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Small-Scale Fisheries Of Frugivorous Fish In Clear And Black Water Rivers Of The Brazilian Amazon

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Dissertação apresentada ao Programa de Pós-Graduação em Ecologia, do Instituto de Biociências da Universidade Federal do Rio Grande do Sul, como parte dos requisitos para obtenção do título de Mestre em Ecologia.

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“It is more than a little strange to think of people accepting as normal a view of Nature from which they are excluded.”

- Neil Evernden

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ABSTRACT

In seasonally flooded forests of lowland Amazonia, frugivorous fish provide different ecosystem services (ESS): They play an important role in seed dispersal (regulating ESS), but they are also an essential resource for artisanal fisheries (provisioning ESS). Extensive use of limited resources can generate conflicts of interest between conservation goals and the needs of local livelihoods. Co-management schemes try to integrate local food security and ecosystem conservation in the form of extractive reserves (RESEX), where inhabitants are exclusively allowed to extract forest resources while following management rules. Here, we assess the influence of co-management on frugivorous fish and local fisheries of Tapajos (clear water) and Negro (black water) River in the Brazilian Amazon. To this end, we test the following hypotheses: *1) Frugivorous fish are important for fisheries and selectively extracted; 2) Frugivorous fish abundance, size and fisheries productivity is higher inside the RESEX than outside*. Fish landings from 1457 fishing trips were registered over four months by local fishermen in eight fishing communities of each river. Further, 12,730 fish were sampled through 208 gillnet placements, in 32 sites in the floodplain lakes and river channels of the communities. Frugivorous fish are among the ten most fished species in both rivers, reflecting their importance for local communities. In both rivers, landing records show a higher percentage of frugivorous fish biomass (22% of 7,342 kg in Tapajós and 14% of 4,609 kg in Negro River) than samplings (5.9% of 349.2 kg in Tapajós and 6% of 458.3 kg in Negro River), indicating a selectivity of fisheries towards frugivores. In both rivers, fishing pressure (measured as demand for fish) on frugivores was higher outside the RESEX (8 ± 5.4 kg of frugivores caught in Tapajós and 5.6 ± 3.1 kg in Negro River) than inside (0.7 ± 0.3 kg in Tapajós and 0.8 ± 0.1 kg in Negro River). Fisheries' productivity, measured in Catch per unit of effort (CPUE), and the proportion of frugivores in the total catch were higher outside than inside the RESEX of Tapajos River (CPUE: $t=-3.7$, $dF = 4.2$, $p = 0.02$, proportion: $t = -6.7$, $dF = 5$, $p = 0.001$), but did not vary in Negro River (CPUE: $t = -1.9$, $dF = 5.6$, $p = 0.1$, proportion: $t = -0.9$, $dF = 4.6$, $p = 0.4$). Overall, frugivorous fish size was bigger inside the reserve in Negro River, but not in Tapajos River. Fishermen caught bigger pacus (*Myleus spp. Mylossoma spp., Myloplus spp., Metynnis spp.*) inside the RESEX of Negro River

(D = 0.42, $p < 0.001$). In Tapajos River, we detected no effects of the RESEX on frugivore parameters measured. The reserve of Negro River seems to favour frugivorous fish size and availability, even considering that frugivorous fish are selectively caught in local fisheries. Despite potentially higher fishing pressures, frugivorous fish in both rivers were as abundant outside the RESEX as inside, possibly due to market demands, spillover effects or low compliance to management rules inside the RESEX. Our study shows that community-based participatory monitoring is cost-efficient tool for characterizing local fisheries. However, controlling the access of outsiders to the protected resources, besides reinforcing compliance with management rules, are necessary to meet conservation goals while granting local food security. However, frugivorous fish seem to fulfil both their roles as food resource and as seed dispersers.. Therefore, it remains possible to maintain both ecosystem services provided by these fish in the studied clear and black water rivers in the Brazilian Amazon.

Key words: *co-management, extractive reserve, ecosystem services, food security, seed dispersal*

RESUMO

Nas florestas sazonalmente inundadas de terras baixas da Amazônia, os peixes frugívoros desempenham diferentes serviços ecossistêmicos: possuem um papel importante na dispersão de sementes (regulação), além de serem um recurso (provisão) para pescadores artesanais. O uso extensivo de recursos limitados pode gerar conflitos de interesse entre os objetivos conservacionistas e as necessidades dos habitantes locais. O co-manejo tenta integrar a segurança alimentar e a conservação dos ecossistemas na forma de reservas extrativistas (RESEX), onde os habitantes locais podem retirar recursos florestais seguindo regras de manejo. Neste trabalho testamos a influência do co-manejo sobre os peixes frugívoros do rio Tapajós (águas claras) e Negro (águas pretas) na Amazônia brasileira. Foram testadas as seguintes hipóteses: *1)Peixes frugívoros são importantes para os pescadores e são seletivamente escolhidos pela pesca; 2) A abundância, tamanho e a produtividade pesqueira dos peixes frugívoros são maior dentro da RESEX.* Durante quatro meses, pescadores locais registraram 1.457 desembarques pesqueiros em oito comunidades em cada rio. Além disso, foram amostrados 12.730 peixes em 208 pontos de malhadeira em 32 sitios em lagos e no canal do rio nas comunidades estudadas. Peixes frugívoros estão entre as dez espécies mais pescadas nos dois rios, indicando a sua importância para as comunidades locais. Nos dois rios a porcentagem de peixes frugívoros era maior no registro dos desembarques pesqueiros (22% de 7.342 kg no rio Tapajós e 14% of 4.609 kg no rio Negro) que

nas amostragens científicas (5,9% de 349,2 kg no rio Tapajós e 6% of 458,3 kg no rio Negro), indicando uma seletividade dos pescadores para os frugívoros. A pressão pesqueira (medida como demanda por pescado) nos frugívoros se mostrou mais elevada fora de cada RESEX (8 ± 5,4 kg no Rio Tapajós e 5,6 ± 3,1 kg no Rio Negro) que dentro (0,7 ± 0,3 kg no Rio Tapajós e 0,8 ± 0,1 kg no rio Negro). A produtividade da pesca, medida em Captura por Unidade de Esforço (CPUE), e a proporção de peixes frugívoros na captura total foram maiores fora da RESEX no rio Tapajós (CPUE: t=-3,7; dF = 4,2; p = 0,02; proporçao: t = -6,7; dF = 5; p = 0,001) e não variaram no rio Negro (CPUE: t = -1,9; dF = 5,6; p = 0,1; proporçao: t = -0,9; dF = 4,6; p = 0,4). No geral, o tamanho dos peixes frugívoros foi maior dentro da RESEX no rio Negro, mas não no rio Tapajós. Os pescadores capturaram pacus de maior tamanho (*Myleus* spp., *Mylossoma* spp., *Myloplus* spp., *Metynnis* spp.) dentro da RESEX no rio Negro (D=0,42; p<0,001). No rio Tapajós não foi possível detectar efeitos da RESEX nos parâmetros medidos para os peixes frugívoros. A reserva do rio Negro parece favorecer o tamanho e a disponibilidade de peixes frugívoros, apesar de eles serem selecionados pela pesca local. Apesar de uma pressão pesqueira possivelmente elevada, peixes frugívoros foram abundantes dentro e fora da RESEX em ambos os rios, possivelmente devido a demandas do mercado, efeitos de spillover ou baixa conformidade às regras de de manejo dentro da RESEX. Contudo, os frugívoros parecem estar cumprindo seu papel de recurso alimentar e de dispersores de sementes. Nosso estudo evidencia que o monitoramento participativo baseado na comunidade é uma ferramenta economicamente eficiente para a caracterização da pesca local. No entanto, para se atingir os objetivos de conservação e assegurar o recurso alimentar, é necessário que haja um controle do acesso de pessoas de fora das áreas de conservação e um reforço do cumprimento das regras de manejo. Portanto, continua sendo possível manter os dois serviços ecossistêmicos fornecidos por esses peixes nos rios de águas claras e negras estudadas na Amazônia brasileira.

Palavras-chave: *co-manejo, reserva extrativa, serviços ecossistêmicos, segurança alimentar, dispersão de sementes*

TABLE OF CONTENTS

ILLUSTRATION INDEX

INDEX OF TABLES

1. INTRODUCTION

Conflict between human resource use and wildlife is one of the most widespread and intractable issues for conservation (DICKMAN 2010). In the 1970s, the tropical ecologist Daniel H. Janzen called public attention to a much subtler conservation problem than species extinction: the loss of biotic interactions due to anthropogenic disturbances (JANZEN 1974 in JORDANO *et al*. 2006). Since then, research has been investigating how ecosystem functioning can be altered through human influence. The focus of biological conservation has shifted from protecting flagship species and areas to maintaining the integrity of ecosystems and interactions between species (GRUMBINE 1994, PIKITCH *et al*. 2004, JORDANO *et al*. 2006). Such interactions between plants, animals or both play a critical role in the maintenance of ecological communities (JORDANO *et al*. 2006, FARWIG & BERENS 2013). Simultaneously, they directly or indirectly fulfil so-called ecosystem services (CONSTANZA & DALY 1992, CONSTANZA *et al.* 1997), which are substantial to human life and wellbeing (KUBISZEWSKI *et al.* 2017). The term ecosystem services (ESS) will be used hereafter in the sense it was defined in the Millennium Ecosystem Assessment (2005, p.1) as ''*the benefits people obtain from ecosystems* ".

As the human population increases, so do the exploitation of natural resources and the demand for provisioning ecosystem services such as food, fiber and water (GORDON *et al.* 2010, BOMMARCO *et al.* 2013). One of the most important sectors of provisioning ecosystem services is fisheries, providing income for millions of people and 25% of animal protein consumed worldwide (FAO 2009). Especially artisanal fisheries play an essential role for local economies and food security of poor populations all over the world (CERDEIRA *et al*. 2000, SILVANO & BEGOSSI 2001, MOSES *et al*. 2002, BÉNÉ *et al.* 2009; NAVY & BHATTARAI 2009; COOMES *et al*. 2010). In the Amazon Basin for example, more than 50% of the total fish landings of the Brazilian Amazon come from artisanal fisheries (BAYLEY & PETRERE 1989, CETRA & PETRERE 2001), proving that local communities are economically and substantially dependent on fishing resources (COOMES *et al*. 2010). The traditional inhabitants of the Amazon Basin, locally referred to as *ribeirinhos* are mostly peasants of mixed ethnicity (indigenous, European and African), whose activities are increasingly linked to regional markets (PIPERATA 2007), but who still heavily rely on fish as their main source of protein and depend on artisanal fisheries and agriculture for subsistence and cash (SILVA & BEGOSSI 2009, OLIVEIRA 2010, HALLWASS *et al.* 2011). In the Amazon Basin, artisanal fisheries are characterized by their multispecificity and high seasonality. Fishermen use a diverse set of gears such as lines, longlines, gillnets, cast nets and spears and are thus able to target distinct fish (CETRA & PETRERE 2001, HALLWASS 2011). Some of these fisheries have shown selectivity towards few high-valued fish species (BAYLEY & PETRERE 1989, HALLWASS & SILVANO 2016).

However, food provisioning is not the only ecosystem service provided by fish. An example for fish as providers of a regulating service, crucial for natural forest regeneration and diversity, is seed dispersal (DE SOUZA 2008, CAVALLERO *et al.* 2013). A plant's seed dispersal mechanism plays an important part in its life cycle as it is closely linked to its reproduction success and ultimately defines its distribution and therefore species composition at a given locality (JORDANO 2000, GARCIA *et al.* 2011, ALBUQUERQUE 2015). From an anthropogenic point of view, seed dispersal provides essential services to some human societies whose lifestyles are based on the use of forest products (MOEGENBURG 2002, JORDANO *et al*. 2006). Only in recent decades have frugivorous fish gained attention as important seed dispersers, first mentioned by GOULDING (1980). They have been shown to be present in all biogeographical regions including the Neo-Tropics (HORN *et al.* 2011). Their abundance across different water types of Amazonian floodplain forests has been initially described by GOULDING (1980). Ichthyochory (seed dispersal by fishes) has been recognized as one of the fundamental seed dispersal mechanisms in these ecosystems (DE SOUZA 2008, HAWES & PERES 2014). These forests are typically shaped by seasonal flooding during the wet season, which is commonly described as "flood pulse" (JUNK *et al*., 1989, JUNK 1997). This phenomenon creates a special interface, where the combination of terrestrial and aquatic features defines the ecosystem and its characteristics (HORN *et al.* 2011). Depending on the water type, the flooded areas may be called *igapó* (black and clear water) or *várzea* (white water). During the wet season, the forest resources serve as food source for a great number of species. The flooding allows fish to enter the floodplain forest and feed on allochtonous organic material from the forest such as detritus, fruits and seeds. Some of them are specialized frugivores others are opportunistic omnivores that adapt their diets based on resource availability (ARAÚJO-LIMA *et al*. 1995, POLLUX 2011). The fruiting peak of many plant species has been found to generally coincide with the period of inundation, which suggests an adaptation to water-mediated seed dispersal (HAWE & SMALLWOOD 1982, KUBITZKI & ZIBURSKI 1994, MANNHEIMER *et al*. 2003).

