



Assessing biological traits of Amazonian high-value fishes through Local Ecological Knowledge of urban and rural fishers

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Abstract Local ecological knowledge (LEK) has been increasingly acknowledged as a potential source of information on natural resources, especially in under sampled areas. In the Amazon, a small-scale fishery is multispecific, and fishers are well acquainted with the biology and life history strategies of fish species. This study analyzed the potential of small-scale fishers' LEK to supply information on the biology and ecology of high-value species, including pirarucu (*Arapaima* spp.), tambaqui (*Colossoma*

macropomum, Cuvier, 1816), and jaraqui (*Semaprochilodus* spp.). We interviewed rural and urban fishers about bio-ecological aspects of these species and reviewed the scientific literature on the same aspects. In addition, we evaluated the possible effects of their category (rural or urban) and fishing experience on responses. Results demonstrate that fishers have detailed knowledge about species predation, diet and habitat use, regardless of the category they fall into. However, LEK on weight and maximum length of pirarucu and tambaqui varied according to fisher category revealing different perceptions. We also found that fishing experience did not influence fisher's LEK on these bio-ecological

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characteristics. Our findings reinforce that LEK can be a useful source of ecological traits for these species, contributing to fisheries management in the Amazon.

Keywords Traditional knowledge · Small-scale fishery · Amazon basin · Amazonian fisheries · Category of fishers · Fishing experience

Introduction

The importance of local ecological knowledge (LEK) in fisheries management has been increasingly acknowledged by scholars and conservation practitioners worldwide (Bender et al., 2014; Berkström et al., 2019; Sánchez-Jiménez et al., 2019). LEK plays particularly important roles in the socioecological context of small-scale fisheries in developing countries, which ensure food security to rural communities, but face lack of information due to the absence of both short and long-term monitoring programs (FAO, 2018; Lynch et al., 2016). This problem is evident in the Amazon basin, where despite of the importance of fish resources as source of protein and income for millions of people (Petrere Jr, 1978; Cerdeira et al., 1997; Fabré & Alonso, 1998; Almeida et al., 2001), data on fisheries are scarce, or inexistent, for most of the basin. The lack of information results, in part, from the challenges of collecting data on fisheries landings that are dispersed over large geographical areas of difficult access, in addition to the limited human and financial resources to do so (Johannes, 1998; Santos & Santos, 2005; Begossi, 2010; Lopes et al., 2019). LEK, thus, can provide a low-cost alternative for generating essential information to support fisheries management decision-making and policies.

Fishers' LEK has been widely used as a source of data on fishing practices, livelihoods, governance, and fish biology and ecology to subsidize fisheries management and conservation (Olsson & Folke, 2001; Davis & Ruddle, 2010; Fischer et al., 2015). In the Mekong river, Asia, LEK has been used to identify environmental physical structure and population dynamics of the target species to establish fish conservation zones (Baird & Flaherty, 2005). In the Roviana Lagoon, in Western Solomon Islands, LEK has been accessed to inform conservation status, habitat selection and responses from fishery pressure

of the bumphead parrotfish (Aswani & Hamilton, 2004). In the Brazilian Amazon, fishers have been using LEK to estimate bio-ecological information in a few locations (Batista & Lima, 2010; Galvão de Lima & Batista, 2012; Braga & Rebêlo, 2014; Braga & Rebêlo, 2017). LEK has been also used to enable fishers themselves to estimate the abundance of giant pirarucu (*Arapaima* spp.) by counting the individuals during their aerial breathing (Castello, 2004). This method has promoted fishers engagement in the management process and recovery of overexploited arapaima population (Castello et al., 2009; Campos-Silva & Peres, 2016). Moreover, LEK of fishery, farming and extractivism of community members in the Brazilian State of Amazonas was used to create a natural resources accord among the resources users (Fabr   et al., 2012).

However, because LEK is dynamic and evolves according to changes in resource use practices and emergence of knowledge and technologies, there are also uncertainties within the LEK approach (Sears et al., 2007). LEK is also heterogeneous among the population, depending to a large extent on experience, history and culture (Berkes et al., 2008; Ruddle & Davis, 2013). Factors such as age, the type of fishers and fishing experience, for instance, are known to affect LEK (Johannes et al., 2000; Davis & Wagner, 2003; Crona & Bodin, 2006; Manzan & Lopes, 2015; Martins et al., 2018), as found in southern Brazil, where older fishers tended to report that their catches comprised greater yields and larger fishes than younger fishers reported (Martins et al., 2018). In Kenya, fishers that fish in deep sea showed a more comprehensive knowledge about the marine ecosystem and its functioning than compared other fishers' categories. Apparently, deep sea fishers establish a knowledge-sharing network with fishers specialists in a wide set of gears, including gillnets, handline, and speargun which enhance their comprehension about ecological processes occurring across the ecosystem (Crona & Bodin, 2006). Despite this variability in LEK among fishers, in the Amazon, to our knowledge only two studies have investigated the potential use of LEK from different types of fishers to understand bio-ecological aspects of commercially important species (Lima & Batista, 2012; Lima et al., 2021). Based on descriptive analyses these studies showed that commercial and subsistence-oriented fishers are capable of providing knowledge on bio-ecological aspects of fish

species, including about diet and reproduction (Battistella et al., 2005; Rebelo et al., 2010; Braga & Rebêlo, 2014; Santos et al., 2016; Braga & Rebêlo, 2017). Quantitative analyses assessing LEK of different fishers in relation to a broader range of key bio-ecological aspects of commercially important species are still lacking.

Exploring the potential of LEK as a source of information in the Amazon will be essential to fill pronounced knowledge gaps associated with the various bio-ecological attributes of fish species that can serve as input to management models and decision-making (Ruddle, 1995; Silvano & Valbo-Jorgensen, 2008). For example, fish length and weight data are useful for estimating values for stock assessments and defining maximum sustainable yields (Sparre & Venema, 1998; Campos et al., 2013; Campos et al., 2015a). Yet, bio-ecological parameters can vary across regions so that species-specific local assessments are many times required (Arantes et al., 2007; Batista et al., 2012; Braga & Rebêlo, 2014; Doria et al., 2014). Testing the use of LEK to provide these sorts of information is pivotal to improve fisheries data management in poor regions, like the Amazon.

Here, we investigate LEK as a potential source of bio-ecological data for fish species in the Amazon. Specifically, we accessed key information for the management of three species of high commercial and cultural value through LEK. Variables such as length and maximum weight are important to evaluate the fishing stock situation. Sexual dimorphism is used to define fishery strategy facing potential differences on sexes' distribution behavior. Predation dynamics of exploited species possibly increase mortality affecting resource availability and diet preferences. Habitat use defines species distribution throughout the environmental mosaic. Our objectives included to investigate local fishers' knowledge of maximum length and weight, sexual dimorphism, predation, diet and habitat use of carnivorous pirarucu (*Arapaima* spp.), frugivorous tambaqui (*Colossoma macropomum*), and detritivore jaraqui (*Semaprochilodus* spp.). In our analyses, we also accounted for the potential influence of two variables: fisher category (from rural or urban areas) and fishing experience. We evaluated the effects of category and fishing experience on LEK estimates, by testing the following hypotheses: (1) LEK of rural and urban fishers differ because they have different levels

of relationship with fishing and target different species. Whereas urban fishers tend to be more commercially oriented and maximize catch, rural fishers can be more subsistence-oriented seeking to maintain the productivity of fishing (Mcgrath et al., 1993); (2) LEK of more experienced fishers tends to be more consistent with the scientific information, because older fishers can have longer empiricism within the surrounding natural environment compared with younger fishers, resulting in higher accumulated knowledge (Huntington, 2000; Drew, 2005).

Materials and methods

Our study area is located in the floodplain of the Amazon river, an ecosystem comprised by a complex myriad of habitats including shrub, lakes, secondary channels (*igarapé*) and forests (*igapó*) that are periodically flooded by the Amazon river (Castello, 2008a; Arantes et al., 2013). This rich ecosystem provides the basis for a high fish production and intense fishing activity (Junk et al., 2007). The study was conducted in the rural community of São João do Araçá and in the municipality of Itacoatiara, both in the Amazonas State, Brazil. São João do Araçá comprises approximately 30 families whose livelihoods are based primarily on agriculture and fishing. This community is part of a Fishing Agreement. Itacoatiara is 266 km distant from the State capital, Manaus, has an area of 8892,038 km² and a population of approximately 101,337 inhabitants (IBGE, 2019). There is one fishing processing facility in the town, with a total storage capacity of 2000 tons and an estimated extractive fishing production of 4500 tons/year (Gandra, 2010). In the Z-13 fishing colony, 1500 urban and rural fishers are registered (Fig. 1).

