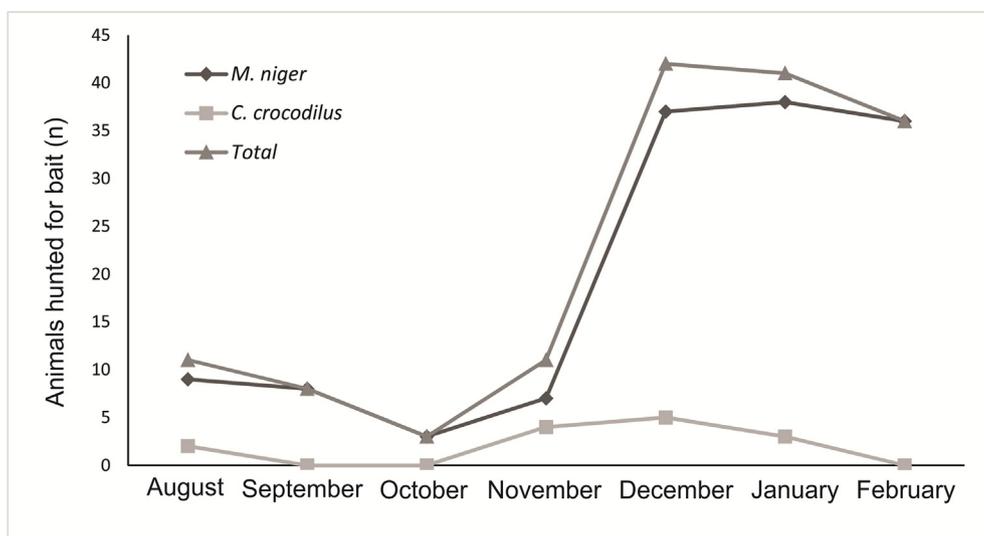


Fig. 5. Amount of caiman hunted for piracatinga bait at Lower Mamirauá Reserve between August 2013 to February 2014.

equally distributed along the Solimões (32.3%), Aranapu (32.3%) and Japurá (35.5%) rivers. However, they did not have a uniform spatial distribution, showing a higher concentration in the northwest portion of the Mamirauá Reserve (Fig. 4), near the municipalities of Maraã, Jutai and Fonte Boa. Twelve communities (38.7% of those characterized as "piracatinga fisher communities") agreed to participate in the monitoring, a relatively high participation rate given that the activity was illegal. Using the data from harvest self-monitoring and from carcass records, we were able to analyze temporal variation of the piracatinga fishery in the MSDR across the study period. A total of 152 hunted caiman were used as bait in 38 fishing events, with an increase in these events from November (Fig. 5). From March to July 2013, participatory monitoring reported no records of caiman hunting for piracatinga fishing. Approximately 78.3% (119) of the caiman killed were used between December and February, indicating an intensification in the piracatinga fishery when seasonal flooding begins in the Solimões river system (Ramalho et al., 2009).

4. Discussion

4.1. The use of baits in the piracatinga fishery in the Mamirauá Reserve

Predominance of use of adult male caiman as bait by piracatinga fishermen indicates selective hunting occurs within the target species. This is a response to marked sexual dimorphism in size and in patterns of habitat use between males and females of both caiman species. Male black and spectacled caiman are larger than females (Best, 1984), so males provide more bait meat and thus guarantee greater profits when fishing for piracatinga (Franco et al., 2016). The intensification of piracatinga fishery during the dry season coincided with the breeding season of the two caiman species. During egg laying, female black caiman goes to the margins of the most isolated lakes, while female spectacled caiman goes into the forest (Villamarín et al., 2011). Consequently, not only are females less desirable because they are smaller, they are also less available during the peak piracatinga fishing season because they have moved to places that are difficult to access by fishermen, who typically hunt caiman in open places, such as paranãs near their communities. Selective hunting of adult males probably has little impact on the caiman population as a whole, since it avoids the extraction of young males, the cohort responsible for dispersal, and females at the reproductive stage, who are responsible for egg laying and offspring care (Barão-Nóbrega et al., 2014; Villamarín-Jurado and Suárez, 2007).

Despite the severe population decline suffered by caiman in

Amazonia as a result of the 20th century skin trade (Smith, 1981), the two species have shown a strong recovery capacity (Rebello and Magnusson, 1983). Once caiman populations were reestablished, human populations in the MSDR began exploiting them, first for caiman meat (da Silveira and Thorbjarnarson, 1999), and later as bait in the piracatinga fishery (da Silveira, 2003). Even so, caiman are now the most abundant game species in the várzea at MSDR (Valsecchi, 2012), with both black and spectacled caiman populations at Mamirauá being the largest recorded anywhere within their ranges (Botero-Arias and Regatieri, 2013; Thorbjarnarson and da Silveira, 2000).