Many of the fish species that have been found to be prominent seed dispersers, such as the tambaqui (*C. macropomum),* the pacu (*Mvlossoma* spp., *Myleus* spp., *Myloplus* spp., Serrasalmidae) and the matrinxã and sardinha *(Brycon* spp., *Triportheus* spp., Bryconini), are among the most exploited and most popular species on fish markets in certain regions of the Amazon (GOULDING 1980, SIOLI 1984, GOTTSBERGER 1987, CERDEIRA *et al*. 2000, BATISTA & PETRERE 2003, MACCORD *et al*. 2007, ZUANON & FEREIRA 2008, DORIA *et al*. 2012, HALLWASS & SILVANO 2016). Fisheries' selective extraction of preferred fish species may alter fish community composition and affect biodiversity and trophic structure (GARCIA *et al*. 2012, CORREA *et al.* 2015a). Ultimately, the overexploitation of frugivorous fish can lead to conflicts of interest between ecosystem services and compromise not only food security but also seed dispersal (HOLMLUND & HAMMER 1999). As large fish are more valuable at the fish market, overfishing has decreased size and abundance of commercial fish with serious ecological consequences (WELCOMME 1999, SHIN *et al*. 2005, CASTELLO *et al*. 2011, COSTA-PEREIRA & GALETTI 2015). Several studies report evidence for over-exploitation of the tambaqui indicated by a reduction in size and abundance (BATISTA & PETRERE 2003, GARCIA *et al*. 2009, CASTELLO *et al*. 2011). GARCIA *et al*. (2009) report a replacement of large fish species by small ones over a period of 22 years in the southwest Amazon of Peru. CORREA *et al.* (2015a) state that overfishing of large frugivorous fish might reduce seed dispersal in quantity and quality because large specimens disperse a higher number, diversity and size range of seeds with more germination success than small individuals. Similar conclusions were reached by COSTA-PEREIRA & GALETTI (2015), who estimated significant seed dispersal deficits due to a reduction in size of a frugivorous fish (*Piaractus mesopotamicus)*.

At this interface between ecological conservation, sustainable resource use and local food security lies one of the biggest challenges for conservationists: developing management strategies that allow the non-conflicting use of multiple ecosystem services such as seed dispersal and food provision to local people (SILVANO *et al*. 2014). Holistic management should consider environmental as well as cultural and socio-economic requirements to ensure resource conservation without penalizing local livelihoods (DE GROOT *et al.* 2010, BEGOSSI 2014, LOPES *et al.* 2015). Most conventional top-down approaches have shown themselves inadequate for dealing with the heterogeneous nature of small-scale fisheries. Strictly arbitrary decisions such as protected areas and fishing bans are difficult to implement, where people strongly depend on resource use (BEGOSSI 2008, RUDDLE & HICKEY 2008, DANIELSEN *et al*. 2010). Participative co-management strategies built upon pre-existing local rules and agreements between resource-users, the government and research institutions, have the potential to reduce conflicts, improve compliance, enhance conservation success and increase social welfare (CARLSSON & BERKES 2005, CINNER *et al*. 2005, GELCICH *et al*. 2008, BEGOSSI 2010, GUTIÉRREZ *et al*. 2011, HAMILTON *et al.* 2011, SILVANO *et al*. 2014).). In the Brazilian Amazon, the focus of extractive reserves often lies on terrestrial ecosystems and despite their importance as food resource for locals, freshwater resources obtain less attention in management plans (LOPES *et al.* 2011). However, some communities are part of fishing agreements, sustainable development reserves and extractive reserves, which regulate fishing efforts and control resource access to outsiders (BEGOSSI *et al*. 1999, CASTRO & MCGRATH 2003, ALMEIDA *et al.* 2009; LOPES et al 2011). Previous studies have shown increases in fish abundance and fishing yields and reduced fishing efforts in communities under co-management in clear and whitewater floodplains (ALMEIDA *et al*. 2009, SILVANO *et al.* 2009, SILVANO *et al.* 2014, KEPPELER *et al.* 2017).

However, co-management initiatives have been poorly studied in black water ecosystems and most existing research has been done on lakes, where monitoring and regulations are easier to apply (SOBREIRO *et al*. 2010). Furthermore, it remains unknown whether participative management can benefit biotic interactions and regulating ecosystem services such as the seed dispersal by frugivorous fish. As mentioned above, some fruit-eating fish are commercially important and overfished in white water regions of the Brazilian Amazon Basin. Although research indicates that certain frugivorous fish, such as the tambaqui, are less abundant in black and clear water rivers than in white water (GOULDING & CARVALHO 1982), little is known about their role in local fisheries of clear and black water rivers and whether they are subjected to fishing pressure (BEGOSSI *et al.* 2004, 2005, SILVANO *et al*. 2008, SILVANO *et al*. 2014).

The present study aims to determine possible effects of co-management on the size, abundance and availability of frugivorous fish, which provide ecosystem services such as food resources (provisioning) and seed dispersal (regulating). We investigate *1) the importance of frugivorous fish for local food security in clear and black water rivers* and *2) how co-management influences their size, abundance in the environment and availability for local fisheries* by testing the following hypotheses:

1) Frugivorous fish are important for fisheries; they are selectively extracted.
2) Frugivorous fish inside extractive reserves are bigger, more abundant and more available for fisheries compared to sites outside these reserves, due to reduced fishing pressure and improved fish conservation inside reserves.

2. METHODS

2.1. Study sites

The study addresses a clear water river (Tapajós River) and a black water river (Negro River). Both are situated in the Amazon Basin, where climate is tropical and humid, with mean temperatures close to 26 °C and little annual variations. All study sites are subjected to seasonal variations in precipitation, resulting in the presence of seasonally inundated flood-plain forests along the margins of each river. With rising waters, fish enter the forest where they stay for the flood season, before returning to the river channel with decreasing water levels. In each river, sampling was conducted in four fishing communities inside and four outside Extractive Reserves (RESEX) in the Tapajós (Fig. 1) and the Negro (Fig. 2) rivers, resulting in eight communities per river (16 in total).

2.1.1. Tapajós River

The Tapajós River is considered a clear water river, with low sediment and nutrient concentrations (GOULDING *et al.* 2003). Water level peaks during wet season in May-June and is lowest in November-December (ANA 2012). The lower section of the Tapajós River is very wide, opposite banks more than 15 km apart in some stretches. Our study site is located in the lower section of the Tapajós River (2° 45’00’’ S – 3° 25’00’’ S and 55°19’00’’ W-54°59’00’’ W), which is part of the municipalities of Santarém and Aveiro, state of Pará (Fig.1).

The area contains two main Conservation Units (CUs): The RESEX of Tapajós-Arapinus, subject of the present study, and the National Forest of Tapajós (FLONA) on the opposite side of the river. The RESEX was established in 1998 following a local initiative against illegal logging (ICMBIO 2008). The local riverine population is allowed to live inside the RESEX and pursue subsistence-related activities such as small-scale agriculture, livestock farming, fishing, hunting and extrativist forest production (IBAMA 2004, ICMBIO 2008). The management plan of the RESEX only allows artisanal fishing gear such as gillnets, handlines, castnets and spears and excludes large-scale commercial fishing and sport fisheries from the CU. The commercialization of fish from local artisanal fisheries is permitted inside as well as outside the conservation area.

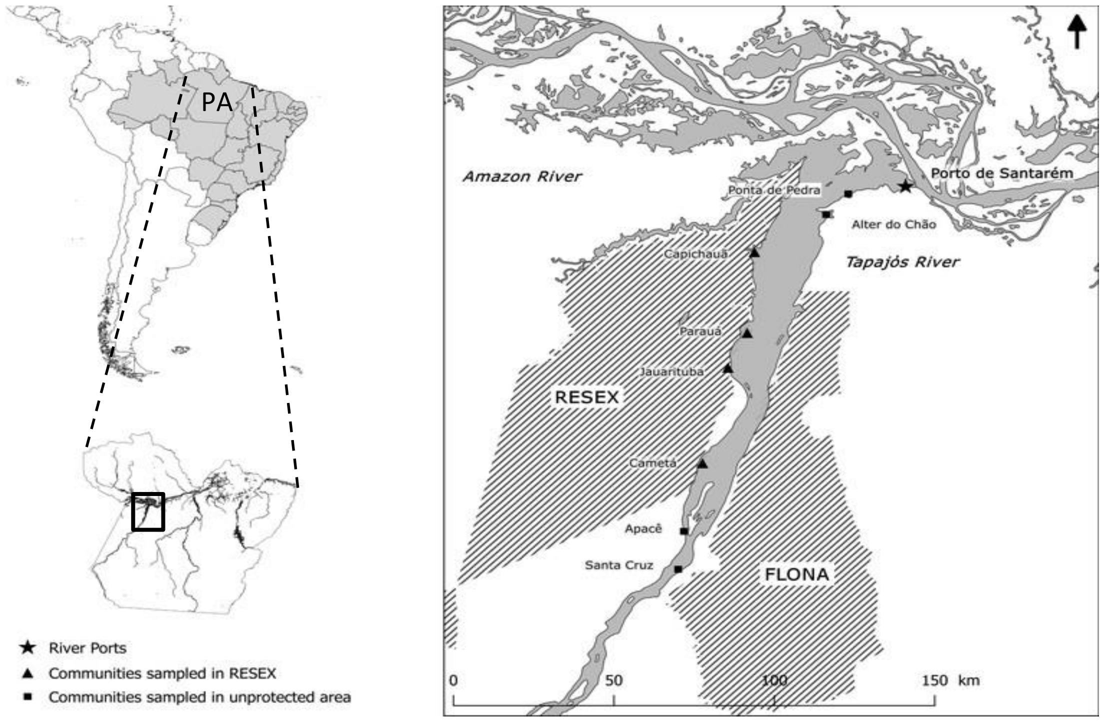


Figure 1: Location of the studied fishing communities in the lower section of the Tapajós River, Pará state (PA), Brazil. Shaded areas designate conservation units (CUs): Extractive Reserve Tapajós-Arapinus (RESEX) and Sustainable Reserve Tapajós National forest (FLONA) on the opposite bank. Sampled communities are marked as triangles (inside the RESEX) and squares (outside). Modified from KEPPELER (2015).

2.1.2. Negro River

The Negro River, one of the biggest tributaries of the Amazon, is a black water river, characterized by extremely low pH, little amounts of solutes, very low nutrient concentrations and staining by tannins and other organic compounds from vegetation, which are responsible for the typical dark colour. Climatic conditions are similar to the ones in Tapajós River (SIOLI 1984). Water levels are lowest from October to November and reach maximum discharge between June and July (ICMBIO 2014). The study area is located around 200 km northeast of Manaus, municipalities of Barcelos and Novo Airão, state of Amazonas. Along the margins of the Unini River, one of the Negro River's major tributaries, lies the Extractive Reserve of Unini River (RESEX Unini) (Fig.2). It was created in 2006, after the demand of local communities for governmental actions against depletion of fish stocks by commercial and sport fisheries (SOBREIRO *et al.* 2010). Similar to the RESEX Tapajós-Arapinus, local people follow management rules and are allowed to exclusively harvest natural resources, while commercial fisheries are forbidden inside this RESEX in contrast to the one in Tapajós River (ICMBIO 2014).

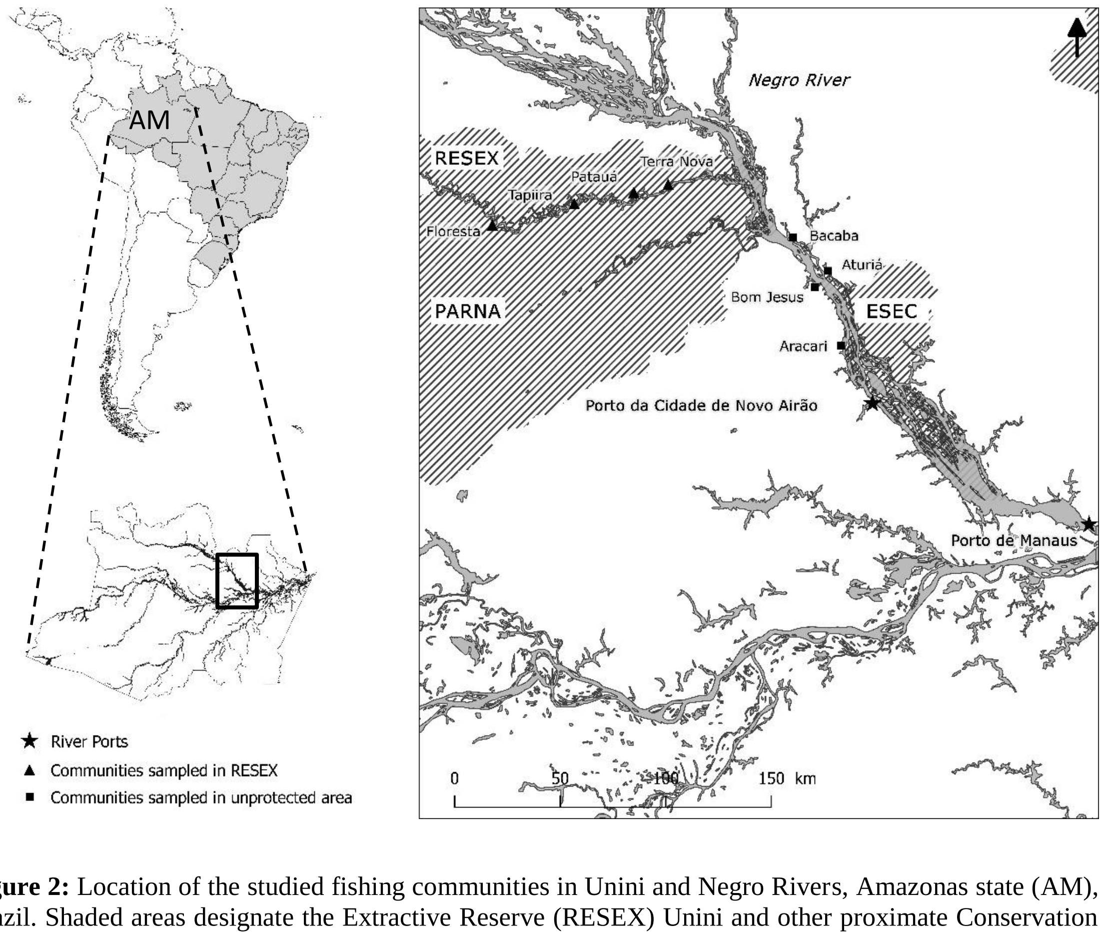


Figure 2: Location of the studied fishing communities in Unini and Negro Rivers, Amazonas state (AM), Brazil. Shaded areas designate the Extractive Reserve (RESEX) Unini and other proximate Conservation Units (National Park of Jaú (PARNA) and National Park of Anavilhanas (only partially shown). Sampled communities are marked as triangles (inside the RESEX) and squares (outside).