Data collection

Target species

Due to their relevance for the Amazonian fisheries management, we selected species of high economic and cultural importance in the Amazon: pirarucu (*Arapaima* spp.), tambaqui (*Colossoma macropomum*) and jaraqui (*Semaprochilodus* spp.). Pirarucu (*Arapaima* spp.) is of great importance both economically and ecologically (Verissimo, 1970) and has been

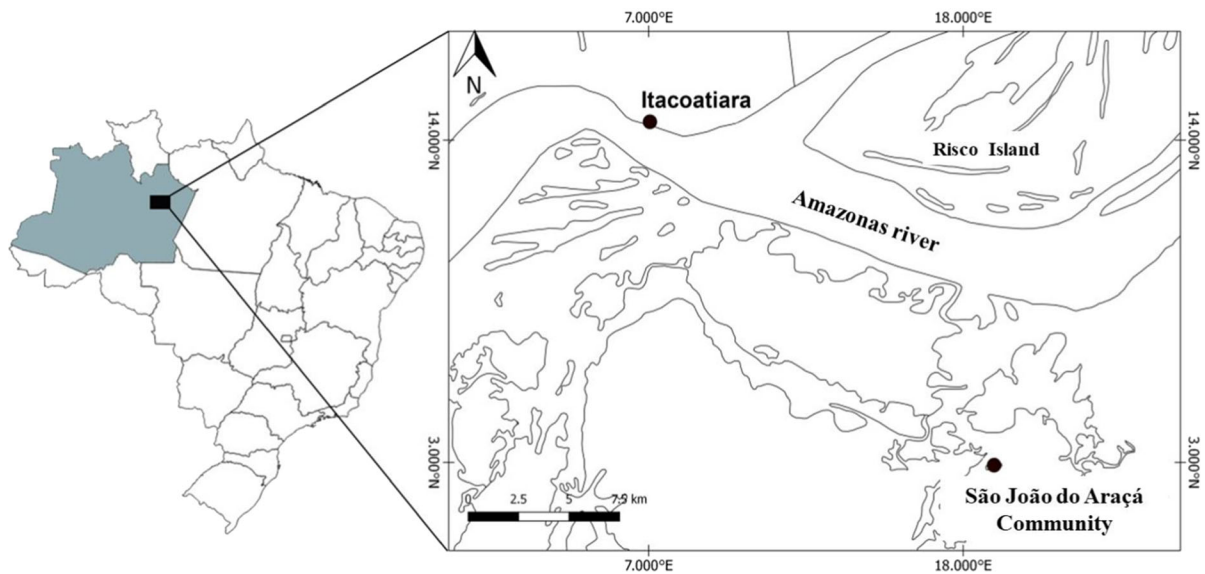


Fig. 1 Location of Itacoatiara and the rural community of São João do Aracá in Brazilian Central Amazon

exploited since pre-Columbian times (Prestes-Carneiro et al., 2016). Although its stocks have experienced dramatic declines throughout the Amazon, the implementation of a co-management scheme based on fishing zoning and harvesting quotas has been proved effective in recovering population in a large scale (Arantes et al., 2007; Castello et al., 2013; Campos-Silva & Peres, 2016; Petersen et al., 2016; Campos-Silva et al., 2017, 2019).

Tambaqui (*Colossoma macropomum*) is a highly important species that has been largely exploited since the 1970's (Petrere Jr, 1978). Despite the establishment of a minimum catch size of 55 cm and the definition of a closed season throughout the Amazonas State, studies have shown signs of overfishing (Barthem & Fabré, 2004; Batista, 2012; Campos et al., 2015b; Arantes & Freitas, 2016).

Jaraqui stocks (*Semaprochilodus insignis* and *S. taeniurus*) are among the main landed fish resource for urban and rural fisheries (Ribeiro & Petrere Jr, 1990; Batista & Petrere Júnior, 2003; Batista, 2012). Its overfishing was recognized as early as the late 1980's (Ribeiro & Petrere Jr, 1990). However, due to a lack of current data on jaraqui fisheries stocks, it remains unclear what the status of its populations is (Goulding et al., 2018).

Scientific data on the biology and ecology of the studied species were obtained through a review of scientific literature. The articles and theses were

compiled from the ISI Web of Knowledge database (Thomson Reuters), SciELO database and CAPES theses bank. The following search strings were applied: ("scientific name" OR "common name") AND ("bio-ecological feature"). We manually filtered the data by: (i) discarding manuscripts outside Amazonia and, (ii) prioritizing studies conducted in natural environments, but when absent, we used the ones from aquaculture (Table S1Supplementary information).

Assessing local ecological knowledge

To access LEK, we interviewed 44 fishers from São João do Aracá and Itacoatiara, from November 2012 to May 2013: 22 rural and 22 urban fishers. All of them had at least 10 years of fishing experience and were male. Interviewees were chosen randomly and were willing to participate. Urban fishers live in towns and fishing is their major source of income. Fishing resources are mostly commercialized. They are often related to large boats, which travel long distances in the search of high value species. Rural fishers (also called riverine fishers) live in rural communities and engage in multi-purpose activities including fishing, agriculture, livestock, plant and/or animal extractivism—all of which are directly linked to the family production unit (Furtado, 1993; Fraxe et al., 2009).

Urban fishers ($N = 22$) lived in Itacoatiara for 40 ± 18 years, on average, and had a monthly income range of US\$ 58–US\$ 477, obtained mostly from fishing. Rural fishers ($N = 22$) lived in the community of São João do Aracá for, on average, 42 ± 14 years, and had a monthly income range of US\$38–US\$1050, mostly from agriculture (91%), with fishing being basically directed to subsistence or small-scale sales to complement their income.

We asked questions about the biology and ecology of the target fish species, including: (1) What are the maximum length and weight an adult fish can reach?; (2) Can you identify any differences between male and female? If so, what are the differences?; (3) What are this species' predators?; (4) What are the main items the fish feeds upon? Are there differences in the fish diet in the dry and wet seasons? and 5) What are the habitat types you often observe the species in during the dry and wet seasons? The interviews were conducted using the common names of the fish species and provided quantitative (question 1) and qualitative (questions 2–5) data that were analyzed as described below. This study was authorized by the Human Research Ethics Committee of the Federal University of Amazonas (CAAE: 02572712.3.0000).

Data analyses

To evaluate the use of LEK for providing bio-ecological data of commercially important species, we first compared the estimated values of LEK for maximum weight and length (quantitative data) of each species group with the mean estimate found in the literature using an analysis of variance. Then, to test the effects of the category of fisher (urban or rural) and the fishing experience on LEK, we quantified the difference between fishers estimates of total weight and total length and the literature, and modeled this difference according to the predictors (category and fishing experience) using linear models with gaussian distributions. To reduce model selection bias and consider uncertainty, we used the model average approach, which takes into account the average regression coefficients across multiple models to capture a variable's overall effect. All models with $\Delta AIC < 4$ were included in the model average (Anderson & Burnham, 2002). We used lmer in lme4 package to fit the models and MuMIn package (Barton, 2019) to examine all combinations of models.

The analyses were performed in R (R Development Core Team, 2017) statistical platform. We evaluated all the model assumptions following Zuur, et al., (2010).

Then, we evaluated the quality of the qualitative data on sexual dimorphism, food items, predation and habitats through the use of descriptive statistics, mean and percentage. These analyses were used in the comparative cognition table (Silvano & Valbo-Jorgensen, 2008), which was specifically used to compare the knowledge of fishers and data from scientific literature (Marques, 1995). Table integrates both types of data (LEK and scientific) by means of a perception probability measure classified as: **High**, when LEK agrees with the scientific literature available; **Medium**, when these two types of knowledge cannot be adequately compared due to the lack of scientific information and only LEK is available; and **Low**, when information presented by LEK is unexpected or even contradicts existing biological data.

This classification is useful to assess if information provided by LEK can be incorporated into local fisheries management strategies or if further investigation is needed. To build the table, the food items mentioned by fishers (Table S2- Supplementary information) were categorized into: organic matter (detritus and slime), plant material (macrophytes and fruits), fish (species of fish), crustaceans (shrimps and crabs), mollusks (species of mollusks), anurans (tadpole of anurans) and chelonians. Fish predators were grouped into fish (all cited species) and birds (all cited species) and the other items were used in a generic way as mentioned by fishers. Sexual dimorphism characteristics were generally presented as reported by fishers (e.g., “thin”, “narrow”, “long” characterizing male's elongated body). However, in a few cases characteristics were grouped because the terms used by fishers indicated similar features (i.e., round, curved, ovate abdomen were grouped as ‘wide’, characterizing adult female's body during the reproductive period; thin, long and straight were grouped as ‘narrow’ characterizing the shape of a male).

Results

Comparing fishers' LEK and literature

Maximum weight and length

LEK estimates of maximum weight for pirarucu were lower than estimates found in the literature (135 kg): on average, 73.9 ± 29.5 kg for rural fishers and 97.6 ± 38.4 kg for urban fishers (Fig. 2a). Rural fishers tended to estimate significantly lower values than the values found in the literature (Fig. 2a, $P = 0.001$). Estimates was not statistically different between the fishers categories ($P = 0.09$). Urban and rural fishers estimates of maximum length for pirarucu were close to the literature ($P = 0.91$) and did not differ between types of fishers ($P = 0.49$) (Fig. 2d).

Urban fishers estimates of maximum weight for tambaqui were close to the value found in the literature (fishers' estimate = 29.6 ± 11.3 kg and literature = 27.2 kg), showing no statistically significant

differences ($P = 0.91$) (Fig. 2b). Rural fishers' estimates were lower (14 ± 6.8 kg) than literature values, but this difference was also not significant ($P = 0.08$). There was significant difference for the estimates between categories of fishers ($P = 0.001$). Considering length, both urban and rural fishers estimated larger tambaqui (104.5 ± 32.3 cm; 73 ± 24.1 cm, respectively) than the values found in the literature (58 cm) (Fig. 2b and e), with significant difference from the estimates of urban fishers ($P = 0.001$). There was also a statistically significant difference for estimates of length between these categories ($P = 0.001$).

For jaraqui, both estimates of weight and length were, on average, close to values found in the literature (Fig. 2c and 2f), with no significant difference ($P = 0.55$). Estimates of both categories of fishers did not show differences as well ($P = 0.9$).