Economic incentives interact with foraging modes and hunting intensity in ways that may have serious consequences for resource sustainability (Damania et al., 2005). Before the legal ban on hunting, the high demand and price commanded by caiman skins had resulted in a highly predatory exploitation of the target species, which had driven many populations to low levels or local extinction (Antunes et al., 2016; Pimenta, 2016; Rebello and Magnusson, 1983; Smith, 1981). Unlike the formerly lucrative, now-collapsed, hunting for the skin trade, the abundance of fishery resources means the piracatinga fishery is not highly remunerative, and so only acts as an additional source of income for riverside human populations (Franco et al., 2016). Bait hunting is both highly seasonal and, like subsistence hunting, seems to use a central-based foraging mode (e.g. Levi et al., 2011; Ohl-Schacherer et al., 2007). Consequently, both the recruitment periods and refuge areas are respected, allowing exploited populations to recover (Sirén et al., 2004).

The set of practices implemented by piracatinga fishermen in relation to caiman-hunting has been in place for some 20 years, and resembles the practices of locals who began hunting caiman for the bush meat trade in the 1980s (da Silveira and Thorbjarnarson, 1999). Measures adopted by caiman hunters within the Mamirauá Reserve comprise a form of informal hunting management that appears to be responsible for the maintenance of caiman populations there, and leads to a better understanding of the resilience of these species to small scale seasonal commercial hunting pressure. However, the extent of várzea, the main caiman habitat at MSDR, as well as the structured community organization that favors the implementation of management practices for the conservation of the aquatic environment as a whole, may be quite distinct from the situation in others protected and unprotected areas of Amazonia. Moreover, the lack of information about population dynamics of both caiman species means it is best to be cautious when assessing the sustainability of caiman hunting for commercial purposes.

Concurrently, the absence of records of boto in bait hunting may suggest that their flesh is no longer used by piracatinga fishermen at

Mamirauá. Beliefs concerning the species' power of enchantment is still strong in local culture (Dutra and Santos, 2014). This, and difficulty in catching them due to their agility (Best and da Silva, 1993), and their relatively low population density (as suggested by Martin and da Silva, 2004), as well as the difficulty in hiding their carcasses, seem to have contributed to the abandonment of boto as bait. However, contemporaneous studies carried out in other areas of Mamirauá Reserve found evidence for the use of boto as bait in communities not participating in our research (Iriarte and Marmontel, 2013a, 2013b), and a reduction in boto survival rates has been found in areas where the piracatinga fishery was occurring (Mintzer et al., 2013). Together, this indicates that the use of boto bait was still current in the Mamirauá Reserve at the time of our study (prior to the moratorium).

It is possible that the absence of records is a result of legislative measures (Lodi and Barreto, 1998) aimed to conserve this charismatic species, which is considered part of the cultural heritage of the Amazon, and whose hunting incurs criminal sentences. Thus, hunting may either have genuinely stopped in our study area, or may have become more profoundly concealed. Sociocultural norms and taboos can act as regulatory measures for hunting of vulnerable species, but can also result in greatly underestimating data on hunting of such species (Vieira et al., 2015), since those involved are reluctant to report illegal hunting events for fear of suffering internal judgment and external punishments. In this context, the moratorium on the piracatinga fishery, motivated by a strong media coverage of the killing of pink dolphins, can make getting data on these species and activities a lot more difficult, without guaranteeing the end of the activity. Instead, the hunt just becomes more concealed and the research on its impacts becomes ever more difficult. Therefore, although the low reproductive rates of the boto make it highly sensitive to exploitation, the real impact of hunting for piracatinga fishery on boto populations remains uncertain.

Likewise, the piracatinga moratorium may also make it difficult to study alternative baits, since catching the fish became illegal. However, the use of other fishes' viscera as bait for the piracatinga fishery found in this study has also been recorded by Brum et al. (2015), Franco et al. (2016) and Gómez et al. (2008) in several different areas within Amazonia, indicating that fishermen themselves have already taken the initiative to look for alternative baits even before the moratorium. Furthermore, a study of the piracatinga production chain has indicated that baits using non-commercial fish or the viscera of already commercialized fish may have the highest profit margin since they have near-zero attainment cost (Franco et al., 2016). Further tests of the viability of fish baits, as well as the development of new tools and fishing techniques, could promote the sustainability of piracatinga fishing by removing hunting pressure on caiman and dolphins. If successful, this would maintain an important source of income for the Amazonian riverine populations during the dry season, also making it possible to maintain the existing closed season for a number of other fish species.