2.1.3 Selection of riverine fishing communities

Communities inside the RESEX were considered as being engaged in co-management, because they took part in the creation of the reserves and follow management rules, which they helped establish. In each river, four communities inside and four outside the RESEX were selected according to the following criteria: a) dedication to fishing of most of the inhabitants, b) willingness to participate in the study, and c) distance of about 5 to 10 km from each other and d) comparable size, aquatic habitats exploited and main economic activities (Table 1).

Table 1: Riverine communities in the Extractive Reserve of Tapajós–Arapiuns and an unprotected area of the Tapajós River (Fig. 1), and in the Extractive Reserve of Unini and an unprotected area of Negro River (Fig.2), with number of fishermen who agreed to record the first five fish landings per month for four months (July-October) and number of fish landing forms distributed, retrieved, excluded and analyzed per community. Asterisks indicate communities inside the extractive reserves.

	Community	Fishers (start)	Fishers (end)	Forms distributed	Forms retrieved	Forms excluded	Forms analyzed
TAPAJOS	Alter do Chao	10	9	200	118	3	115
	Apace	12	11	240	189	5	184
	Cametá*	15	12	300	146	6	140
	Capichaua*	9	8	180	76	2	74
	Jauarituba*	11	9	220	129	12	117
	Parauá*	11	11	220	194	0	194
	Ponta de Pedras	10	8	200	99	0	99
	Santa Cruz	8	5	160	73	0	73
	TOTAL	86	73	1720	1024	28	**996**
	Community	**Fishers (start)**	**Fishers (end)**	**Forms distributed**	**Forms retrieved**	**Forms excluded**	**Forms analyzed**
NEGRO	Aracari	5	3	100	23	0	23
	Atúria	4	4	80	40	6	34
	Bacaba	9	4	180	29	4	25
	Bom Jesus	10	10	200	103	12	91
	Floresta*	10	9	200	120	15	105
	Patauá*	5	4	100	38	5	33
	Tapiira*	13	11	260	81	0	81
	Terra Nova*	13	12	260	79	10	69
	TOTAL	69	57	1380	513	52	**461**

2.2. Data Collection

2.2.1. Fish Landings

In each fishing community, fishers were invited to voluntarily record their first five fish landings per month, from July to October 2016. During this period, fish are dispersing from the forest and migrating into the river channel as the water recedes. A total number of 155 fishers (86 in Tapajós River and 69 in Negro River) agreed to record their landings. To ensure that participants were equally capable of recording fish landings, only fishermen with at least basic school education were chosen. Participants were also individually trained and equipped with a toolkit for the recording of fish landings. The kits contained a wristwatch, manual scales, a tape, flashlights, pencils and standard forms (Appendix 1) to be filled with fishing data (duration and time of fishing, type of fish caught, amount and biomass of fish caught, sizes of the smallest and the biggest individuals of each fish caught per fishing trip). A total of 1720 forms were distributed in Tapajós River and 1380 forms in Negro River (Table 1). Some fishers, who had originally agreed to record their landings, withdrew from participation during the project or did not fill in all forms. Complete forms were collected by researchers during two field trips in November and December, 2016 (1024 and 513 forms for Tapajós and Negro Rivers respectively). All forms were carefully checked for eventual mistakes or missing data before tabulating. Forms containing inconsistencies or missing essential information were excluded from the analysis (33 and 54 forms for Tapajós and Negro Rivers respectively). The success rates (proportion of forms included in the analysis considering the total number of forms distributed) were 58% and 34% for Tapajós and Negro River respectively.

2.2.2. Fish Sampling

Each river was visited in two sampling trips, one during the high-water season (June/July) and one during the low-water season (November/December). Fish were collected using two sets of gillnets (420 m² each) with different mesh sizes (15 to 80 mm between opposite knots) during a continuous period of 24 h. To avoid fish damage by predators, gillnets were checked every four hours. At each studied community (= replicates) two fish samplings were conducted, one in a floodplain lake and one in the river channel (Fig.3). In each sampling, three gillnets were placed: One in the center of the river/lake, one at the margin and one randomly placed with a special gillnet called "feticeira", which consists of three layered 80m gillnets of different mesh sizes (25, 35 and 50 mm). During flood season, one additional sampling per community was conducted inside the floodplain forest. Local fishers were hired to assist the sampling. Each fish collected was weighted, measured to standard length and identified to species level.

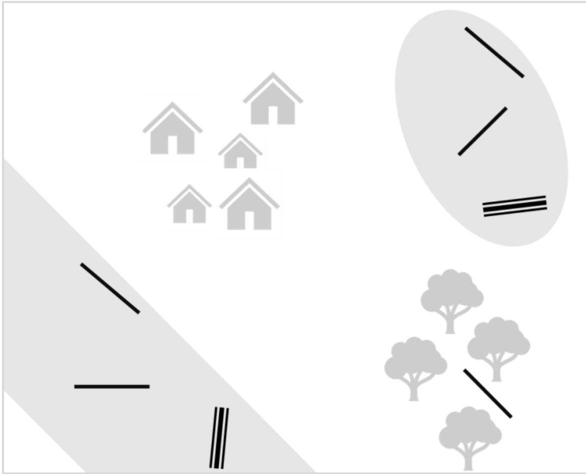


Figure 3: Representation of the fish sampling layout in each fishing community (n=16). Black lines represent gillnets, triple lines stand for special layered gillnets ("feticeira"). Three nets each were placed in floodplain lake and river channel, and one additional net in the floodplain forest during flood season (208 net placements in total). Houses represent fishing communities, trees stand for the floodplain forest. Grey areas represent water bodies.

2.2. Data Analysis

2.2.1. Selection of frugivorous fish

Fish common names mentioned in the fish landing records and fish species from the gillnet sampling were classified into frugivorous and non-frugivorous fish. Common names used by fishers in landing forms frequently encompass more than one scientific species. Often, but not always, these species are closely related with similar dietary habits (Table 2). In a conservative approach, only those species mentioned as classic frugivores species in the literature (GOULDING 1980, ALMEIDA 1984, LUCAS 2008, ANDERSON *et al*. 2011, CORREA & WINEMILLER 2014, CORREA *et al.* 2014, 2015a, 2015b), were considered as frugivorous (Table 2). Other species, for which opportunistic frugivory has been reported, but which generally adopt omnivorous feeding behavior, were not considered as frugivorous in this study. In case of the aracu, we considered *Leporinus* spp. as frugivorous, while *Schizodon* spp. was considered non-frugivorous (Table 2) according to existing literature (FERRETTI *et al.* 1996). We joined all frugivorous fish species for most of our analyses, aiming to detect possible conflicts between the two ecosystem services, food provisioning and seed dispersal, fulfilled by this guild.

2.2.2. Evaluating the socio-economic importance of frugivorous fish

For a general overview of the importance of frugivorous fish for local food security, fish common names were ranked according to the mean biomass extracted by local fisheries. If appearing among the ten most caught fish in the ranking of mean biomass landed per fishing trip, we considered a given fish as important for local food security. We checked the normality of the data with the Shapiro-Wilkes test and homogeneity of variances with the Bartlett test. Data which did not fulfil premises for parametric tests was log-transformed to achieve normal distribution and homoscedasticity. For most of the data from fish landings, normal distribution and homoscedasticity could not be achieved even after log-transformation due to a skewed distribution towards small catches with an excess of zeroes as it is common for tropical small-scale fisheries (HALLWASS *et al.* 2013a). In these cases, non-parametric tests were used. To check, how the importance of frugivores for fisheries differs between black and clear water rivers, we compared the mean percentage of frugivore biomass in fish samplings and landings between rivers with the student t-test and the Wilcoxon rank sum test. Selectivity of artisanal fisheries was evaluated by comparing frugivorous percentage between samplings and landings data for each river separately with a paired t-test and a paired Wilcoxon signed rank test. Communities were used as replicates, grouping fish landing data per community. Randomization tests for pairwise comparison of means were used to compare frugivore and non-frugivore biomass landed within each fishing community. For comparison of frugivorous fish biomass landings between communities within each river we applied Kruskal Wallis tests and Dunn tests for post-hoc pairwise comparison.

2.2.3. Evaluating the Influence of The Extractive Reserve on Frugivorous Fish

We checked for differences in relative (%) and absolute biomass of frugivorous fish sampled inside and outside the RESEX of each river using student t-tests with fishing communities (4 inside and 4 outside the reserve) as replicates. Further, fish landings inside and outside the RESEX were used as indicators for fishing pressure on frugivorous fish and availability of frugivores for fisheries. For comparison of conservation units in each river, we analyzed frugivorous fish biomass as well as catch per unit of effort (CPUE) and percentage of frugivore biomass in the total catch since these variables provide complementary information. Total fish biomass caught informs about the amount of fish extracted from the environment and indicates whether the RESEX is successful in reducing fishing pressure by artisanal fisheries. CPUE represents fisheries' productivity, considering fishing effort invested for catching a given amount of fish and can be interpreted as a proxy for the availability of fish for local food security. For obtaining the CPUE values in kg of fish caught per day, we divided the biomass landed of each fish per fishing trip by the time spent fishing and multiplied the value by 24 hours. We did not consider the number of fishers participating in the trip and the quantity of gear used, because this information was missing in many landing forms. Using only complete forms would have resulted in low sample sizes we were only able to use data from July to October. Finally, the percentage of the total catch occupied by frugivores informs about the relative availability of frugivores in relation to non-frugivores. For all three analyses, we grouped fish landing data per community for two reasons. Firstly, the grouping allowed us to eliminate the excess of zeroes in the data set. Secondly, we considered that data from different fishing trips but from the same community might not be totally independent.

Frugivorous fish sizes (standard length) from sampling and landing data inside and outside the RESEX of each river were compared using Kolmogorov-Smirnov tests and t-tests. Fish that had been predated during sampling to a point that standard length was not measurable, were excluded from the analyses. Scientific species from samplings were grouped into the common names cited by fishers in fish landing forms for better comparability (Table 2) and because an analysis per species would not be possible due to the high diversity and resulting low numbers of individuals per species typical for Amazonian freshwater-ecosystems. For our analysis of fish sizes landed, we considered maximum sizes more informative, since overfishing usually manifests in a reduction fish sizes (downsizing) and therefore impact maximum sizes more than minimum sizes (CORREA *et al.* 2015a, COSTA-PEREIRA 2015). Thus, we used only the sizes of the biggest individuals of each species per landing for comparing size distributions of fish landed inside and outside the RESEX.

3. RESULTS

3.1. The importance of frugivorous fish for local food security

In total, the analyses included 996 fish landings from Tapajos River, yielding 17,342 kg of fish (3,840 kg or 22% frugivores) and 461 fish landings from Negro River, yielding 4,609 kg of fish (660 kg or 14% frugivores). Five frugivorous fish were documented in fish landings: aracu, pacu, matrinchã, pirapitinga, sardinha and tambaqui (Table 2). Sixteen corresponding species were identified from collected specimens (Table 2).

Table 2: Frugivorous fish landed by artisanal fisheries in Tapajos and Negro River and corresponding scientific names according to the literature and scientific gillnet sampling.

Common name	**Scientific name**
Aracu	*Laemolyta* spp. *Leporinus* spp. *Leporinus fasciatus* [a)] *Schizodon spp.*[b)]
Pacu	*Metynnis* spp. *Metynnis cf. lippinocottianus* [a)] *Metynnis cf. luna* [a)] *Metynnis cf. maculatus* [a)] *Metynnis lippinocotianus* [a)] *Metynnis asterias* [a)] *Metynnis guaporensis* [a)] *Myleus* spp. *Myloplus maculatus* [a)] *Myloplus lobatus* [a)] *Mylossoma duriventre*
Matrinchã	*Brycon melanopterus* [a)] *Brycon pesu* [a)]
Pirapitinga	*Piaractus brachypomus*
Sardinha	*Triportheus albus* [a)] *Triportheus auritus* [a)] *Triportheus rotundatus* [a)] *Triportheus sp.*[a)]
Tambaqui	*Colossoma macropomum* [a)]

[a] Fish species collected in scientific samplings and considered frugivorous
[b] Fish species collected, but considered non-frugivorous

In both Tapajos and Negro River, a high number of common names (45 and 24 respectively) were registered by fishers. Mean fish biomass landed in fishing trips did not exceed an average of 5 kg per species, a high variability between fishing trips can be noted. In both rivers, frugivorous fish appear among the ten most caught fish considering the mean biomass landed (Fig.4): aracu (2.5 ± 9.1 kg), pacu (0.9 ± 7.3 kg) and tambaqui (0.6 ± 3.9 kg) in Tapajos River and pacu (1.4 ± 4.4 kg), aracu (0.6 ± 4.7 kg) and matrinchã (0.1 ± 0.9 kg) in Negro River.