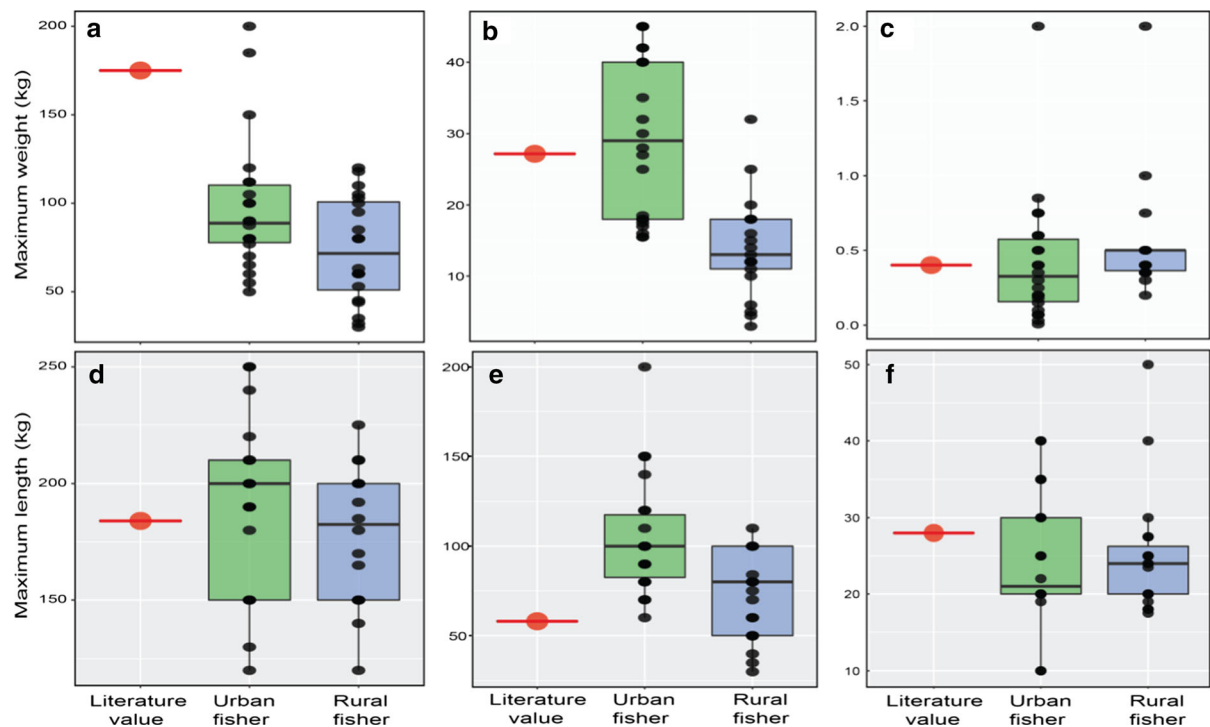


Fig. 2 Box plot showing variation of estimates from urban and rural fishers at maximum weight (white background) and length (gray background) of high-value fishes. Red symbols represent mean values found in literature. Blue and green boxes represent urban and rural fishers, respectively. Lower case in the boxes

a maximum weight for pirarucu, **b** maximum weight for tambaqui; **c** maximum weight for jaraqui; **d** maximum length for pirarucu; **e** maximum length for tambaqui; and **f** maximum length for jaraqui

Sexual dimorphism

Both urban and rural fishers reported that the female body of pirarucu was longer than the male's, while the male's head was larger than the female's. According to the literature, body size is not a characteristic that can be used to distinguish the sexes (Lopes & Queiroz, 2009). Another characteristic reported by urban fishers was the female color turning to red. Instead, rural fishers reported that this feature is found in males, not females. According to the literature (Monteiro et al., 2010), the most intense red color is a characteristic of males during the reproductive period. Because of the disagreement between the characteristics of body size and color cited by urban fishers and scientific literature, LEK of sexual dimorphism of pirarucu was classified as having 'medium agreement' (Table 1).

65% of urban fishers' LEK of morphological differences between males and females of *Colossoma macropomum* corresponded to the information available in the literature: females have bulging bellies and are slightly larger than males, while males have a very slim body. Therefore, LEK showed high agreement for sexual dimorphism of tambaqui (Table 1).

On average, 35% of fishers identified female body sizes as being larger than males' during jaraqui's reproductive phase. Only urban fishers reported bristly scales and white secretion in males. However, there is very little literature for this species to confirm if these characteristics can be used to identify dimorphism. In addition, about 50% of both categories of fishers reported that they were unable to identify any dimorphism features. Thus, LEK of sexual dimorphism on jaraqui showed medium agreement (Table 1).

Predation

Overall, LEK of fish predation showed a medium agreement with the scientific literature as fishers reported information that was not found in the literature for any of the species (Table 2). The only piece of information matching the literature was cited by both rural and urban fishers: the main predators of the studied species are fish species, with piranhas *Serrasalmus* spp. and/or *Pygocentrus nattereri* having the largest number of citations. Rural fishers also cited a bird of the Ardeidae family (common name: heron) as a predator of the three studied species.

Unfortunately, heron's feeding behavior is not well-known and not described with details in scientific literature. In addition, rural fishers cited the anaconda (*Eunectes murinus*) as a major predator for pirarucu. However, no record was found in the available scientific literature to support this citation. No information on predators, in general, was found neither for tambaqui nor jaraquis.

Diet

LEK of fish diet showed high agreement with the information found in scientific literature (Table 3). Urban and rural fishers mentioned five distinct food items consumed by tambaquis, with the greatest percentage of plant material (above 70%) and three items consumed by jaraqui, with organic material showing the greatest percentage (70.2% of urban fishers and 64% of rural fishers). Fish was the most cited food item for pirarucu (~ 80%).

Habitat use

LEK of habitat use during two seasons of the hydrologic cycle (dry and flooded) also demonstrated high agreement with the information available in scientific literature (Table 4). Lakes were the main habitats reported by fishers as preferred by the studied species. Some fishers highlighted microhabitats within lakes, such as deep areas ("poço") that remain flooded even during strong dry seasons, "aningals"—areas covered by *Aninga* (*Montrichardia linifera*)—, and aquatic macrophyte meadows of rice grass (*Oryza* spp.) as important habitats of foraging and refuge for the three species.

LEK and fishing experience

Fishing experience did not influence LEK estimates between the categories of fishers.

Discussion

Our study reinforces that fishers' ecological knowledge represents a potential source of information on bio-ecological aspects of fishes in the Amazon. Particularly, LEK on diet, predation and habitat of the studied species showed high degree of agreement

Table 1 Comparative cognition table on sexual dimorphism

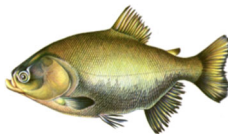
Fish species	Sexual dimorphism from fishers' LEK (%)				Sexual dimorphism from the scientific literature	Likelihood
	CF		SF			
	Male	Female	Male	Female		
<i>Colossoma macropomum</i> (Tambaqui) 	Long (28)	Wide (41,3)	Long (32,6)	Smaller head (2,2)	There are morphometric differences in the between males and females of tambaqui, indicating the existence of sexual dimorphism in tambaqui in the adult phase, being the female more and more in captivity after reaching the stage of reproductive (Mello et al., 2015; Almeida et al., 2016)	High
	It is smaller, narrow and its head is larger (2,2)	Smaller (6,5)	Narrow (2,2)	Wide(32,6)		
	Narrow(17,4)			Smaller (2,2)		
<i>Semaprochilodus</i> spp. (Jaraqui) 	Long (6,4)	Thing scale (2)	Has scale erection (2)	Wide (19)	The jaraqui fine scale can be identified during their reproductive phase through simple observation females, in addition to presenting the belly is slightly bulging greater, while males present the body is fine (Alves e Filho, 1992)	Low
	Thick scale (2)	Wide (21,3)	Narrow (8,5)	Larger(2)		
	Has scale erection (2)	Wide and smaller head (2)	NA (30)	NA (25,5)		
	Fino (10,6)	NA (25,5)			Females show a higher growth rate than males, and consequently reach higher lengths for the same age (Vieira et al. 1999)	
	Smaller (2)					
	NA (27,6)					
	White secretion (2)					

Table 1 continued

Fish species	Sexual dimorphism from fishers' LEK (%)				Sexual dimorphism from the scientific literature	Likelihood
	CF		SF			
	Male	Female	Male	Female		
<i>Arapaima</i> spp.(pirarucu) 	Turns red (7)	Smaller head (2,3)	Turns red (18,2)	Smaller head (4,5)	The red color is more prominent in the male of this species(Queiroz, 2000)	Medium
	Larger head (2)	Turns red (13,6)	Larger head(7)	Turns red (9)	Discrimination between the sexes by means of visual criteria is only possible efficient way in the days prior to spawning, when the red coloration of the male becomes become more intense (Lopes, 2005)	
	Long (11)	Wide (13,6)	Long (11,3)	Wide(7)		
	Narrow (9)	Larger (11,4)	Narrow (4,5)	Larger (7)		
	Smaller (7)	More white (2,3)	Smaller(4,5)	More white (4,5)	Males have a higher proportion of the surface of the body covered by the color red than the females. The largest female length was not identified as a distinguishing feature of the sexes (Lopes e Queiroz, 2009)	
	NA (13,6)	NA (9)		Smaller (4,5)		
	Does not turn red (2,2)			Does not turn red (4,5)		

UF urban fishers and RF rural fishers. Terms highlighted in bold represent the highest percentage of information reported by them. NA = No answer

with the literature. Estimates of weight and length were also similar to those found in the literature, with a few exceptions. These results corroborate previous studies showing that LEK can provide valuable data on life history strategy parameters (Begossi et al., 2016; Froese, 2017), particularly, for species that are part of fishers' daily lives as sources of food and income (Barthem & Fabr , 2004; Batista & Lima, 2010; Braga & Reb lo, 2014). In addition, our results showed that LEK of weight and total length of pirarucu and tambaqui varied according to the categories of fishers revealing different perceptions that may be related to the type of habitat they exploit, the type of fishing gear they use and even the economic importance that fishing represents for each group. However, contrary to expectations, fishing experience did not influence fishers' LEK of all aspects for the

studied species, demonstrating that LEK of these aspects is already incorporated into the body of knowledge of the fishing group.