4.2. Participatory monitoring and its implications for conservation

Self-monitoring data meant we could identify characteristics of the exploited animals, and identify temporal and spatial patterns in bait hunting for the piracatinga fishery in the Mamirauá Reserve. As noted in previous analyses of piracatinga (Franco et al., 2016) and caiman meat commerce in MSDR (da Silveira and Thorbjarnarson, 1999), the spatial patterning of caiman hunting for the piracatinga fishery in MSDR is linked to the ease of access to cold storage facilities, which are concentrated in Maraã and Fonte Boa municipalities, nearby the consumer market in Colombia. The high intensity of piracatinga fishery activity during the dry season overlaps with the local closed season for several of commercially-exploited species of fish which reproduce at this time (IN Ibama n°034/2004, IN Ibama-AM n°01/2005, IN MMA n°035/2005, IN Ibama n°01/2012). However, with low water level, caiman, previously dispersed widely throughout the flooded forest,

become concentrated in the main channel of water bodies (da Silveira et al., 2008), greatly facilitating their capture. Thus, intensification of the piracatinga fishery in the dry season indicates the strongly seasonal nature of the activity, which becomes a source of income for the riverside-dwellers during the closed-season for other commercial fish species. High water levels, which make caiman hunting more difficult, combined with the increased availability of species of greater commercial value, were the main reasons given by fishermen for the lack of records of hunting for piracatinga bait between March and July of 2013. However, it was during this period that we began the first contacts between researcher and fishermen, where the bonds of trust were still being established, and the records could have been undisclosed.

Community-based monitoring studies of wildlife harvesting suggest that hunting data for commercial purposes are generally subsampled whenever the activity is illegal (Noss et al., 2004; Vieira et al., 2015). Even sampling for subsistence hunting will often have detection failures, usually caused by lack of economic incentive or by low level of appropriate instruction of the participants (Noss et al., 2004). In this context, it is likely that hunting for piracatinga bait was under-recorded, so the true extent of hunting of caiman and dolphins for piracatinga fishery has been underestimated. Nevertheless, it is possible that the long-term monitoring and the remuneration of a community monitor accompanying the activities of local piracatinga fishermen would greatly assist the gaining of desired information. In addition, adapting data sheets, so that they focus on recording only that data essential for research, plus the use of symbols and drawings that make the table self-explanatory, without the need for literacy, could minimize such loss of information on biometric characteristics as occurred in our research. However, the broad participation of the communities in this study demonstrates the recognition by local population of the importance of co-management of natural resources (interest also reported by Noss et al., 2004; Ohl-Schacherer et al., 2007; Souza-Mazurek et al., 2000; Vieira et al., 2015).

Our study suggests that long-term participatory monitoring can promote the creation of sustainable solutions for the piracatinga fishery in the Mamirauá Reserve by engaging the local community in the search for alternative baits, and/or for managing caiman populations through commercial hunting, as has already been indicated on the previous Amazonas state legislation from 2011 (CEMAAM n° 008). The success of community-based monitoring of this illegal activity reinforces the potential of linking participatory methods to hunting and biodiversity monitoring, thus supporting community agreements for use of fauna, especially where governance is limited and funds for research are very scarce due to high cost of implementation (Yu et al., 2010). Consequently, we also suggest that community-based monitoring and management is an effective tool for game species conservation, as well as for food security and socioeconomic welfare of Amazonian rural populations (Campos-Silva et al., 2017).

5. Final considerations

Although Amazonia-based, the current research highlights the importance of the participation of local communities in the management of natural resources and in the search for economic alternatives linked to conservation in human-natural systems and the global applicability wherever such systems are in conflict. The Mamirauá Sustainable Development Reserve has played a prominent role in providing a model that addresses such issues and interests. The Mamirauá's success has been to bring together representatives of local communities, social and environmental researchers, and members of governmental and non-governmental organizations to mutually establish a co-management model which enables the protection of the landscape and resources for the maintenance of both the regional biodiversity and the way of life of the local population. This co-management reflects a growing demand from local populations for participation in decision-making to improve their standard of living, and aims to bring conservation policies closer

to the local ecological, social and cultural context. However, environmental policies at the national scale persist with the “top-down” model, and this generally results in failure, as illustrated by current Brazilian hunting legislation.

Although wildlife hunting has been banned in Brazil since 1967, there is a clear contradiction between legislation and practice, since hunting continues to be a resource widely exploited by rural populations in Amazonia for both commercial and subsistence purposes (Peres, 2000; Robinson and Bennett, 2013). Besides the lack of communication between population, academia and State (Campos-Silva et al., 2017), the inefficiency of environmental legislation in the Brazilian Amazon is due to large distances and the scarcity of skilled labor, which makes environmental inspection and enforcement of legislation compliance largely impractical. In consequence, it is likely that the prohibition of piracatinga fishing will only “sweep the dirt under the carpet”, and the practice will continue but in a manner invisible to the authorities. In order to avoid environmental laws directed to fauna protection doomed to failure, it is necessary to start easing the access to information through changes in the legislation regarding professional secrecy of hunting studies in Brazil (Verdade and Seixas, 2013) and, especially, in the national hunting legislation. Encouraging wildlife professionals to involve local populations in research on hunting and in decision-making on resources use in the most diverse human-natural system of the world is needed to promote effective environmental and cultural conservation in the tropics.

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