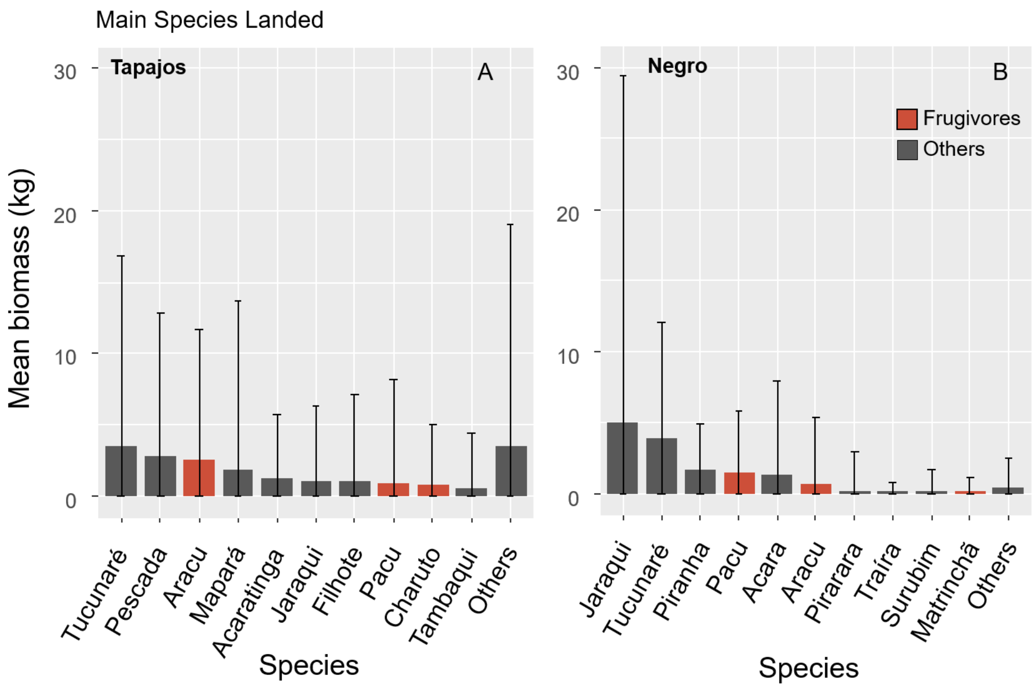


Figure 4: Most extracted fish species in Tapajos (A) and Negro (B) River according to mean biomass per landing. Frugivorous fish species are indicated in red. Grey bars illustrate non-frugivorous species. Error bars represent standard deviation (sd) from the mean biomass extracted per landing event. NTapajos = 876, NNegro = 304. Category "Others" includes several less extracted species.

The percentage of frugivores within the total catch per community did not vary between rivers ($T=-0.2$; $dF = 11.7$; $CI= -0.93, 0.78$; $p>0.847$): On average, 21.1 ± 19.7 % and 18.9 ± 16 % of the total catch were frugivores in Tapajos and Negro River respectively (Fig.5). Further, frugivores occupy a similar percentage of the fish fauna of Tapajos and Negro River (6.4 ± 7.5 % and 5.6 ± 1.3 % respectively) according to sampling results ($W=25$, $p=0.505$). However, in Negro River frugivores were significantly higher represented in fish landings than in samplings (Tab. 3, Fig. 5), indicating a pattern of selectivity towards frugivorous fish in artisanal fisheries. In Tapajos River, data show the same tendency, but no significant difference in frugivore proportion was detected between landings and samplings, indicating less selectivity towards frugivorous (Fig. 5, Tab. 3).

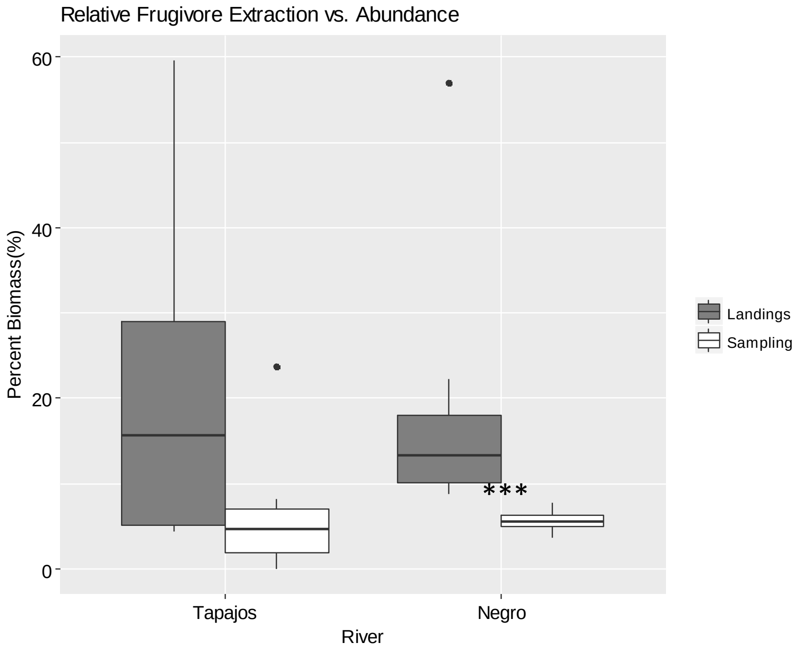


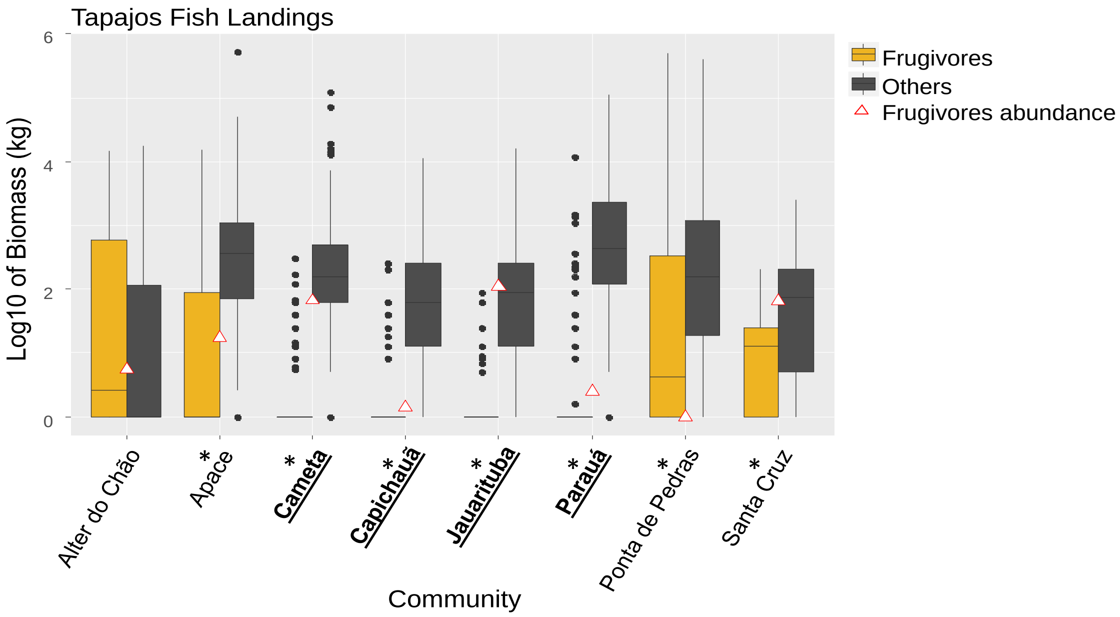
Figure 5: Percentage of frugivorous fish biomass extracted ("Landings") and present in the environment ("Sampling") in Tapajos and Negro River. N = 8 communities in each river. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%); circles are outliers. Wilcoxon-Mann-Whitney and Student t-test for pairwise comparison of means: *p<0.05, **p<0.005, ***p<0.001. Test results are presented in Table 3.

Table 3: Wilcoxon-Mann-Whitney (W, V) and student t-test (T) results comparing the mean percentage of frugivorous fish biomass in the environment (data from scientific sampling) and in artisanal fisheries landings in Tapajós and Negro River. DF = degrees of freedom; CI = confidence intervals. Paired tests were used for comparisons between sampling and landing data within the same river.

		Test value	**DF**	**p**	**CI**
Tapajos vs. Negro	**Samplings**	W=25	-	0.505	-
	Landings	T=-0.2	11.7	0.847	-0.93, 0.78
Samplings vs. Landings	**Tapajos**	T=1.9	7	**0.095**	-0.25, 2.48
	Negro	V=0	-	**<0.008**	-

In Tapajos River, all communities but one extracted on average less frugivorous than non-frugivorous fish (Fig. 6, for mean values and statistical test results see Table 4). In Alter do Chão, fishers landed slightly more frugivores than other fish, however the difference was non-significant. Frugivore mean biomass caught (Table 4) differed significantly between communities (X2 =137.4, dF = 7, p<0.001). Post-hoc analyses for pairwise comparison between communities revealed that the mean biomass of frugivores caught did not differ among communities of the same management scheme, apart from one difference between Apacê and Ponta de Pedras outside the RESEX (Tab. 5). However, communities inside the RESEX (Cameta, Capichauã, Jauarituba and Parauá), extracted much less frugivorous fish than communities outside the RESEX (Alter do Chão, Apacê, Ponta de Pedras and Santa Cruz) (Tab 5). Total frugivorous fish biomass in samplings (red triangles in Figure 6) was highest in the communities of Cametá, Jauarituba and Santa Cruz and did not show any pattern related to the RESEX.

Figure 6: Fish biomass per landing per fishing community in Tapajos River. Frugivore fish biomass is



represented in yellow, other fish biomass in grey. Red triangles represent total frugivorous fish biomass caught in scientific gillnet samplings. Riverine communities considered are: Alter do Chão (n=103), Apacê (n=164), Cametá (n=107), Capichauã (n=65), Jauarituba (n=94), Parauá (n=192), Ponta de Pedras (n=98) and Santa Cruz (n=53). Communities involved in co-management (inside the RESEX) are indicated by underlining and bold letters. For better legibility data is shown on a logarithmic scale. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%); circles are outliers. Randomization test for pairwise comparison of means (frugivorous vs. other fish biomass): *p<0.05, **p<0.005, ***p<0.001. Test results are presented in Tables 4 and 5.

Table 4: Mean biomass landed per community for frugivorous and non-frugivorous fish and randomization test results and number of replicates for pairwise comparison of mean biomass of frugivorous and other fish landed by artisanal fisheries in eights communities of Tapajós River. Communities inside the RESEX are indicated by underlining and bold letters.

Community	Mean frugivore BM (kg)	Mean others BM (kg)	Observed mean difference	p	n
Alter do Chão	10.5 ± 16.6	7.1 ±13.3	-0.81	0.706	103
Apacê	5.1 ± 10.9	17.6 ± 28.5	**12.70**	**0.001**	164
Cametá	0.7 ± 2	14.5 ± 22.7	**13.87**	**0.001**	107
Capichauã	0.8 ± 2	8 ± 9.4	**6.57**	**0.001**	65
Jauarituba	0.5 ± 1.2	8.5 ± 9.8	**8.04**	**0.001**	94
Parauá	1.2 ± 5.3	22.5 ± 26.4	**21.17**	**0.001**	192
Ponta de Pedras	14.3 ± 35.5	24.2 ± 45.6	**9.86**	**0.028**	98
Santa Cruz	2.2 ± 2.3	6.1 ± 6.3	**3.96**	**0.002**	53

Table 5: P-values resulting from Dunn's test for pairwise comparisons of frugivorous fish biomass landed by artisanal fisheries between eight communities of Tapajós River. Communities involved in co-management are indicated by underlining and bold letters.

	Alter do Chão	Apace	**Cametá**	**Capichauã**	**Jauarituba**	**Parauá**	Ponta de Pedras
Apace	0.05	-	-	-	-	-	-
Cameta	**< 0.001**	**0.002**	-	-	-	-	-
Capichauã	**< 0.001**	0.065	1	-	-	-	-
Jauarituba	**< 0.001**	**0.011**	1	1	-	-	-
Parauá	**< 0.001**	**< 0.001**	1	1	1	-	-
Ponta de Pedras	1	**0.049**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	-
Santa Cruz	1	0.108	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	1

In Negro River, frugivorous fish were caught as much as non frugivourous fish in most of the communities (Fig. 7; mean values and statistical test results are presented in Table 6). Only in Bom Jesus (outside the RESEX), Tapiira and Terra Nova (both inside the RESEX) mean biomass extracted was lower for frugivores than for non-frugivores. Comparing mean frugivore biomass landed, we observed a significant difference among communities (X^2=6.66, dF=7, p<0.001). In pairwise comparison, Bom Jesus was the only community to be different, showing higher values than the communities inside the RESEX (Table 7). Frugivorous fish biomass caught in fish samplings did not vary in the same way as landing data.