Urban and rural fishers' LEK as a source of information

Maximum weight and length

Although few estimates of maximum weight and length of pirarucu differed from those found in the literature, LEK was mostly consistent with the available knowledge. The few differences of estimates among fishers and literature such as those found for pirarucu weight can be explained by the fact that we used average values from the literature, thereby missing fine scale information and potential spatial

Table 2 Comparative cognition table on predation

Fish species	Predators from fishers' LEK (%)		Predators from the scientific literature	Likelihood
	UF	RF		
<i>Colossoma macropomum</i> (tambaqui) 	Alligator (1)	Alligator (1,8)	Fish are an important food for <i>Paleosuchus trigonatus</i> above 40 cm (Magnusson et al., 1987) and the main food item found in the alligator-tinged (<i>Caiman crocodilus</i>) stomach above 35 cm (Silveira e Magnusson, 1999)	Medium
	Dolphin (5,4)	Dolphin (9)	Alligator-sugar (<i>Melanosuchus niger</i>) adults eat at Adapting to the availability of fish, small mammals, reptiles and birds (Castellanos et al., 2006)	
	Fish (32,1)	Fish (43,75)	The species red boto (<i>Inia geoffrensis</i>) and tucuxi (<i>Sotalia fluviatilis</i>) are two species of freshwater cetaceans of the New World, which are at the top of the food chain and are among the largest predators in the aquatic systems of the Amazon basin, exploit diverse habitats and have a very diversified diet that includes more than 68 species of fish (Rosas et al., 2003)	
	Human (1)	Human (3,6) Birds (2,7)	Pimelodida catfish are highly piscivorous, registering an occurrence of tambaqui as prey of cubs of piraíba (<i>Brachyplatystoma filamentosum</i>) (Barthem e Goulding, 1997). The pirarucu (<i>Arapaima spp.</i>) in the past may have been an important predator (Araújo-Lima e Goulding, 1998) Commercial fisherman has ecological predator function over the fishing resources (Batista, 2002) <i>No data</i>	
<i>Semaprochilodus</i> spp. (jaraqui) 	Alligator (2)	Alligator (11)	Fish are an important food for <i>Paleosuchus trigonatus</i> above 40 cm (Magnusson et al., 1987) and the main food item found in the alligator-tinged (<i>Caiman crocodilus</i>) stomach above 35 cm (Silveira e Magnusson, 1999)	Medium
			Alligator-sugar (<i>Melanosuchus niger</i>) adults eat at Adapting to the availability of fish, small mammals, reptiles and birds (Castellanos et al., 2006)	
	Fish (37)	fish (24)	Large catfish, such as the Piraíba (<i>Brachyplatystoma filamentosum</i>) are the most common predators of <i>Semaprochilodus</i> (Santos et al. 2006)	
	Dolphin (5)	Dolphin (10)	The species red boto (<i>Inia geoffrensis</i>) and tucuxi (<i>Sotalia fluviatilis</i>) are two species of freshwater cetaceans of the New World, which are at the top of the food chain and are among the largest predators in the aquatic systems of the Amazon basin, exploit diverse habitats and have a very diversified diet that includes more than 68 species of fish (Rosas et al. 2003)	
	Human (3)	Human (5) Birds (2) Giant otter (1)	Commercial fisherman has ecological predator function over the fishing resources (Batista, 2002) <i>No data</i> Increased predation by the otters at species that are coming out of central igarapés, located on the mainland (Braga e Rebêlo, 2014)	

Table 2 continued

Fish species	Predators from fishers' LEK (%)		Predators from the scientific literature	Likelihood
	UF	RF		
<i>Arapaima</i> spp. (pirarucu) 	Alligator (9)	Alligator (9)	Fish are an important food for <i>Paleosuchus trigonatus</i> above 40 cm (Magnusson et al., 1987) and the main food item found in the alligator-tinged (<i>Caiman crocodilus</i>) stomach above 35 cm (Silveira e Magnusson, 1999)	Medium
		Birds (4)	Alligator-sugar (<i>Melanosuchus niger</i>) adults eat at Adapting to the availability of fish, small mammals, reptiles and birds (Castellanos et al., 2006)	
		Fish (36)	The pirarucu as a youngster has as its “main predators” the birds (<i>Anhinga anhinga</i> , <i>Ceryle torquata</i> , <i>Phalacrocorax brasilianus</i>). Other important predators of the young pirarucu are: a piranha (<i>Serrassamus spp.</i>), and jeju (<i>Hopterythrinus sp.</i>). The occasional ones are <i>Cichla monoculus</i> (tucunaré) and <i>Astronotus ocellatus</i> (Acará açu). (Neves, 2000)	
		Fish (22)	Studies on the diet of <i>Arapaima</i> spp. characterize it as piscivorous when adult (Fontenele, 1948; Imbiriba, 2001)	
		Dolphin (1,3)	Before spawning in the rivers, some species leave the igapó to the lakes and in these environments intense predation occurs by pirarucus (<i>Arapaima</i> spp.) and alligators (Braga e Rebelo, 2014)	
		Human (6,4)	The species red boto (<i>Inia geoffrensis</i>) and tucuxi (<i>Sotalia fluviatilis</i>) are two species of freshwater cetaceans of the New World, which are at the top of the food chain and are among the largest predators in the aquatic systems of the Amazon basin, exploit diverse habitats and have a very diversified diet that includes more than 68 species of fish (Rosas et al., 2003)	
		Human (9)	Commercial fisherman has ecological predator function over the fishing resources (Batista, 2002)	
		Giant otter (1,3)	Increased predation by the otters at species that are coming out of central igarapés, located on the mainland (Braga e Rebêlo, 2014)	
		Snakes (1,3)	<i>No data</i>	

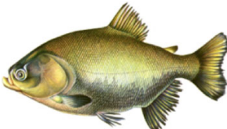
UF urban fishers and RF rural fishers. Terms highlighted in bold represent the highest percentage of information reported by them

variability on the species' weight. For example, although maximum weight values reported by fishers differed (i.e., were smaller) from the average maximum values from the literature, they were in accordance with those recorded in the Jurua reserve, Central Amazon (Silva, 2014). It is also possible that differences may be related to the potential overexploitation of pirarucu populations in our study area, which may have promoted declines of larger/heavier individuals (Hrbek et al., 2005). Even if fisheries agreements and management initiatives exist, compliance with management rules is generally poor and illegal fishing still

takes place in the region (Sagar, 2000; Cavole et al., 2015). Yet previous studies have shown that this region has been under intense fishing pressure since the 1970s (Smith, 1981; Espínola, 2015).

Likewise, values of maximum length for tambaqui reported by fishers were higher than those found in the literature, which also may be explained by our use of average values from the lengths reported in the literature. In this case, some reports were based on landing data that reflects the large scale overexploitation status of the species in both Amazonas and Pará (Isaac et al., 1996, 2000; Campos et al., 2015a). The

Table 3 Comparative cognition table on food items

Fish species	Food items from fishers' LEK (%)		Food items from the scientific literature	Likelihood
	UF	RF		
<i>Colossoma macropomum</i> (tambaqui) 	Crustaceans (6,4)	Crustaceans (5,3) Fish (5,3) Molluscs (2) Organic matter (10) Plant material (77,3)	Fruits, seeds and zooplankton (Goulding & Carvalho, 1982) Fruits and seeds Isaac and Ruffino (1996), Roubach and Saint-Paul (1994) Omnívoros (da Silva, Pereira-Filho & de Oliveira-Pereira, 2000) Algal carbon in zooplankton was the main source of carbon for tambaqui from the Solimões-Amazon River, especially during the low water period, followed by C 4 plants (macrophyte leaves and roots). C 3 plants were important only during flooding (Benedito-Cecilio et al., 2000) Presence of fruits and seeds was important, except during periods of low water levels. Food items, like insects, sediment, molluscs and fish were present mainly at low water. (Oliveira et al., 2006a, b) Decapoda (Scrimp), Plant material (fruits, flowers, leaves and seeds) Arthropoda (spiders and insects), detritus (mud/land), Periphyton (slime), fishes. (Rebello et al, 2010)	High
<i>Semaprochilodus</i> spp. (jaraqui) 	Fish (3,5) Organic matter (70,2) Plant material (21)	Organic matter (64) Plant material (33)	The family representatives (Prochilodontidae: curimatã, jaraqui) have a detritus eating habit, consuming debris, particulate organic matter, algae and periphyton (Santos et al., 2006). The two species <i>S. taeniurus</i> and <i>insignis</i> are detritivorous (Isaac et al., 1993)	High
<i>Arapaima</i> spp. (pirarucu) 	Anurans (1,8) Crustaceans (10) Fish (86,2)	Chelonians (1,2) Crustaceans (8,3) Fish (89)	Fish piscivores (Sánchez 1969 and Queiroz, 2000) Carnivore (Santos et al., 2006) Juveniles of pirarucu with the size smaller than 50 cm, the main items found in the stomachs were microcrustaceans. According to these same authors, shrimps have been frequently found in individuals longer than 150 cm; the only items common to all ages are the aquatic insects, mainly, Coleoptera and Hemiptera (Queiroz & Sardinha, 1999; Oliveira et al, 2006a, b)	High

UF urban fishers and RF rural fishers. Terms highlighted in bold represent the highest percentage of information reported by them

records of smaller individuals in landings reduce the average value obtained from the literature. Another potential explanation is that since a minimal size catch of 55 cm is established by regulation, concerned by possible retaliation, the fishers we interviewed may have overestimated tambaqui sizes.

Estimates of tambaqui weight and length differed between fishers categories possibly because these fishers explore different types of habitats within floodplains, which are selected by distinct length classes of tambaqui: young fish (i.e., smaller individuals) spend most of their life cycle in floodplain lakes

Table 4 Comparative cognition table on habitat use

Fish species	Habitats from fishers' LEK (%)				Habitats from the scientific literature	Likelihood
	UF		RF			
	Dry	Flood	Dry	Flood		
 <i>Colossoma macropomum</i> (tambaqui)	Connecting channel (1,75)	“igapó” (33,6)	Lakes (37,25)	“igapó” (33)	Depending on floodplain morphology and water level, the fishes remain in flooded forest from four to seven months. When water level drops and the flooded forests are drained, most of the adult biomass of- <i>C. macropomum</i> flees to the river channels, while much lesser quantities move into floodplain lakes (Goulding & Carvalho 1982)	High
		Lakes (47,27)			Its life cycle is associated with the floodplains of white water rivers in the Amazon basin. During the flood season, adults and juveniles make lateral migrations into the flooded forest in search of food and shelter. The adult fish exit floodplains at the end of the flood season, forming schools and moving to the river channels where they remain during the dry season (Carolsfeld et al. 2004)	
				Lakes (12)	Flood plains with numerous lakes, fluctuating macrophyte banks and seasonally flooded forests along the main white water rivers in the Amazon, are the preferred habitats of tambaqui (Araújo-Lima & Goulding 1998)	
	igarapé (1,75)	Lakes (10,50)	igapó (6,2)	Rivers (2)		
	Rivers (3,5)	Rivers (1,75)	Rivers (2)			

Table 4 continued

Fish species	Habitats from fishers' LEK (%)				Habitats from the scientific literature	Likelihood
	UF		RF			
	Dry	Flood	Dry	Flood		
 <i>Semaprochilodus</i> spp. (jaraqui)	“igaró” (3,7)	“igaró” (13)	“chavascal” (4)	“chavascal” (4)	In the Rio Negro, the migrant jaraqui colonize 10 distinct biotopes: the flooded forest; the main channel of the river and its tributaries; marginal open lakes; islands open lakes; terra firme central lakes; islands central lakes; sand pools in the sedimentation zone of igarapes; muddy pools in the mouthbays of igarapes; littoral zone of igarapes; main river and islands; and sand beaches along the igarapes, main channel, and islands (Ribeiro e Petrere, 1990)	High
	“igarapé” (5,56)	“igarapé” (1,85)	“igaró” (2)	“igaró”(8)	Young and adult fish occupy simultaneously lacustrine environments of white water and black water.(Vieira et al., 1999)	
	Beach of river (1,85)	“chavascal” (5,56)	Lakes(24)	Lakes (24)		
	Lakes (26)	Lakes (12,85)	River(12)	River (14)	The headwaters of the igarapés and the terra firme lakes of the Amazonian plain have ecological importance for several species of migratory fish, as the jaraquis (<i>Semaprochilodus insignis</i> and <i>S. taeniurus</i>). The young, newly born jarkys occupy the floodplain lakes where they remain during the flood, feeding and growing rapidly, and adults and sub-adults are found in the flooded forest feeding intensely (Barthem e Fabr�, 2004)	

Table 4 continued

Fish species	Habitats from fishers' LEK (%)				Habitats from the scientific literature	Likelihood
	UF		RF			
	Dry	Flood	Dry	Flood		
 <i>Arapaima</i> spp. (pirarucu)	Rivers (18,5)	Rivers (11)				
	“igapó”(1,85)	“igapó”(27,8)	Connecting channel (2)	“igapó”(26)	They mainly inhabit lakes and connecting channels. Perform lateral migration (Castello, 2008a, b)	High
	“igarapé”(3,7)	Lakes(12,7)	Lakes (46)		Live in lake environment (Barthem & Fabré, 2004)	
	Beach of river (1,85)	Rivers(1,85)		Lakes(12)	They inhabit floodplain lakes during the dry season (Goulding et al., 1996; Queiroz e Sardinha, 1999)	
	Lakes (48,2)		Rivers (2)	Rivers(6)	The distribution of arapaima in the varzea during low water levels appears to be influenced primarily by the depth and area of lakes (i.e., their dry-season volume; the connectivity of such lakes to other water bodies, and by depth of water column in sections of connecting channels (Arantes et al., 2013)	

UF urban fishers and RF rural fishers. Terms highlighted in bold represent the highest percentage of information reported by them

(Goulding, 1982) where rural fishers usually fish (Pereira & Fabre, 2009). In contrast, larger adults (sexually mature tambaquis) are often caught by urban fishers in other habitats such as the river channel (Goulding, 1982). Alternatively, differences in length estimates may also be explained by potential differences in growth patterns occurring in the different fishing areas in response to fishing selection, or even to potential genetic variations (Arantes et al., 2010; Gurdak et al., 2019).

Sexual dimorphism, predation, diet and habitat use

Fishers' LEK on sexual dimorphism of pirarucu, tambaqui and jaraqui showed a medium agreement

with the literature. This was due to the fact that some fishers reported a few characteristics, such as larger head size for male pirarucus and erect scales for male jaraquis, that were not found in the literature. We suggest further studies to investigate the presence of these characteristics as they possibly can be used as features to identify these species' sex and to inform sustainable fishing strategies such as avoiding catches of females during their reproductive period (Gama, 2014). Understanding sexual dimorphism characteristics can help refine size regulations using gender-specific minimum size limits in management strategies (Halvorsen et al., 2016) and contribute to the development of fishery biology studies and reproductive monitoring programs (Lopes & Queiroz, 2009).

Rural fishers cited predators that were not yet recorded in the literature, including herons and the snake *sucuriju* (another common name for anaconda, *Eunectes murinus*). The little information available on the feeding behavior of heron and snakes for the Amazon river floodplain shows that they feed on a wide variety of items, including diverse fish, amphibians, crustaceans, and sometimes reptiles, insects, birds and mammals (Martins & Oliveira, 1998; Bernarde & Abe, 2010; Lorenzón et al., 2013; Machado et al., 2018). Therefore, it is possible that these species can indeed predate on tambaqui and jaraqui, especially, on smaller/younger individuals. However, in some cases, such as for species that have parental care and invest in their offspring survivorship such as pirarucus, that protect their eggs and juveniles, predation in earlier stages may be less strong (Castello, 2008b). Future studies on fishers' LEK should consider aspects that can influence species vulnerability to these predators, including life stage, mobility strategies (sedentary or migratory) and seasonality.

The high number of food items reported by fishers is consistent with studies showing the trophic plasticity among neotropical fishes (McConnell & Lowe-McConnell, 1987; Duarte et al., 2019). Specially in floodplain ecosystems, fishes' diets vary including the amount and quality of food resources in response to seasonal flood pulses (Oliveira et al., 2006a, b; Arantes et al., 2018). Fishers may gain detailed knowledge about fish diets through daily observation of their stomach content while clean the fish for their own consumption or selling in local markets, or by handling the food items that are used as baits (Silvano & Begossi, 2010; Ramires et al., 2015). The identification of consumed items derived from forests, such as fruit that serves as food for tambaqui, can reinforce the importance of conservation strategies in response to deforestation (McCauley et al., 2012; Arantes et al., 2018; Duarte et al., 2019).

Our results regarding fish predation and diet reinforce the importance of LEK as a tool to increase the understanding of ecological interactions in tropical aquatic environments (Lima & Batista, 2012; Ramires et al., 2015; Braga & Rebêlo, 2017) and potential impacts of anthropogenic actions on fishery and fish ecology. For example, tambaqui returns to floodplains during high water periods to feed (Goulding & Carvalho, 1982), dispersing seeds of at least 76 plant

species (Correa et al., 2015), that are miles away from their place of origin (Anderson et al., 2009, 2011). In this context, local knowledge can be a useful source of knowledge to assess how deforestation would affect tambaqui's food sources (Arantes et al., 2019). For example, LEK could be used to evaluate the extent to which forest loss is affecting tree species that mostly contribute to tambaqui's diet which could, in turn, affect these plant's dispersion and potentialize their decline.

Fishers reported a variety of habitats that fish use according to the river level. This information matched data from the scientific literature describing how the flood pulse influences the spawning and feeding activities of the studied species (Goulding, 1982; de Brito Ribeiro & Junior, 1990; Queiroz, 2000; Castello, 2008a). The information provided by fishers also corroborated data on factors driving the spatial distribution of species (Arantes et al., 2013). For example, consistently with Arantes et al. (2013), fishers cited that habitats selected by pirarucu individuals are larger and deeper and usually have deeper channels. This knowledge of the spatial dynamics of fish species is gained during daily observations of fish behaviors and is transmitted over generations (Ruddle, 1991). Therefore, LEK could be potentially used to assess local features that are key for determining species distribution and to identify locations with these features to inform priority habitats for management and conservation (Hrbek et al., 2007).

LEK and fishing experience

Contrary to our hypothesis, results showed no differences of LEK of biological traits according to time of fishing experience. This result contradicts previous findings on fishers' experience influencing other estimates of LEK parameters, including fish abundance and production (Castello et al., 2011; Lima et al., 2016). For example, fishers experienced on traditional fishing techniques such as harpoons estimated pirarucu abundance more accurately than non-experienced fishers (Arantes et al., 2007). This contrast may be a result of the different types of information provided by LEK, which in this study were biological parameters that fishers are visually exposed to every day (e.g., length and weight) (Ruddle, 1991; Begossi & de Figueiredo, 1995; Nunes et al., 2011). In other case studies (Lima et al., 2016;

Hallwass et al., 2019), other parameters that may require longer time of learning (e.g., resource abundance) were observed.

In this study, few information provided by fishers was either not found or different from the literature, raising issues to be further addressed. For example, understanding the reproductive behavior of species such as jaraquis, that swim in schools, as well as their sexual dimorphism features can be useful to confirm specific reproductive behavior for each sex. Understanding what the predators of the fish species are, will be useful to access the potential roles of terrestrial predators, including herons and snakes, in the aquatic food webs. Thus, continued research on biological traits as well as on LEK of the fishery-targeted species is needed to strengthen knowledge in the Amazon.

In the Brazilian Amazon, scarcity of human and financial resources to collect and develop studies on bio-ecological parameters of fishes hinders the provision of bio-ecological information that is necessary to ensure proper management plans in a rapidly changing environment. Our results demonstrate that fishers' LEK represents a potential and reliable source of information that can be used to provide these data to support conservation and management strategies. However, to improve robustness and consistency of results there is still a need to develop future studies that encompass large sample sizes and spatial–temporal scales.

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Data availability The authors declare that the necessary materials are available.

Declarations

Conflicts of interest The authors declare no conflict of interest.

Consent to participate The participants agreed to participate in the research (Informed Consent Form).

Consent for publication The authors declare their agreement for publication.

Ethical approval Human Research Ethics Committee of the Federal University of Amazonas (CAAE: 02572712.3.0000).