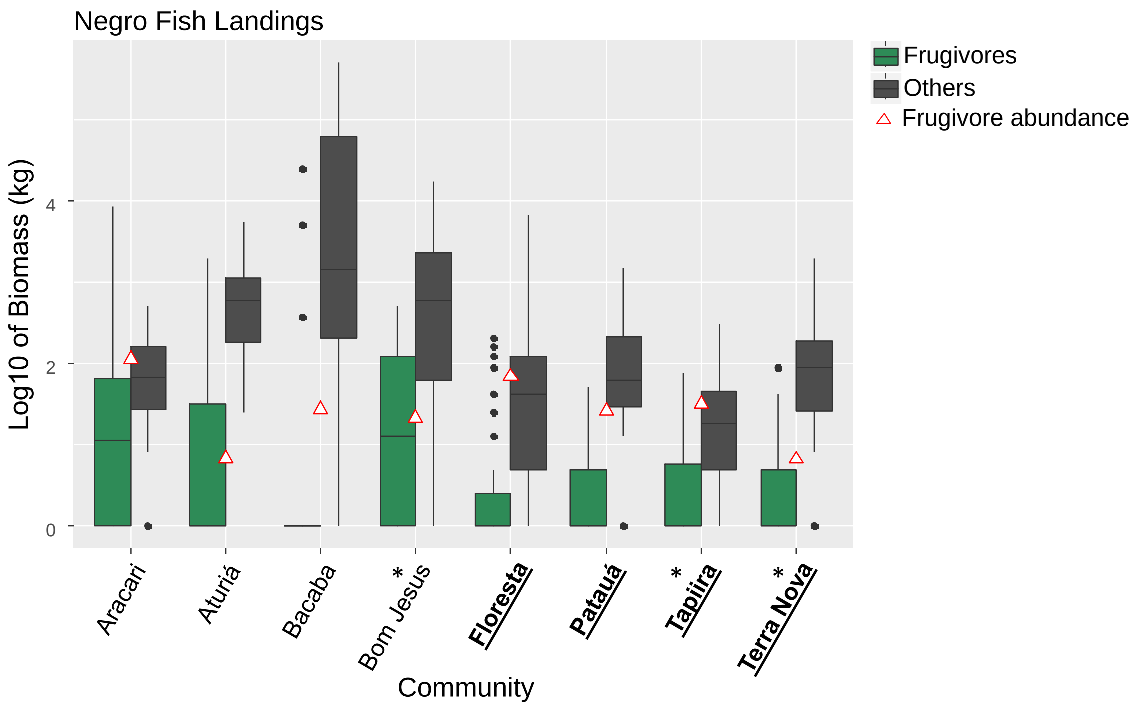


Figure 7: Fish biomass per landing per fishing community in Negro River. Frugivore fish biomass is represented in green, other fish biomass in grey. Red triangles represent total frugivorous fish biomass caught in scientific gillnet samplings. Riverine communities considered are: Aracari (n=8), Aturiá (n=29), Bacaba (n=17), Bom Jesus (n=65), Floresta (n=70), Patauá (n=27), Tapiira (n=44), and Terra Nova (n=42). Communities involved in co-management are indicated by underlining and bold letters. For better legibility data is shown on a logarithmic scale. Median (darker line in the box plot), minimum and maximum values (vertical lines) and outer lines of the box plots showing the quartiles (25% and 75%); circles are outliers. Randomization test for pairwise comparison of mean (frugivore vs. other fish biomass): *p<0.05, **p<0.005, ***p<0.001.

Table 6: Mean biomass landed per community for frugivorous and non-frugivorous fish and randomization test results and number of replicates for pairwise comparison of mean biomass of frugivorous and other fish landed by artisanal fisheries in eights communities of Negro River. Communities involved in co-management are indicated by underlining and bold letters.

Community	Mean frugivore BM (kg)	Mean others BM (kg)	Observed mean difference	p	n
Aracari	8 ± 17.1	5.8 ± 4.4	9.00	0.077	8
Aturiá	2.3 ± 5.1	15.7 ± 9.9	-1.50	0.740	29
Bacaba	8.5 ± 21	74.1 ± 99.3	8.38	0.210	17
Bom Jesus	3.7 ± 4.1	18.4 ± 15.7	**15.80**	**0.005**	65
Floresta	0.9 ± 2	5.5 ± 6.6	0.43	0.896	70
Patauá	0.7 ± 1.2	6.8 ± 5.3	-4.00	0.293	27
Tapiira	0.9 ± 1.3	3 ± 2.6	**8.72**	**0.001**	44
Terra Nova	0.7 ± 1.3	6.9 ± 5.6	**6.68**	**0.001**	42

Table 7: P-values resulting from Dunn's test for pairwise comparisons of frugivorous fish biomass between eight communities of Negro River (data from fish landing forms). Communities involved in co-management are indicated by underlining and bold letters.

	Aracari	Aturiá	Bacaba	Bom Jesus	**Floresta**	**Patauá**	**Terra Nova**
Aturiá	1	-	-	-	-	-	-
Bacaba	1	1	-	-	-	-	-
Bom Jesus	1	0.103	0.117	-	-	-	-
Floresta	0.882	1	1	**9.4e-06**	-	-	-
Patauá	1	1	1	**0.005**	1	-	-
Tapiira	1	1	1	**0.025**	1	1	-
Terra Nova	1	1	1	**0.0003**	1	1	1

3.2 The influence of the RESEX on frugivorous fish abundance in the environment

Mean biomass landed by fishers (Fig. 8A) was higher outside than inside the RESEX in both Tapajos and Negro River ($W = 0$, $p = 0.03$ for both sites). When considering fishing effort for the analysis, using biomass caught per 24 hours (Fig. 8B), mean values were higher outside than inside the RESEX of Tapajos River ($t = -3.7$, $dF = 4.2$, $p= 0.02$), but we observed no difference in Negro River ($t = -1.9$, $dF = 5.6$, $p = 0.1$). We found a similar pattern when comparing the mean percentage of frugivores landed (Fig. 8C), with higher values outside the RESEX than inside for Tapajos River ($t = -6.7$, $dF = 5$, $p = 0.001$) and no difference between sites in Negro River ($t = - 0.9$, $dF = 4.6$, $p = 0,4$).

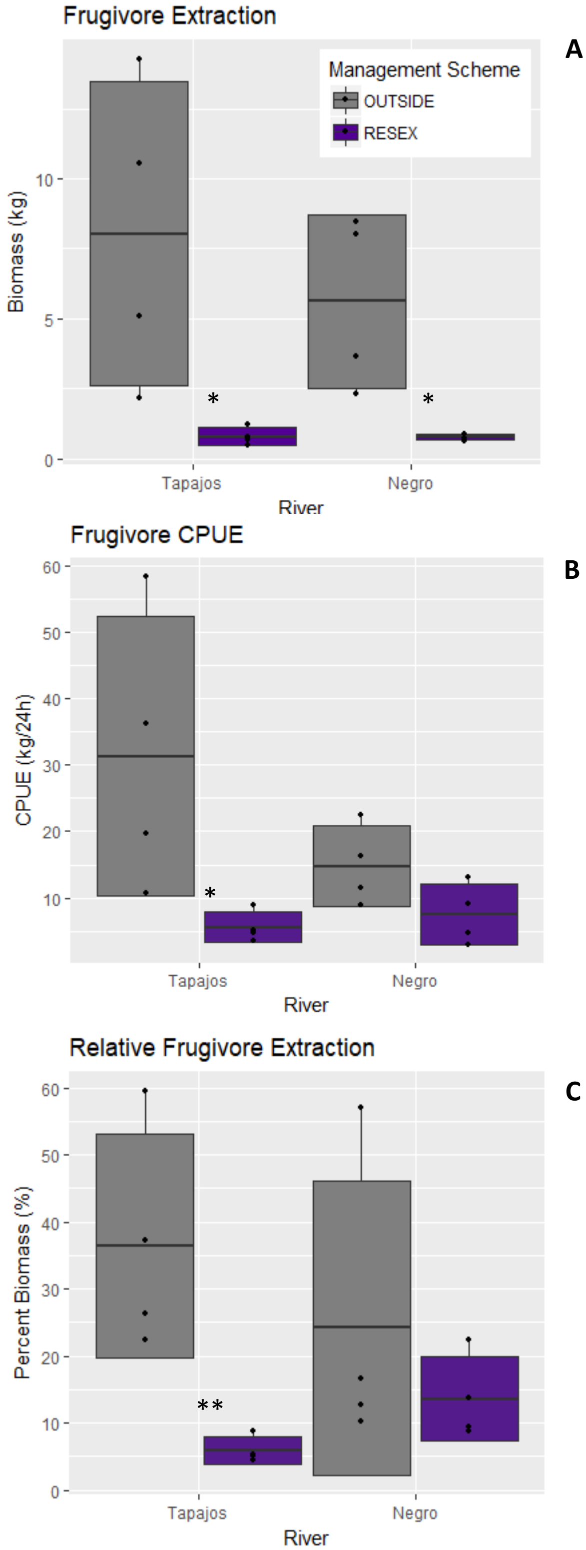


Figure 8: Frugivorous fish landed by artisanal fisheries inside and outside the extractive reserves RESEX Unini ("Negro") and RESEX Tapajos-Arapinus ("Tapajos"). A – Frugivore Biomass (kg), B – Frugivore CPUE (Catch per Unit of Effort) (kg per 24h), C – Relative Frugivore Biomass (%). Data from outside the RESEX is represented in grey, inside in purple. N = 4 per category. Boxplots represent group means (middle line), minimum and maximum values (vertical lines) and standard deviation (outer horizontal lines of the box); circles are individual data points. Wilcoxon rank sum tests and t-tests for comparison between conservation units: *p<0.05, **p<0.005, ***p<0.001.

In scientific samplings, we caught 12,730 individuals or 811,5 kg of fish, including 1,091 (8.6%) individuals or 75.6 kg (9.3%) of frugivores in both rivers. In Tapajos River, 5.9% (20.6 kg) of the fish biomass or 9.8% (575 fish) of all individuals sampled were frugivores. In Negro River, frugivores accounted for 6% of the total biomass (27.5 kg) and 9% of all individuals (617 specimens). Mean frugivore biomass (Fig.9A) did not differ between areas inside and outside the RESEX of Tapajos ($t= 0.33$, $dF = 7.3$, $p = 0.75$) and Negro River ($t = -0.09$, $dF = 5$, $p = 0.93$). Further, frugivores inside the RESEX occupied on average the same percentage of the total fish fauna (Fig. 9B) as outside in both rivers ($t=1.03$, $dF=3.7$, $p=0.88$ and $t= -0.16$, $dF=6$, $p=0.88$ for Tapos and Negro River respectively).

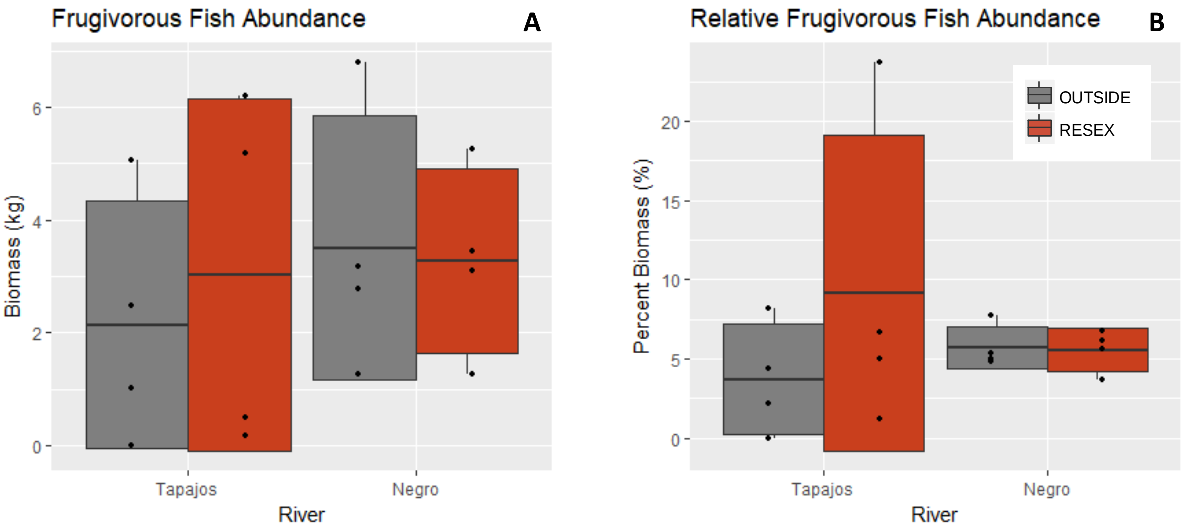


Figure 9: Absolute (A) and relative (B) frugivorous fish biomass sampled in Tapajos and Negro River**.** Fish biomass inside the extractive reserves RESEX Unini and RESEX Tapajos- Arapiuns is indicated in red, outside in grey ($n = 4$ for each category). Boxplots represent group means (middle line), minimum and maximum values (vertical lines) and standard deviation (outer horizontal lines of the box); circles are individual data points.

For testing the effect of co-management (RESEX) on frugivorous fish size, we measured standard length of 560 fish in Tapajos River and 578 in Negro River (Table 8). Fishers documented frugivorous fish sizes of 165 individuals in Tapajos River and 193 individuals in Negro River. Fish sampled outside the RESEX of Tapajos River were bigger than inside when analyzing all fish together and for the sardinha separately. The other fish did not differ in size (Figure 10, Table 9). Fish landed by local fishers did not differ in size inside and outside the RESEX of Tapajos River. In Negro River, sampled aracus and sardinhas were bigger inside the RESEX than outside. Joining all frugivorous fish, higher sizes were encountered inside the

RESEX as well (Figure 11, Table 9). Pacus caught by artisanal fisheries inside the RESEX were bigger than outside (Fig. 11).