References

- Almeida, F. L., J. S. Lopes, R. Crescencio, A. C. U. Izel, E. C. Chagas, & C. Bojink, 2016. Early puberty of farmed tambaqui (*Colossoma macropomum*): Possible influence of male sexual maturation on harvest weight. *Aquaculture* 452: 224–232. <https://doi.org/10.1016/j.aquaculture.2015.10.031>.
- Almeida, O. T., D. G. McGrath & M. L. Ruffino, 2001. The commercial fisheries of the lower Amazon: an economic analysis. *Fisheries Management and Ecology* 8: 253–269.
- Anderson, D. R. & K. P. Burnham, 2002. When using information-theoretic pitfalls avoiding. *The Journal of Wildlife Management* 66: 912–918.
- Arantes, C. C., L. Castello, M. Cetra & A. Schilling, 2013. Environmental influences on the distribution of arapaima in Amazon floodplains. *Environmental Biology of Fishes* 96: 1257–1267.
- Arantes, C. C., L. Castello, D. J. Stewart, M. Cetra & H. L. Queiroz, 2010. Population density, growth and reproduction of arapaima in an Amazonian river-floodplain. *Ecology of Freshwater Fish* 19: 455–465.
- Arantes, C. C., K. O. Winemiller, M. Petrere, L. Castello, L. L. Hess & C. E. C. Freitas, 2018. Relationships between forest cover and fish diversity in the Amazon River floodplain. *Journal of Applied Ecology* 55: 386–395.
- Arantes, C., L. Castello & D. Garcez, 2007. Variações entre contagens de Arapaima gigas (Schinz) (Osteoglossomorpha, Osteoglossidae) feitas por pescadores individualmente em Mamirauá, Brasil. *Pan-American Journal of Aquatic Sciences* 2: 263–269.
- Arantes, M. L. & C. E. C. Freitas, 2016. Effects of fisheries zoning and environmental characteristics on population parameters of the tambaqui (*Colossoma macropomum*) in managed floodplain lakes in the Central Amazon. *Fisheries Management and Ecology* 23: 133–143.

- Araújo-Lima C, G. M., 1998. Os Frutos do Tambaqui: Ecologia, Conservação e Cultivo na Amazônia. Tefé: Sociedade Civil Mamirauá.
- Aswani, S. & R. J. Hamilton, 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation* 31: 69–83.
- Baird, I. G. & M. S. Flaherty, 2005. Mekong River Fish Conservation Zones in southern Laos: Assessing effectiveness using local ecological knowledge. *Environmental Management* 36: 439–454.
- Barthem, R., & N. N. Fabr , 2004. Biologia e diversidade dos recursos pesqueiros da Amaz nia. A pesca e os recursos pesqueiros na Amaz nia Brasileira, v. 1, p. 17–62.
- Barthem R, G. M., 1997. Os Bagres Balisadores: Ecologia, Migra  o e Conserva  o de Peixes Amaz nicos. Vol. 3. Tef : Sociedade Civil Mamirau .
- Barton, K., 2019. Package ‘MuMIn’.
- Batista, S., 2002. Caracteriza  o da frota pesqueira de Parintins, Itacoatiara e Manacapuru, Estado do Amazonas. *Acta Amazonica*, 33(2), 291–302.
- Batista, V., V. Isaac, F. N.N.J.C. Gonzalez, O.T. Almeida, S. Rivero, J. N. Junior, M. Ruffino, C.O. Silva, & U. Saint-paul, 2012. Peixes e Pesca Solim es- Amazonas IBAMA (Fish and Fisheries in the Solim es- Amazonas).
- Batista, V. S., 2012. Peixes e Pesca Solim es - Amazonas: uma avalia  o integrada..
- Batista, V. S., & L. G. Lima, 2010. In search of traditional bio-ecological knowledge useful for fisheries co-management: the case of *jaraquis Semaprochilodus* spp. (Characiformes, Prochilodontidae) in Central Amazon, Brazil. *Journal of ethnobiology and ethnomedicine* 6: 15.
- Batista, V. S., & M. Petreire J nior, 2003. Characterization of the commercial fish production landed at Manaus, Amazonas state, Brazil. 33.
- Batistella, A. M., C. P. de Castro & J. D. do Vale, 2005. Conhecimento dos moradores da comunidade de Boas Novas, no Lago Janauac —Amazonas, sobre os h bitos alimentares dos peixes da regi o. *Acta Amazonica* 35: 51–54.
- Begossi, A., 2010. Small-scale fisheries in Latin America: management models and challenges. *Mast* 9: 7–31.
- Begossi, A. & J. L. de Figueiredo, 1995. Ethnoichthyology of southern coastal fishermen: cases from Buzios Island and Sepetiba Bay (Brazil). *Bulletin of Marine Science* 56: 710–717.
- Begossi, A., S. Salivonchik, P. F. M. Lopes & R. A. M. Silvano, 2016. Fishers’ knowledge on the coast of Brazil. *Journal of Ethnobiology and Ethnomedicine*. <https://doi.org/10.1186/s13002-016-0091-1>.
- Bender, M. G., G. R. Machado, P. J. De Azevedo Silva, S. R. Floeter, C. Monteiro-Netto, O. J. Luiz & C. E. L. Ferreira, 2014. Local ecological knowledge and scientific data reveal overexploitation by multigear artisanal fisheries in the Southwestern Atlantic. *PLoS ONE* 9: 27.
- Benedito-Cecilio, E., C. A. R. M. Araujo-lima, B. R. Forsberg, M. M. Bittencourt, & L. C. Martinelli, 2000. Carbon sources of Amazonian fisheries. *Fisheries Management and Ecology* 7: 305–315.
- Berkes, F., J. Colding, C. Folke, E. Applications & N. Oct, 2008. Rediscovery of traditional ecological knowledge as adaptive management. *America* 10: 1251–1262.
- Berkstr m, C., M. Papadopoulos, N. S. Jiddawi & L. M. Nordlund, 2019. Fishers’ Local Ecological Knowledge (LEK) on connectivity and seascape management. *Frontiers in Marine Science* 6: 1–10.
- Bernarde, P. S. & A. S. Abe, 2010. H bitos alimentares de serpentes em Esp  o do Oeste, Rond nia, Brasil Introdu  o Material e M todos Resultados. *Biota Neotropica* 10: 167–173.
- Braga, T. M. P. & G. Henrique Reb lo, 2014. Conhecimento tradicional dos pescadores do baixo rio Juru : aspectos relacionados aos h bitos alimentares dos peixes da region. *Interciencia* 39: 659–665.
- Braga, T. M. P., & G. Henrique Reb lo, 2014. Conhecimento tradicional dos pescadores do baixo rio Juru : Aspectos relacionados aos h bitos alimentares dos peixes da regi o. *Interciencia* 39: 659–665.
- Braga, T. M. P. & G. H. Reb lo, 2017. Traditional Knowledge of the Fishermen of the Lower Juru  River: understanding the Reproductive Patterns of the Region’s Fish Species. *Desenvolvimento e Meio Ambiente* 40: 385–397.
- IBGE, 2019. Instituto Brasileiro De Geografia. Estat stica, Censo Demogr fico.
- Campos-Silva, J. V., J. E. Hawes & C. A. Peres, 2019. Population recovery, seasonal site fidelity, and daily activity of pirarucu (*Arapaima* spp.) in an Amazonian floodplain mosaic. *Freshwater Biology* 64: 1255–1264.
- Campos-Silva, J. V. & C. A. Peres, 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. *Scientific Reports Nature Publishing Group* 6: 1–13.
- Campos-Silva, J. V., C. A. Peres, A. P. Antunes, J. Valsecchi & J. Pezzuti, 2017. Community-based population recovery of overexploited Amazonian wildlife. *Perspectives in Ecology and Conservation Associa  o Brasileira de Ci ncia Ecol gica e Conserva  o* 15: 266–270.
- Campos, C. P., R. G. Costa Sousa, M. F. Catarino, G. de Albuquerque Costa & C. E. C. Freitas, 2015a. Population dynamics and stock assessment of *Colossoma macropomum* caught in the Manacapuru Lake system (Amazon Basin, Brazil). *Fisheries Management and Ecology* 22: 400–406.
- Campos, C. P., C. E. de C. Freitas, & S. Amadio, 2015b. Growth of the *Cichla temensis* Humboldt, 1821 (Perciformes: Cichlidae) from the middle rio Negro, Amazonas, Brazil. *Neotropical Ichthyology* 13: 413–420. Din mica populacional do tucunar  cichla temensis (humboldt, 1833) do m dio Rio Negro, Amazonas, Brasil. 55, <http://bdtd.inpa.gov.br/handle/tede/1577>.
- Carolsfeld, J., B. Harvey, C. Ross, & A. Baer, 2004. Migratory fishes of South America: Biology, Fisheries, and Conservation Status. Washington, DC, USA and Ottawa, ON, Canada: World Fisheries Trust/ Word Bank/ International Development Research Centre.
- Castello, L., 2004. A method to count Pirarucu *Arapaima* Gigas: fishers, assessment, and management. *North American Journal of Fisheries Management* 24: 379–389.

- Castello, L., 2008a. Lateral migration of *Arapaima gigas* in floodplains of the Amazon. *Ecology of Freshwater Fish* 17: 38–46.
- Castello, L., 2008b. Nesting habitat of *Arapaima gigas* (Schinz) in Amazonian floodplains. *Journal of Fish Biology* 72: 1520–1528.
- Castello, L., D. G. McGrath, C. C. Arantes & O. T. Almeida, 2013. Accounting for heterogeneity in small-scale fisheries management: the Amazon case. *Marine Policy Elsevier* 38: 557–565.
- Castello, L., J. P. Viana, & M. Pinedo-Vasquez, 2011. Participatory conservation and local knowledge in the Amazon Várzea: The Pirarucu Management Scheme in Mamirauá.
- Castello, L., J. P. Viana, G. Watkins, M. Pinedo-Vasquez & V. A. Luzadis, 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon. *Environmental Management* 43: 197–209.
- Castellanos, L., R. A. Maldonado, & J. C. Alonso Gonzável, 2006. Caimán Negro de la Amazonía Colombiana (*Melano-suchus niger*): Conocimiento para su Conservación y Uso Sostenible. Instituto Sinchi. Bogotá, Colombia. 20.
- Cavole, L. M., C. C. Arantes & L. Castello, 2015. How illegal are tropical small-scale fisheries? An estimate for arapaima in the Amazon. *Fisheries Research* 168: 1–5.
- Cerdeira, R. G. P., M. L. Ruffino, & V. J. Isaac, 1997. Consumo de pescado e outros alimentos pela população ribeirinha do lago Grande de Monte Alegre, PA-Brasil. *Acta Amazonica*.
- Crona, B. & Ö. Bodin, 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology And Society* 11: 7.
- Davis, A. & J. R. Wagner, 2003. Who Knows? On the Importance of Identifying “Expert” When Researching Local Ecological Knowledge. *Human Ecology* 31: 463–489.
- Davis, A. & K. Ruddle, 2010. Constructing confidence: on the importance of rational scepticism and systematic enquiry in local ecological knowledge research. *Ecological Applications* 20: 880–894.
- da Doria, C. R., M. A. L. L. Lima, A. Santos, S. T. Souza, M. O. A. R. Simão & A. R. Carvalho, 2014. O uso do conhecimento ecológico tradicional de pescadores no diagnóstico dos recursos pesqueiros em áreas de implantação de grandes empreendimentos. *Desenvolvimento e Meio Ambiente* 30: 89–108.
- Da Silveira, R., & W. E. Magnusson, 1999. Diets of spectacled and black Caiman in the Anavilhanas Archipelago, Central Amazonia, Brazil. *Journal of Herpetology* 33: 181–192.
- da Silva Batista, N. N., V., M. O. de Albuquerque Ribeiro & R. J. Ladle, 2012. A new framework for natural resource management in Amazonia. *Ambio* 41: 302–308.
- de Lima, L. G., A. O. Souza & V. S. da Batista, 2021. Conhecimento ecológico local utilizado para cogestão na pesca: o caso tucunaré, *Cichla* spp (cichlidae), na Amazônia Central, Brasil. *Brazilian Journal of Animal and Environmental Research* 4: 532–546.
- de Ribeiro, M. C. L. & M. Petrer Jr., 1990. Fisheries ecology and management of the jaraqui (*Semaprochilodus taeniurus*, *S. insignis*) in central amazonia. *Regulated Rivers* 5: 195–215.
- dos Santos, G. M. & A. C. M. dos Santos, 2005. Sustentabilidade da pesca na Amazônia. *Estudos Avançados* 19: 165–182.
- dos Santos, A. L., F. C. da Cunha, M. G. M. Soares, L. P. de Souza & A. C. Florentino, 2016. Conhecimento dos pescadores artesanais sobre a composição da dieta dos pacus (Characiformes: Serrasalminidae) na Floresta Nacional do Amapá, rio Araguari, Amapá. Brasil. *Biotemas* 29: 101.
- Drew, J. A., 2005. Use of traditional ecological knowledge in marine conservation. *Conservation Biology* 19: 1286–1293.
- Duarte, C., A. E. Magurran, J. Zuanon & C. P. Deus, 2019. Trophic ecology of benthic fish assemblages in a lowland river in the Brazilian Amazon. *Aquatic Ecology* 53: 707–718.
- Espínola, H., 2015. A defesa do peixe pelos ribeirinhos do Amazonas..
- Fabré, N. N. & J. C. Alonso, 1998. Recursos ícticos no Alto Amazonas: sua importância para as populações ribeirinhas. *Boletim do Museu Paraense Emílio Goeldi* 14: 19–55.
- Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V. Norström, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, & J. Tenhunen, 2015. Advancing sustainability through mainstreaming a social-ecological systems perspective. *Current Opinion in Environmental Sustainability*.
- Food and Agriculture Organization of the United Nations (FAO), 2018. El estado de la seguridad alimentaria y la nutrición en el mundo 2019. El estado de la seguridad alimentaria y la nutrición en el mundo 2018.
- Fraxe, T. J. P., A. C. Witkoski, & S. C. P. Da Silva, 2009. A pesca na Amazônia Central: ecologia, conhecimento tradicional e formas de manejo.
- Froese, R. and /D. P., 2017. World Wide Web electronic publication. www.fishbase.org.
- Furtado, L., 1993. Pescadores do rio Amazonas: Um estudo antropológico da pesca ribeirinha numa área amazônica.
- Fontenele, O., 1948. Contribuição para o conhecimento da biologia do pirarucu (*Arapaima gigas* Cuvier), em cativeiro: (Actinopterygii, Osteoglossidae). *Revista Brasileira de Biologia* 8: 445–459.
- Galvão de Lima, L. & V. S. da Batista, 2012. Estudos etnoicitológicos sobre o pirarucu *Arapaima gigas* na Amazônia central. *Acta Amazonica* 42: 337–344.
- Gama, C., 2014. Confirmation of sexual dimorphism in *Hoplias aimara* (Valenciennes, 1847) (Erythrinidae: Characiformes) proposed by local expertise in Amapá, Brazil. *Brazilian Journal of Biology* 74: 687–690.
- Gandra, A. L., 2010. O mercado do pescado da região metropolitana de Manaus O mercado do pescado nas grandes cidades latino-americanas. 84.
- Goulding, M., 1982. Life history and management of the tambaqui (*Colossoma macropomum*, characidae); an important amazonian food fish. *Revista Brasileira de Zoologia*; Revta 1: 107–133.
- Goulding, M., E. Venticinque, B. Forsberg, M. L. D. B. R. Ribeiro, R. Barthem, P. Petry, L. Hess, C. Durigan, & C. Cañas, 2018. Ecosystem-based management of Amazon fisheries and wetlands. 22:1–21.
- Goulding, M., & M. L. Carvalho, 1982. Life history and management of the tambaqui (*Colossoma macropomum*,

- Characidae): an important Amazonian food fish. *Revista Brasileira de Zoologia* 1: 107–133.
- Goulding, M., N. J. H. Smith, & D. J. Mahar, 1996. *Floods of fortune: Ecology and economy along the Amazon*. Columbia University Press.
- Gurdak, D. J., D. J. Stewart, L. Castello & C. C. Arantes, 2019. Diversity in reproductive traits of arapaima (*Arapaima* spp., Müller, 1843) in Amazonian várzea floodplains: conservation implications. *Aquatic Conservation* 29: 245–257.
- Hallwass, G., A. Schiavetti & R. A. M. Silvano, 2019. Fishers' knowledge indicates temporal changes in composition and abundance of fishing resources in Amazon protected areas. *Animal Conservation* 24: 1–12.
- Halvorsen, K. T., T. K. Sjørdalen, C. Durif, H. Knutsen, E. M. Olsen, A. B. Skiftesvik, T. E. Rustand, R. M. Bjelland & L. A. Vøllestad, 2016. Male-biased sexual size dimorphism in the nest building corkscrew wrasse (*Symphodus melops*): implications for a size regulated fishery. *ICES Journal of Marine Science* 73: 2586–2594.
- Hrbek, T., M. Crossa & I. P. Farias, 2007. Conservation strategies for *Arapaima gigas* (Schinz, 1822) and the Amazonian várzea ecosystem. *Brazilian Journal of Biology* 67: 909–917.
- Hrbek, T., I. P. Farias, M. Crossa, I. Sampaio, J. I. R. Porto & A. Meyer, 2005. Population genetic analysis of *Arapaima gigas*, one of the largest freshwater fishes of the Amazon basin: implications for its conservation. *Animal Conservation* 8: 297–308.
- Huntington, H. P., 2000. Using traditional ecological knowledge in science: methods and applications. *Ecological Applications* 10: 1270–1274.
- Imbiriba, E., 2001. Potencial de Criação de Pirarucu, *Arapaima gigas*, em cativeiro. *Acta Amazonica* 31: 299–316.
- Isaac, V. J., A. Milstein & M. L. Ruffino, 1996. Characterization of the commercial fish production landed at Manaus, Amazonas State, Brazil. *Acta Amazonica* 26: 185–208.
- Isaac, V. J. & M. L. Ruffino, 1996. Population dynamics of tambaqui, *Colossoma macropomum* Cuvier, in the Lower Amazon, Brazil. *Fisheries Management and Ecology* 3: 315–333.
- Isaac, V. J., M. L. Ruffino & P. Mello, 2000. Considerações sobre o método de amostragem para a coleta de dados sobre captura e esforço pesqueiro no médio Amazonas. *Coleção Meio Ambiente. Série Estudos Pesca* 22: 175–199.
- Isaac, V. J., V. L. C. Rocha, & S. Mota. 1993. Considerações sobre a legislação da “piracema” e outras restrições da pesca da região do Médio Amazonas. In *Ministério de Ciência e Tecnologia, Conselho Nacional de Pesquisa, M. P. E. G. (org), Povos das águas, realidade e perspectivas na Amazônia*. Belém, Pará: 188–211.
- Johannes, R. E., 1998. The case for data less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* 13: 243–246.
- Johannes, R., M. M. Freeman & R. J. Hamilton, 2000. Ignore fishers' knowledge and miss the boat. *Fish and Fisheries* 1: 257–271.
- Junk, W. J., M. G. M. Soares & P. B. Bayley, 2007. Freshwater fishes of the Amazon River basin: their biodiversity, fisheries, and habitats. *Aquatic Ecosystem Health & Management* 10: 153–173.
- Lima, E. G., A. Begossi, G. Hallwass & R. A. M. Silvano, 2016. Fishers' knowledge indicates short-term temporal changes in the amount and composition of catches in the south-western Atlantic. *Marine Policy Elsevier* 71: 111–120.
- Lopes, K. & H. L. De Queiroz, 2009. Avaliação Do Conhecimento Tradicional Dos Pescadores Da Rds. *Uakari* 5: 59–66.
- Lopes, K. S. 2005. Aspectos da Biologia Reprodutiva de Pirarucu, *Arapaima gigas*, Cuvier 1817, com Subsídios para o Manejo da sua Reprodução. *Dissertação de mestrado*.
- Lopes, P. F. M., G. Hallwass, A. Begossi, V. J. Isaac, M. Almeida, & R. A. M. Silvano, 2019. The Challenge of Managing Amazonian Small-Scale Fisheries in Brazil: 219–241.
- Lorenzón, R. E., A. L. Ronchi Virgolini & A. H. Beltzer, 2013. Ecología trófica de la Garza blanca *Ardea alba* (Pelecaniformes: Ardeidae) en un humedal del río Paraná, Argentina. *UNED Research Journal* 5: 121–127.
- Lynch, A. J., B. J. E. Myers, C. Chu, L. A. Eby, J. A. Falke, R. P. Kovach, T. J. Krabbenhoft, T. J. Kwak, J. Lyons, P. Craig, J. E. Whitney, & C. P. Paukert, 2016. Fish populations and assemblages climate change effects on North American inland fish populations and assemblages. *Fisheries* 41: 346–361.
- Machado, C., B. Hamdan, J. L. B. Neves & B. A. R. Filho, 2018. Predation of *Boa constrictor* LINNAEUS, 1758 by *Eunectes murinus* (LINNAEUS, 1758) in captivity (SERPENTES: BOIDAE). *SaBios: Rev. Saúde e Biol.* 13: 2014–2016.
- Magnusson, W. E., E. V. Da Silva, A. P. LIMA. 1987. Diets of Amazonian crocodilians. *Journal of Herpetology*, 85–95.
- Manzan, M. F., & P. F. M. Lopes, 2015. Fishers' knowledge as a source of information about the estuarine dolphin (*Sotalia guianensis*, van Bénédén, 1864). *Environmental Monitoring and Assessment* 187.
- Marques, J. G. W., 1995. Pescando pescadores: etnoecologia abrangente no baixo São Francisco alagoano.
- Martins, I. M., R. P. Medeiros, M. Di Domenico & N. Hanazaki, 2018. What fishers' local ecological knowledge can reveal about the changes in exploited fish catches. *Fisheries Research Elsevier* 198: 109–116.
- Martins, M. & M. Oliveira, 1998. Natural history of snakes in forests of the Manaus region, Central Amazonia, Brazil. *Natural History* 6: 78–150.
- McCauley, D. J., P. A. Desalles, H. S. Young, R. B. Dunbar, R. Dirzo, M. M. Mills, & F. Micheli, 2012. From wing to wing: The persistence of long ecological interaction chains in less-disturbed ecosystems. *Scientific Reports* 2:.
- McConnell, R. & R. H. Lowe-McConnell, 1987. *Ecological studies in tropical fish communities*. Cambridge University Press, Cambridge.
- Mcgrath, D. G., F. De Castro & C. Fudemma, 1993. Fisheries and the evolution of resource management on the lower Amazon Floodplain. *Human Ecology* 21: 167–195.