Table 8: Number of individuals measured per frugivorous fish inside and outside the extractive reserves (RESEX) of Tapajós and Negro River. Data from scientific samplings and artisanal fisheries (fish landing forms). Data between parentheses were not considered for separate analysis per fish name, but included into the category "ALL".

	Tapajos				Negro			
	Samplings		Landings		Samplings		Landings	
	RESEX	OUTSIDE	RESEX	OUTSIDE	RESEX	OUTSIDE	RESEX	OUTSIDE
All	324	236	65	100	145	433	95	98
Aracu	(5)	(5)	28	24	21	25	14	30
Pacu	35	11	29	38	49	52	74	49
Sardinha	277	213	(0)	(0)	75	355	(0)	(2)
Matrinchã	(6)	(1)	(0)	(3)	(0)	(1)	(7)	(14)
Tambaqui	(1)	(6)	(6)	(30)	(0)	(0)	(0)	(3)
Pirapitinga	(0)	(0)	(2)	(5)	(0)	(0)	(0)	(0)

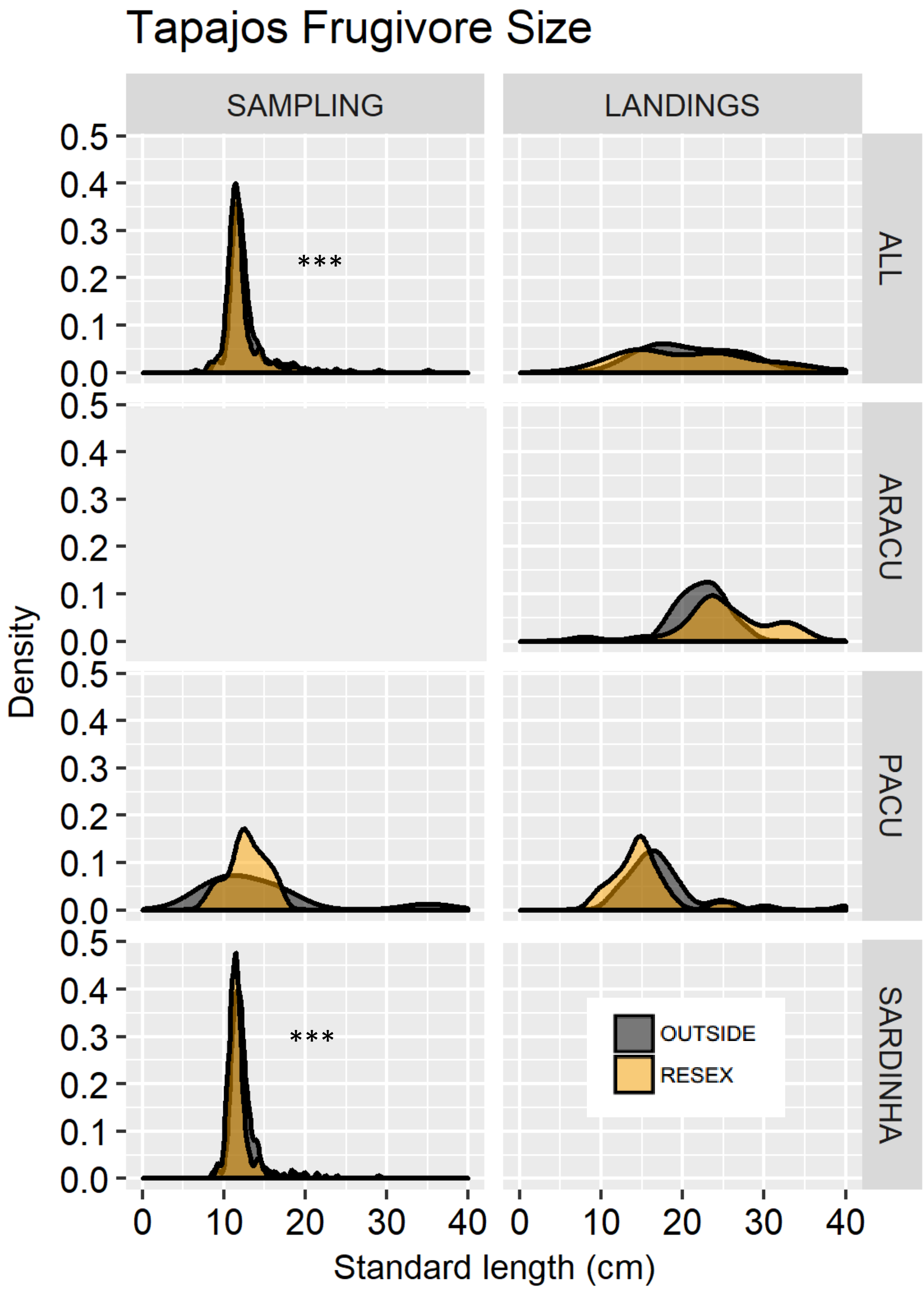


Figure 10: Frequency distributions of frugivorous fish sizes inside and outside the extractive reserve (RESEX) of Tapajos River. The left column ("SAMPLING") represents size distributions in the environment (data from scientific sampling). The right column ("LANDINGS") illustrates size distributions of fish landed by artisanal fisheries. Data from inside the RESEX are shown in yellow, data from non-protected areas in grey. Category "ALL" includes fish sizes of sardinha, pacu, aracu, matrinchã, tambaqui and pirapitinga. Due to very low sample sizes (Table 10), matrinchã, tambaqui and pirapitinga were not analyzed separately. Kolmogorov-Smirnov and Student T-Tests for comparison of size distributions: *p<0.05, **p<0.005, ***p<0.001.

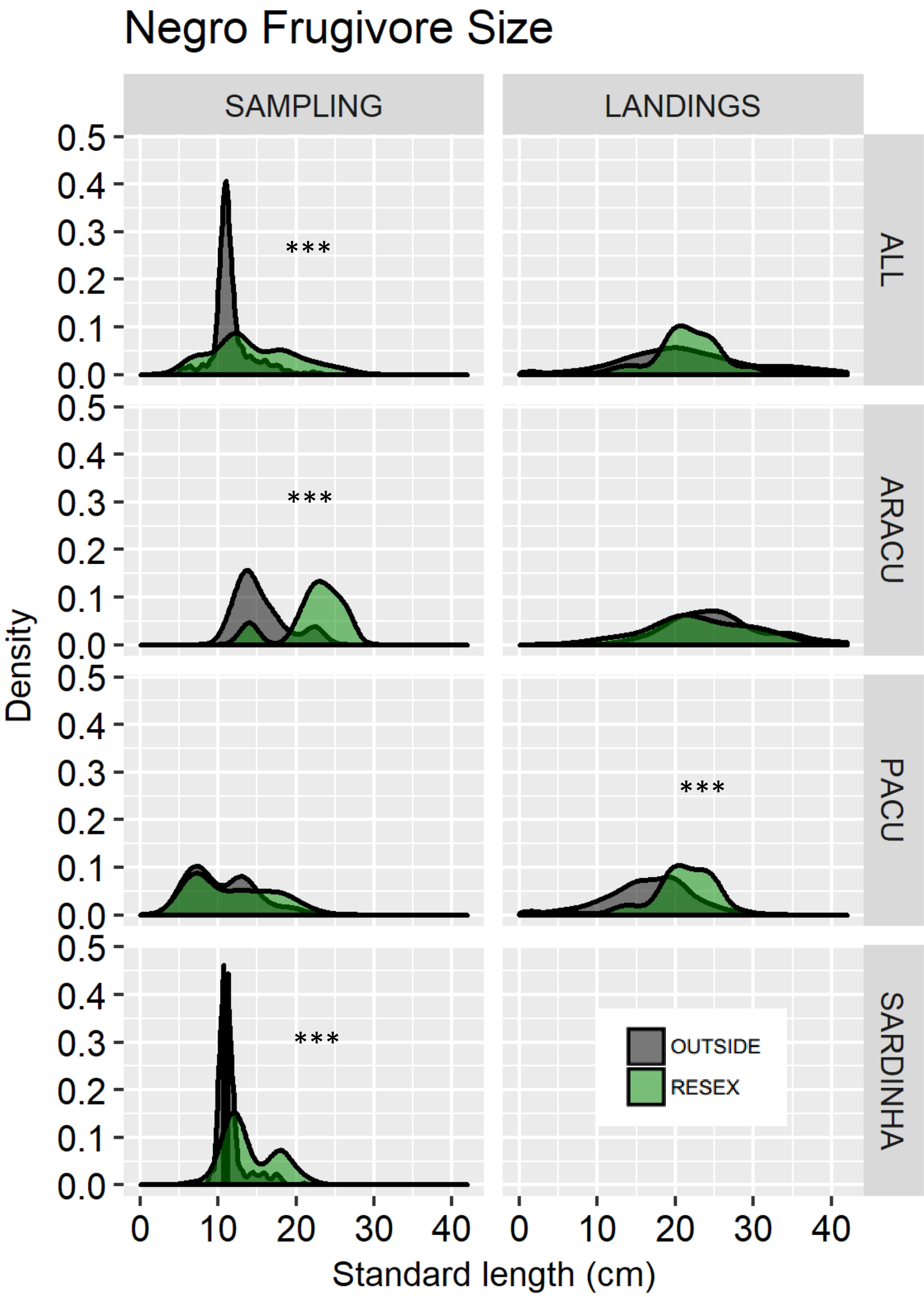


Figure 11: Frugivorous fish sizes inside and outside the extractive reserve (RESEX) of Negro River. The left column ("SAMPLING") represents size distributions in the environment (data from scientific sampling). The right column ("LANDINGS") illustrates size distributions of frugivorous fish landed by artisanal fisheries. Data from inside the RESEX are shown green, data from non-protected areas in grey. Category "ALL" includes fish sizes of sardinha, pacu, aracu, matrinchã, tambaqui and pirapitinga. Due to very low sample sizes (Table 10), matrinchã, tambaqui and pirapitinga were not analyzed separately. Kolmogorov-Smirnov and Student T-Tests for comparison of size distributions: *p<0.05, **p<0.005, ***p<0.001.

Table 9: Kolmogorov-Smirnov and t-test results for comparison of size distributions of frugivorous fish inside and outside the extractive reserves (RESEX) of Tapajós and Negro River. Category "ALL" includes the ethnospecies aracu, pacu, sardinha, tambaqui, matrinchã and pirapitinga. Data from scientific samplings and artisanal fisheries (fish landing forms).

	Tapajos Samplings		Landings		Negro Samplings		Landings	
	test	p	test	p	test	p	test	p
All	D=0.18	0.0002	D=0.18	0.16	D=0.40	8.882e-16	D=0.17	0.13
Aracu	D=0.31	0.41	D=0.33	0.13	D=0.74	8.211e-06	T=-1.14	0.26
Pacu	T=-1.76	0.12	D=0.32	0.07	D=0.19	0.3	D=0.42	7.351e-05
Sardinha	D=0.21	0.0001	-	-	D=0.50	4.552e-14	-	-

4. DISCUSSION

In general, our results corroborate our first hypothesis, that frugivorous fish are important for small-scale artisanal fisheries in clear and black water rivers. The appearance of frugivorous fish among the ten most caught fish in both Tapajos and Negro River (Figure 4) demonstrates their relevance for local food security. In particular the aracu and the pacu fish seem to play an important role in local fisheries. In our samplings, we caught no pirapitinga and only one individual of the tambaqui in Tapajos River (0.14 % of the total fish biomass sampled), indicating that these two fish species are very rare in the studied sites. Indeed, GOULDING & CARVALHO (1982) described *Colossoma macropomum* as *"widely distributed in the Amazon Basin, though rare or absent in […] blackwater and clearwater rivers."* Relative abundance of frugivorous fish was very similar in Tapajos and Negro River (5.9% and 6% of the total biomass sampled), which could indicate that frugivorous fish are equally represented in fish communities of these two nutrient-poor rivers. SAINT-PAUL *et al.* (2000) studied fish assemblages in one black water and one white water lake of Negro and Solimões River. Using the data they provided on biomass sampled per fish species in each ecosystem, we were able to calculate frugivorous fish proportions of 9.9% and 9.1 % for black and white water respectively; again two very similar values for two different water types, although total biomass was more than double in the white water river. The value for black water fish from SAINT-PAUL *et al.* (2000) being higher than the one we found (9,9 % versus 5.9%), might be due to differences in the sampling method or to higher proportions of frugivores in lakes than in the river channel. It is interesting, that despite different nutrient levels and physio-chemical properties, frugivores seem to be similarly abundant within the fish communities of black, white and clear waters.

When comparing the relative abundance of frugivorous fish between fish samplings and landings, a preference for frugivores in fisheries is evident. In Negro River, artisanal fishers caught a higher proportion of frugivore than that present in the samplings (Figure 5), indicating a pattern of selectivity of artisanal fisheries towards preferred frugivorous species (mainly pacu and aracu). In Tapajos River, although non-significant, a similar trend of frugivore selection is visible from the data. However, frugivores seem to be relatively less important for fisheries In Tapajos than in Negro River.