- Mello, F., C. A. L. Oliveira, R. P. Ribeiro, E. K. Resende, J. A. Povh, D. C. Fornari, R. V. Barreto, C. McManus, & D. Streit, 2015. Growth curve by Gompertz nonlinear regression model in female and males in tambaqui (*Colossoma macropomum*). *Anais da Academia Brasileira de Ciencias* 87: 2309–2315.
- Monteiro, L. B. B., M. do Carmo Figueredo Soares, M. T. J. Catanho & A. Honczaryk, 2010. Aspectos reprodutivos e perfil hormonal dos esteróides sexuais do pirarucu, *Arapaima gigas* (SCHINZ 1822, em condições de cativeiro. *Acta Amazonica* 40: 435–450.
- Neves, A. M. 2000. Conhecimento atual sobre o pirarucu *Arapaima gigas*. Recursos pesqueiros do médio Amazonas. Brasília: Ed. IBAMA.: 90–113.
- Nigel J.H.Smith, 1981. Man, fishes and the amazon.
- Nunes, D. M., S. M. Hartz & R. A. M. Silvano, 2011. Conhecimento ecológico local e científico sobre os peixes na pesca artesanal no sul do Brasil. *Boletim do Instituto de Pesca* 37: 209–223.
- Oliveira, A. C. B., M. G. M. Soares, L. A. Martinelli & M. Z. Moreira, 2006a. Carbon sources of fish in an Amazonian floodplain lake. *Aquatic Sciences* 68: 229–238.
- Oliveira, A. C. B., L. A. Martinelli, M. Z. Moreira, M. G. M. Soares, & J. E. P. Cyrino, 2006b. Seasonality of energy sources of *Colossoma macropomum* in a floodplain lake in the Amazon - Lake Camaleão, Amazonas, Brazil. *Fisheries Management and Ecology* 13: 135–142.
- Olsson, P. & C. Folke, 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. *Ecosystems* 4: 85–104.
- Pereira, S. A. & N. N. Fabre, 2009. Uso e gestão do território em áreas de livre acesso no Amazonas, Brasil. *Acta Amazonica* 39: 561–572.
- Petersen, T. A., S. M. Brum, F. Rossoni, G. F. V. Silveira & L. Castello, 2016. Recovery of *Arapaima* sp. populations by community-based management in floodplains of the Purus River, Amazon. *Journal of fish biology* 89: 241–248.
- Petrere Jr., M., 1978. Pesca e esforço de pesca no Estado do Amazonas. *Acta Amazonica* 3: 439–454.
- Prestes-Carneiro, G., P. Béarez, S. Bailon, A. Rapp Py-Daniel & E. G. Neves, 2016. Subsistence fishery at Hatahara (750–1230 CE), a pre-Columbian central Amazonian village. *Journal of Archaeological Science* 8: 454–462.
- Queiroz, H. L., 2000. Natural history and conservation of pirarucu, *Arapaima gigas*, at the Amazonian varzea: red giants in muddy waters. Thesis.
- Queiroz, H.L., & A. D. Sardinha, 1999. Preservação e o uso sustentado dos pirarucus em Mamirauá. Estratégias para o manejo de recursos pesqueiros em Mamirauá. Sociedade Civil Mamirauá/ Ministério de Ciência e Tecnologia / Conselho Nacional de Pesquisa, Brasília, Brasil: 108–141.
- Ramires, M., M. Clauzet, W. Barrella, M. M. Rotundo, R. A. M. Silvano & A. Begossi, 2015. Fishers' knowledge about fish trophic interactions in the southeastern Brazilian coast. *Journal of Ethnobiology and Ethnomedicine* 11: 1–11.
- Rebello, S. R. M., C. E. de Freitas & M. G. M. Soares, 2010. Fish diet from Manacapuru Big Lake complex (Amazon): a approach starting from the traditional knowledge. *Biota Neotropica* 10: 39–44.
- Ribeiro, M. C. L. de B., & M. Petrere Jr, 1990. Fisheries ecology and management of the Jaraqui (*Sernapruchilodus taeniurus*, S. insignis) in central Amazonia. *Regulated Rivers: Research & Management* 5: 195–215.
- Rosas, F. C. W., R. S. Sousa-Lima, S. V., Da Silva, V. M. F. 2003. Avaliação preliminar dos mamíferos do baixo rio Purus. In: *Piagaçu-Purus: Bases Científicas para a Criação de uma Reserva de Desenvolvimento Sustentável*, ed. C. F. de Deus, R. Da Silveria, L.H. R. Py-daniel. Expedição Científica ao Rio Purus: 49–59.
- Roubach, R., & U. Saint-Paul, 1994. Use of fruits and seeds from Amazonian inundated forests in feeding trials with *Colossoma macropomum* (Cuvier, 1818) (Pisces, Characidae). *Journal of Applied Ichthyology* 10: 134–140.
- Ruddle, K., 1991. The transmission of traditional ecological knowledge kenneth ruddle. *Second Annual Meeting of the Society for the Study of Common Property* 24: 26–29.
- Ruddle, K., 1995. The role of validated local knowledge in the restoration of fisheries property rights: the example of the New Zealand Maori.
- Ruddle, K., & a Davis, 2013. Local Ecological Knowledge (LEK) in Interdisciplinary Research and Application: a Critical Review. *Asian Fisheries Science* 26: 79–100, http://www.msvu.ca/site/media/msvu/Documents/RuddleandDavis_AJFS1.pdf.
- Sánchez, J. 1969. El “paiche:” aspectos de su historia natural y aprovechamiento. *Revista de Caza y Pesca* 10: 17–61.
- Sánchez-Jiménez, A., M. Fujitani, D. MacMillan, A. Schlüter, & M. Wolff, 2019. Connecting a trophic model and local ecological knowledge to improve fisheries management: The case of gulf of Nicoya, Costa Rica. *Frontiers in Marine Science* 6:.
- Santos, G. M., J. G. F. Efrem, & J. Zuanon. 2006. Peixes Comerciais de Manaus. Manaus, IBAMA. 144p.
- Sears, R. R., C. Padoch & M. Pinedo-Vasquez, 2007. Amazon forestry tranformed: integrating knowledge for smallholder timber managemet in eastern Brazil. *Human Ecology* 35: 697–707.
- SILVA, M. D. C., 2014. Análise do manejo comunitário de pirarucu (*Arapaima spp.*) na Resex Médio Juruá e RDS Uacari, município de Carauari, Amazonas, Brasil. Dissertação, https://ipsas.upm.edu.my/upload/dokumen/IISS_022.pdf.
- Silva, J. A., M. Pereira-Filho, & M. I. Oliveira-Pereira, 2000. Seasonal variation of nutrients and energy in tambaqui's (*Colossoma Macropomum* Cuvier, 1818) natural food. *Revista brasileira de biologia* 60: 599–605.
- Silvano, R. A. M. & A. Begossi, 2010. What can be learned from fishers? An integrated survey of fishers' local ecological knowledge and bluefish (*Pomatomus saltatrix*) biology on the Brazilian coast. *Hydrobiologia* 637: 3–18.
- Silvano, R. A. M. & J. Valbo-Jorgensen, 2008. Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management. *Environment, Development and Sustainability* 10: 657–675.
- Sparre, P. & S. C. Venema, 1998. Introduction to tropical fish stock assessment. Manual, Part I.
- Veríssimo, J. 1970. A pesca na Amazônia. Coleção Amazônica. Série José Veríssimo. Universidade Federal do Pará.

- Vieira, E., N. Fabré, & U. SAINT-PAUL, 1999. Aspectos do ciclo de vida de *Semaprochilodus insignis* e *S.taeniurus* Characiformes-Prochilodontidae nos Lagos Incio e Prato da Amazônia Central, Brasil. Boletim do Museu Paraense Emílio Goeldi. Série Zoológica 15(1).
- Zuur, A., Ieno, E. N., Walker, N., Saveliev, A. A., & Smith, G. M., 2010. Mixed effects models and extensions in ecology with R..

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