When looking at frugivorous biomass landed by each of the communities studied (Figure 6), the majority of communities of the Tapajos River land mostly non-frugivorous fish. It is notable that communities inside the RESEX caught less frugivores than outside, although the fish are equally abundant in the environment inside and outside the RESEX. Fishing pressure on frugivores is therefore considerably lower inside the RESEX. Only in the community of Alter do Chao, frugivorous catch is similar to non-frugivorous catch. During fieldwork, we noted this community to be the most distinct from the others in socio-economic terms. Alter do Chao is closest to the city of Santarém and a popular destination for tourists, which reflects in local economies (personal observation). Many of the fishers interviewed in the context of our project pursue activities related to tourism in addition to fishing (Renato Silvano, unpublished data). Frugivorous fish being popular on the fish market and in restaurants, this interaction between tourism and fisheries might influence fishing habits and therefore the composition of fish landings. In Negro River, frugivores are caught as much as non-frugivores in five out of eight communities studied (Figure 7). In the community Bacaba, values for frugivores and non-frugivores seem very different, however, no significance was detected probably due to some fishing trips with very high frugivore catch. In general, Bacaba shows very distinct values with a very high data variation, probably due to the socio-economic context. Many of the fishers here work for so-called "geleiros", big fishing boats, which exploit great amounts of fish for commercialization at local markets of the cities of Novo Airão and Manaus. In the rest of the communities, fish is caught for subsistence purposes or sold on a much smaller scale.

Our second hypothesis, stating that fish are more abundant, bigger and more available for fisheries inside the RESEX, was only partly corroborated. Fishers of both rivers caught more frugivorous fish outside the RESEX than inside (Fig. 8A). In Negro River, this difference between was not observed when comparing the CPUE (Fig. 8B), suggesting that fisheries of frugivorous fish are equally productive inside and outside the RESEX, but that fishing effort is higher outside the RESEX. The proportion of frugivores in the total catch of Negro River (Fig. 8C) also being similar inside as outside the RESEX, it can be concluded that fishers generally fish more outside the RESEX, but that frugivores are equally available in both regions, which is supported by scientific samplings showing no difference in abundance between sites inside and outside the RESEX. Although this does not corroborate our hypothesis, in terms of frugivore abundance, the RESEX of Negro River seems to play a role in reducing fishing pressure on frugivores.

In Tapajos River, on the other hand, CPUE and proportion of the total catch of frugivorous fish were much higher outside the extractive reserve than inside. Results for biomass and CPUE were similar, which reflects similar fishing effort in both conservation units. On the one hand, this could mean that, although as abundant, frugivorous fish are more available outside the RESEX than inside. More likely, results may indicate that fishing behavior differs between conservation units and that fisheries outside the RESEX are more selective towards frugivores. A possible explanation could be local demands favoring frugivores on the market. On the other hand, local inhabitants of the RESEX are legally allowed to sell the fish they catch on the market if they follow some management rules. According to our interviews, around half of the fish caught is sold both in communities inside as well as outside the RESEX on the same local fish markets, ruling out market demands as a driver for higher selectivity for frugivores outside the RESEX. However, inside the RESEX locals hold exclusive rights over the use of natural resources, while outside resources are heavily exploited by geleiros. In workshops and meetings that we held in each community to discuss some of our results, fishers repeatedly reported the activity of such geleiros, extracting high amounts of catfish, a more valuable fishing resource in this region. It is possible, that inside the RESEX of Tapajos River, these fish are more abundant and therefore more targeted by local fishers with the intent to sell them on the market. Outside the RESEX on the contrary, the higher concentration artisanal fishers on frugivores could be a response to resource competition with geleiros, which may reduce the availability of preferred commercial fish.

Contrary to our expectations, no effect of the RESEX on frugivore abundance or proportion in the environment was detected (Fig.9). This is surprising, considering that management and a reduced demand for fish can reduce fishing pressure inside the RESEX in the Tapajos River, as suggested by KEPPELER *et al.* 2017). The absence of a relation between frugivorous fish abundance and the amount extracted, suggests that fishing patterns are driven by other factors than fish availability. Equal frugivore abundance despite of unequal fishing pressure between conservation units could have different explanations:

First, it could be a sign that frugivores are still able to sustain fishing pressure in the studied regions and that frugivore abundance is rather limited by environmental and geographical factors. In Tapajós River, two communities outside the RESEX (Alter do Chao and Ponta de Pedras) are close to the Amazon River. The influence of its productive white waters, which may support a higher frugivore fish biomass, could play a role in improving frugivore fisheries' productivity, s. In the two communities upstream of the RESEX (Santa Cruz and Apace), a similar effect might result from a different river physiognomy, comprising a narrower river channel and a higher number of islands. Frugivores could might benefit from these features through increased habitat heterogeneity and better fruit availabilities, even considering a higher fishing pressure. Environmental alterations, such as deforestation and dams might therefore impact frugivore abundance in these areas. In the Turucuí Reservoir of the Lower Tocantins River for example, local ecological knowledge (LEK) of fishermen about the environmental impacts of the dam was studied by HALLWASS *et al*. (2013b). Fishermen there reported, that among other fish, the pacu decreased in abundance after the impoundment of the river (HALLWASS *et al.* 2013b).

Second, possible differences between frugivore abundance inside and outside the RESEX could be masked by so-called "spillover" effects, where protected areas have positive effects on the fauna of surrounding non-protected areas due to fish migration. Especially in aquatic environments, this phenomenon is well documented, for example by (MCCLANAHAN & MANGI 2000, RUSS *et al.* 2004). Similarly, it is possible that frugivorous fish stocks benefit from co-management inside the RESEX and spread along the river, thus balancing the effect of higher fishing pressure outside. Long-distance movement patterns of frugivores such as the tambaqui, the pirapitinga, and the matrinchã, mainly linked to reproduction and seasonality, have been described in existing literature (GOULDING & CARVALHO 1982, ZANIBONI 1985, MAKRAKIS *et al.* 2007, ANDERSON *et al.* 2011). This theory is reinforced by the GOULDING (1980), who describes seasonal migrations along the river channel of several fruit-eating Characins (*Colossoma*, *Mylossoma*, *Brycon*, *Triportheus* ans *Leporinus*), dispersing after reproduction. Such migrations might equalize frugivore abundance along the river channel and mask possible effects of the RESEX in increasing fish abundance.

Third, besides the jaraqui in Negro River, geleiros outside the RESEX primarily target big catfish (ALMEIDA *et al.* 2001). GARCIA-VASQUEZ *et al.* (2009) and TORRES (1974) reported some species of the pacu and sardinha among the main food items of the dourada catfish (*Brachyplatystoma rousseauxii*). BARTHEM & GOULDING (1997) state, that some catfish target *Brycon* spp. as prey. Higher fishing pressure on catfish outside the RESEX could therefore have led to higher survival rates of frugivores due to predator release and thus mask possible effects of the RESEX.

A fourth explanation could be a possibly low compliance to management rules inside the RESEX. Since, at present, there exists no mechanism for testing whether existing regulations are followed by locals, this study assumed *a priori*, that these rules are being applied. In practice however, the rules might not be respected by some or many fishers, leading to similar exploitation of fish resources inside and outside the RESEX. A low compliance with existing rules would explain the missing effect of the RESEX on frugivore abundance.

Concerning fish sizes, the reserve in Tapajos River had the opposite effect of what we expected, frugivores in general and the sardinha in particular being smaller inside the RESEX than outside (Fig. 10). The reserve of Negro River however, seems to benefit fish size of the aracu and the sardinha and of frugivores in general. Further, fishers here caught bigger pacus inside the RESEX than outside (Fig.11). This suggests that the RESEX Unini efficiently protects frugivores from downsizing through overfishing as described by COSTA-PEREIRA & GALETTI (2015) and CORREA *et al.* (2015a). The targeting of big fish is usually a response to the market, where the value of fish increases with their size. The commercialization of fish caught inside the RESEX Unini was prohibited in by the Brazilian Federal Justice in 2008. Since then, inhabitants of the reserve fish only for subsistence, except for the pirarucu (*Arapaima gigas)* and the acara disco (*Symphisodon* spp*.)*, which can legally be sold (ICMBIO, personal communication). The prohibition has probably contributed, together with local management rules such as no-take lakes and spatial or temporal restrictions, to the success of the RESEX in reducing fishing pressure and preserving fish sizes, despite local preferences and selectivity for frugivores. Furthermore, the reserve of Negro River is located along the bank of a tributary of the main channel, where constant control of boats entering the area is provided by a floating station of the ICMBIO at the entrance of the tributary. The reserve of Tapajos River on the other hand has more than one "entry", which makes surveillance of intruders more difficult. The geographic situation of the reserves influences control possibilities, which might be one of the reasons for differences in success concerning fish sizes. In general however, co-management seems to have potential in maintaining fish sizes, which are be important for the persistence of ecological interactions.

Our results are consistent with existing literature on resource use in the Brazilian Amazon Basin. BEGOSSI *et al.* (2005), SILVA & BEGOSSI (2004, 2007) and SILVA (2007) have studied resource use in Negro River and found several species of pacus and aracus among the most consumed fish in riverine populations of the studied regions. Besides, more than 50% of the local inhabitants interviewed by SILVA & BEGOSSI (2007) cited these two fish as their preferred fish for consumption. Similar preferences for pacu, aracu and/or other frugivorous species (matrinchã, pirapitinga and tambaqui) have been encountered in Tocantins River by BEGOSSI & BRAGA (1992), in Madeira River by OLIVEIRA *et al*. (2010) and in Solimoes River by QUEIROZ (1999). In their study on fishers' food preferences and taboos in Araguaia, Jurua, Negro, and Tocantins River, BEGOSSI *et al.* (2004) suggest that riverine cultures tend to ban carnivorous fish during illness, while frugivores like the aracú and the pacu are usually recommended. These preferences are also reflected by preliminary analyses of data from interviews conducted in the bigger framework of our project, where frugivores were cited among the most important fish by the majority of participants (Renato Silvano, unpublished data). However, the importance of the tambaqui and the pirapitinga for riverine communities studied here seemed to be lower than what has been described by previous research in white water rivers, where the tambaqui is highly appreciated and one of the most sold species on fish markets (GOULDING & CARVALHO 1982, BARBOSA & SILVA BATISTA 2013).

Concerning selectivity of fisheries, it has been previously demonstrated that fishers in the Amazon Basin possess detailed insights on fish ecology and spatial and temporal variations in fish abundance and modify their behavior related to fishing gear used and fishing spot to maximize fishing reward and select preferred species (SILVANO *et al*. 2008, BRANDAO & DA SILVA 2009, HALLWASS *et al.* 2013a). HALLWASS & SILVANO (2016) analyzed fisheries of 56 sites along the Amazon basin and found most of them to be selective towards few fish species, mainly driven by market demands. On the other hand, as discussed by HALWASS & SILVANO (2015), fisheries selectivity risks to be overestimated, if there is a high amount of bycatch discarded before landing. In the case of the present study, this is however unlikely, since the small-scale fisheries of the studied system tend to use low-value species for subsistence and sell high-value species on the market, therefore reducing effects of bycatch (BEGOSSI & RICHERSON 1992, BATISTA *et al*. 1998).

Our research has some limitations. Landing forms included in the analyses only document fish landings of four months (July – October), while fish samplings took place in June/July and November/December. The well-marked seasonality of the Amazon floodplain forests shows variations in the water level of up to 10 m (JUNK 2001). This hydrological variation impacts the life histories and behavior of fish (GOULDING 1980) and thus, fishers adapt their behavior, which affects catch composition (HALLWASS et al. 2011, 2013b). Fish landings used in this study were registered at the end of wet season, when water levels were starting to recede. Since fruiting of most trees coincides with highest water levels (MANNHEIMER *et al*. 2003, KUBITZKI & ZIBURSKI 1994) one would expect a higher proportion of frugivorous fish present. In the dialogue with fishers of Alter do Chao for example, seasonal variation in the presence of the aracu fish was described. Using data of the part of the year where frugivores are more abundant, could have biased the comparability of fish landing data with data from our scientific samplings and led to an overestimation of fisheries' selectivity.

In this study, we considered only the fishing pressure exerted by small-scale artisanal fisheries. Landings of commercial fisheries, which account for a much bigger amount of fish extraction in communities outside the RESEX, were not included in the study design. Monitoring of commercial fish landings is a very sensitive topic, which may result in mistrust of fishermen and their resistance to collaborate. During meetings with fishermen from our studied communities, commercial fisheries were repeatedly accused of not respecting fishing rules regarding gear and quantity of fish and of invading the area of the RESEX. However, to elucidate eventual conflicts between artisanal and commercial fisheries, and get a better idea of the amount of fish extracted from the environment, future studies should aim to include data from the landings of the geleiros.

Although we did not directly test the extent to which frugivorous fish contribute to seed dispersal and plant recruitment in our study system, literature strongly supports their role as essential dispersal agents in floodplain forests. Numerous studies involving feeding experiments, germination tests and radio telemetry show that seed ingestion by frugivorous fish can have positive effects on plant reproduction (HORN *et al*. 2011), increase germination success (KUBITZKI & ZIBURSKI 1994, CHICK *et al.* 2003, DE SOUZA 2008; ANDERSON *et al.*, 2009), disperse seeds over extremely long distances (ANDERSON *et al*. 2011) and disperse high numbers of large and non-buoyant seeds (CORREA *et al*. 2007, GALETTI *et al*. 2008). We therefore consider frugivorous fish abundance and size as a proxy for fish-mediated seed dispersal.

In order to maintain the different ecosystem services provided by frugivorous fish (seed dispersal and food security), management efforts should aim to improve compliance to management rules and restrict the access of outsiders to fishing resources. Stricter controls at the entrance and exit points of the reserve of Tapajos River should be implemented to reduce intrusions by *geleiros*. Even outside the RESEX, the conservation of fish and fisheries could be improved through the establishment of fishing agreements with locals, in order to reduce fishing pressure from *geleiros.*

The commercialization of fish being prohibited in the RESEX of Negro River seems to positively impact fish sizes. Similar measures could be considered for frugivores inside the RESEX of Tapajos River in order to prevent downsizing. However, efforts of prohibiting commercialization might encounter high resistance by fishermen. Measures like size limits or fish quotas might be more compatible with local needs. Considering the economic importance of fish commercialization for locals, close collaboration with fishermen in the elaboration of such rules is important to ensure that food security is maintained.

Finally, similar percentages of frugivore biomass across water types with different productivities underline that their abundance is less influenced by autochtonous than by allochtonous resources. Therefore, conservation plans should include terrestrial resources and adapt to the physiognomy of the area. Island-rich landscapes and natural variations in the width of the river channel should be maintained in order to provide heterogenous habitats for frugivores. Human disruptions of the natural flow of the river such as dams should be prevented.

5. CONCLUSIONS

We conclude that frugivorous fish in the two rivers studied in this paper continue to fulfill their ecological role as seed dispersers while contributing to local food security. Fisheries do not seem to compromise the ability of frugivores to fulfill other ecosystem services. However, environmental and geographical factors might influence frugivore abundance and should be considered in management schemes. Testing the effect of these variables on fish abundance should be part of further analyses, in order to be able to improve conservation plans.

Our study confirms the importance of including local populations in ecological studies and management plans. Especially in fisheries, people and natural resources are closely related and fish often play a role in providing several ecosystem services at a time. In such complex systems, continuous monitoring and the consideration of local ecological knowledge are crucial to the success of management strategies. Further, controlling the influence of market mechanisms and the access of outsiders to managed resource seems to be crucial for the success of conservation units.

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FINAL CONSIDERATIONS

In small rural communities, whose inhabitants fish and hunt for subsistence, people are closely interlinked with and dependent on the ecosystems they live in. Therefore, accounting for the needs of resource users and reconciling ecosystem functioning with the maintenance of local livelihoods is crucial to the success of conservation strategies that aim to resolve human-wildlife conflicts (BERKES 2004, TREGIDO 2017). Our results reinforce the fact that local ecological knowledge (LEK) of people provides invaluable information on resource availability and use and allows managers to detect future or existing subjects of conflict (BERKES *et al.* 2000, CALHEIROS *et al.* 2000, BERKES 2004, BEGOSSI 2008, BROOK & MCLACHLAN 2008, SILVANO & VALBO-JORGENSEN 2008). Besides, LEK is a fast and cost-efficient alternative tool for gaining information that would be difficult to obtain through other scientific methods (HALLWASS 2011). Conservationists should therefore consider local people not only as stakeholders but as partners in the development of management schemes (BERKES *et al.* 2000, CALHEIROS *et al.* 2000, GADGIL *et al.* 2003, SILVANO & BEGOSSI 2010).

We have established that seed dispersal and food provisioning by frugivorous fish do not seem to be in conflict in the studied systems. However, we could not fully explain variations in frugivorous abundance, size and extraction by artisanal fisheries inside and outside the RESEX. In the future, we will be able to assess and account for seasonal variations in artisanal fisheries, using already existing landing data over one full year, instead of only four months. With the extended data set, we also intend to extend our analyses by including more socio-economic and environmental factors that are likely to influence frugivorous abundance, size and fisheries. As an example, we plan to include already collected information on commercial use of the fish resources, market values, fishing gear and proximity to big cities. Some of these variables have been previously found to influence small-scale fisheries productivity in the Brazilian Amazon (HALLWASS *et al.* 2009, 2013). Furthermore, our study group is currently working on assessing possible effects of vegetation cover and deforestation on fish abundance and community composition. Similar research from New Zealand (HANCHET 1990) and North Carolina, US (JONES *et al*. 1999, SUTHERLAND *et al.* 2002) shows, that deforestation and land use change led to shifts in fish assemblages and abundance. It will be particularly interesting to investigate these same mechanisms in our study system with a special focus on the frugivorous guild, given the special importance of forest resources for frugivorous fish in nutrient-poor rivers (ARAUJO-LIMA 1995)

Fish diet can show a high plasticity according to seasonal and spatial variations in resource availability and due to niche partitioning (DABROWSKI & PORTELLA 2005, LUZ-AGOSTINHO *et al.* 2006, CORREA *et al* 2014). Our study did not assess the degree of frugivory of the fish cited as frugivorous in the literature. However, future research will include stable isotope analysis for a more in-depth knowledge of fish dietary habits. To that end, we have already extracted tissue samples of fish mentioned as frugivorous in the literature (GOULDING 1980, ALMEIDA 1984, LUCAS 2008, ANDERSON et al. 2011, CORREA & WINEMILLER 2014, CORREA et al. 2014, 2015a, 2015b) and of plants and fruits cited to be consumed by these fish in interviews with local fishermen.

The focus of the present paper lies on the abundance, size and availability of frugivorous fish in relation to co-management (RESEX). From our results, we inferred possible consequences on their ability to fulfil both their roles in food provisioning and seed dispersal. However, we did not to directly evaluate the actual contribution of frugivorous fish to seed dispersal and plant recruitment in tropical forests. Instead integrated existing literature with our results to reach our conclusions. For confirming the actual contribution of fish to plant recruitment on the studied floodplain forests, it would be interesting to compare plant distribution patterns of flood-plains with forests, where zoochory is mediated by only terrestrial animals.

The maintenance of most ecosystem services, including seed dispersal and food provisioning, does not only depend on one group of organisms. For example, frugivorous birds and mammals play a major role for seed dispersal in tropical forests (HOWE 1984) and as a protein source for people (SILVA & BEGOSSI 2009). Management rules established for only one group of organisms can appear as a solution, while in reality dislocating the pressure to other taxa. A comprehensive assessment of frugivores as protein sources of Amazonian communities, similar to what has been done by SILVA & BEGOSSI (2009) for various resources, could be important for early detection of conflicts between human resource use and ecosystem functioning.

Local artisanal fisheries are not the only stakeholders exerting pressure on fish stocks in the Amazon region. Commercial fishing boats extract high amounts of fish from outside (ALMEIDA *et al.* 2003) and allegedly also from inside the RESEX, according to local fishers. In order to take adequate management decisions, detailed information on fishing activities of all stakeholders is necessary. Further research and management schemes should therefore include landings of commercial fisheries in data collection and monitoring programmes.

CONSIDERACÕES FINAIS

Em pequenas comunidades rurais, cujos habitantes pescam e caçam para a subsistência, as pessoas estão estreitamente interligadas e dependentes dos ecossistemas em que vivem. Portanto a contabilização das necessidades dos usuários dos recursos, e reconciliando o funcionamento do ecossistema com a manutenção das subsistências locais, faz-se crucial para sucesso das estratégias conservacionistas (BERKES 2004, TREGIDO 2017). Nossos resultados reforçam o fato de que o conhecimento ecológico local (LEK) fornece informações inestimáveis sobre disponibilidade e uso de recursos, permitindo que os gestores detectem conflitos futuros ou existentes (BERKES *et al.* 2000, CALHEIROS *et al.* 2000, BERKES 2004, BEGOSSI 2008, BROOK & MCLACHLAN 2008, SILVANO & VALBO-JORGENSEN 2008). Além disso, o LEK é uma ferramenta alternativa rápida e econômica para obter informações que seriam difíceis de obter através de outros métodos científicos (HALLWASS 2011). Os conservacionistas devem, portanto, considerar os habitantes não apenas como partes interessadas, mas como parceiros no desenvolvimento de planos de gestão (BERKES *et al.* 2000, CALHEIROS *et al.* 2000, GADGIL *et al.* 2003, SILVANO & BEGOSSI 2010).

Nós estabelecemos que a dispersão de sementes e a provisão de alimentos por peixes frugívoros não parecem estar em conflito nos sistemas estudados. No entanto, não podemos explicar completamente variações na abundância, tamanho e uso dos frugívoros pelas diferentes práticas de pescaria artesanal dentro e fora do RESEX. No futuro, seremos capazes de avaliar e explicar as variações sazonais na pesca artesanal, usando dados de desembarque pesqueiro já existentes ao longo de um ano completo, em vez de apenas quatro meses. Com o conjunto de dados estendidos, também pretendemos ampliar nossas análises, incluindo fatores socioeconômicos e ambientais que possam influenciar a abundância, tamanho e pesca dos frugívoros. Como exemplo, planejamos incluir informações já coletadas sobre o uso comercial dos peixes, valores de mercado, artes de pesca e proximidade com as grandes cidades. Para algumas dessas variáveis tem estudos anteriores encontraram uma influencia na produtividade geral das pescas na Amazônia brasileira (HALLWASS et al., 2009, 2013). Além disso, nosso grupo de estudo está atualmente trabalhando na avaliação dos possíveis efeitos da cobertura vegetal e do desmatamento na abundância de peixes. Pesquisas semelhantes da Nova Zelândia (HANCHET 1990) e Carolina do Norte, EUA (JONES et al., 1999, SUTHERLAND et al., 2002) mostram que o desmatamento e a mudança do uso do solo levaram a alterções na abundância e nas assembléias de peixes. Será interessante relacionar investigar esses mecanismos no nosso sistema de estudos com foco especial nos frugívoros, dado que os recursos florestais são particularmente importantes para os peixes frugívoros em rios pobresem nutrientes (ARAUJO-LIMA 1995).

A dieta de peixe pode mostrar uma alta plasticidade de acordo com as variações sazonais e espaciais na disponibilidade de recursos e devido à partição de nicho (DABROWSKI & PORTELLA 2005, LUZ-AGOSTINHO *et al.* 2006, CORREA *et al* 2014). Nosso estudo não avaliou o grau de frugivoria dos peixes citados como frugívoros na literatura. No entanto, pesquisas futuras incluirão análises de isótopos estáveis para um conhecimento mais aprofundado dos hábitos alimentares dos peixes. Para esse fim, já tomamos amostras de tecidos de peixes mencionados como frugívoros na literatura (GOULDING 1980, ALMEIDA 1984, LUCAS 2008, ANDERSON et al. 2011, CORREA & WINEMILLER 2014, CORREA et al. 2014, 2015a, 2015b) e de plantas e frutos citados em entrevistas com pescadores por serem consumidos por esses peixes (Renato Silvano, unpublished data).

O foco do nosso estudo é a abundância, tamanho e disponibilidade de peixes frugívoros em relação ao co-manejo (RESEX). A partir de nossos resultados, inferimos possíveis consequências sobre sua capacidade de cumprir tanto seus papéis no provisionamento de alimentos quanto na dispersão de sementes. No entanto, não avaliamos diretamente a contribuição real de peixes frugívoros para a dispersão de sementes e o recrutamento de plantas em florestas tropicais mas integramos literatura existente com os nossos resultados para chegar nas nossas conclusões. Para determinar a contribuição do peixe para o recrutamento de plantas, seria interessante comparar os padrões de distribuição de plantas das planícies com florestas, onde o zoocoria é mediado apenas por animais terrestres.

A manutenção de grande parte dos serviços ecossistêmicos, incluindo a dispersão de sementes e a provisão de alimentos, não depende apenas de um grupo de organismos. Por exemplo, aves e mamíferos desempenham um papel importante na dispersão de sementes em florestas tropicais e como fonte de proteína para pessoas (HOWE 1984, SILVA & BEGOSSI 2009). As regras de manejo focadas para um único grupo de organismos pode parecer uma solução, mas na realidade podem estar deslocando a pressão para outros táxons. Uma avaliação abrangente de frugívoros como fontes proteicas de comunidades amazônicas, semelhante ao que foi feito por SILVA & BEGOSSI (2009) para uma variedade de recursos, poderia ser importante para a detecção precoce de conflitos entre o uso de recursos humanos e o funcionamento do ecossistema.

A pesca artesanal não é a única a exercer pressão sobre os estoques de peixes na região amazônica. Os barcos de pesca comercial extraem grandes quantidades de peixe de fora (ALMEIDA *et al.* 2003) e alegadamente também de dentro do RESEX, de acordo com os pescadores locais. A fim de tomar decisões de gestão adequadas, é necessária informação detalhada sobre as atividades de pesca de todas as partes interessadas. Novos planos de pesquisa e gestão devem, portanto, incluir desembarques de pescarias comerciais em programas de coleta e monitoramento de dados.

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APPENDIX 1: Example of a fish landing form for one fishing trip of Tapajos River, translated to English. Original landing forms were in A4 format and in Portuguese language.

MONTH OF JUNE

Fisherman's name:________________________________ Community:______________

Date: ___/___/___ **Start hour**:__________ **Finish hour**:____________

FISHING SPOT (name): **Time of travel to the fishing spot:___________**

( ) Tapajós River ( ) Lake:_______________ ( ) Igarapé:____________

( ) Other:______________________________

FISHING GEAR

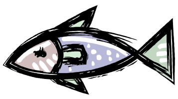
( ) gillnet: Mesh size:___________ number of gillnets:___________

( ) Line or pole and line ( ) Longline: number of hooks:__________

( ) Spear ( ) Castnet ( ) Others:_______________

BOAT

( ) Paddle boat ( ) Boat ( ) Longtail powered boat ( ) Large motor boat ( ) Other:_____



CAPTURE

Fish (local name)	Number of fish	Total weight (Kg)	Smallest Size (cm)	Largest Size (cm)	Number with eggs

Sold: ( ) Yes ( ) No → **Quantity:** _______**Kg**

Amount received = ___________ R$

Consumed fish: ( ) Yes ( ) No → **Quantity:** _______**Kg**

Other fishermen in the crew? ( ) Yes ( ) No → How many?________

How many Kg of fish captured by all?_______________ Kg.

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