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Original Article

Spatial dynamics of Amazonian commercial fisheries: an analysis of landscape composition and fish landings

Dinâmica espacial da pesca comercial amazônica: uma análise da composição da paisagem e dos desembarques de pescado

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Abstract

Amazonian commercial fishing is artisanal, and landings can be influenced by the flood pulse, the consumer market, the level of exploitation of species, habitat quality and vegetation cover. In this study, landscape variables and the river level were evaluated as possible drivers in the composition of catches landed in three regions of the Solimões-Amazon River. Fish landing data were collected in the upper and lower Solimões River and lower Amazon River. Fishing locations were mapped with information from fishers, civil defense departments and from the literature. Information related to river level and landscape was acquired from databases available online. Maps with the the radius of action of the fishing fleet and the quantification of landscape variables were made for periods of high and low-water, and non-metric multidimensional scaling analysis (nMDS) with catches by species, by region and hydrological period were performed. The largest operating radius of the fishing fleet was of 1,028 km and was identified in the lower Amazon River, which is probably due to the larger size of the consumer market, vessel characteristics and level of exploitation of the species near the landing center. The proportion of vegetation cover was reduced from 87% in the upper stretches of the Solimões River to 46% in the lower stretches. The upper and lower Solimões River regions presented a greater variety of species in the composition of landings. It was identified that the composition of landings between the three analyzed regions possibly varied according to the availability of habitats, indicating the importance of landscape variables for fish landings.

Keywords: artisanal fisheries, commercial fish, landscape variables, Amazon.

Resumo

A pesca comercial amazônica é artesanal e os desembarques podem ser influenciados pelo pulso de inundação, mercado consumidor, nível de explotação das espécies, qualidade do hábitat e cobertura da vegetação. Nesse estudo, avaliamos as variáveis da paisagem e o nível do rio como possíveis impulsionadores na composição das capturas desembarcadas em três regiões do rio Solimões-Amazonas. Os dados de desembarque de pescado foram coletados no Alto e Baixo rio Solimões e Baixo rio Amazonas. Os locais de pesca foram mapeados com informações dos pescadores, da defesa civil e literatura. As informações relacionadas ao nível do rio e a paisagem foram adquiridas em bancos de dados disponíveis online. Mapas com o raio de atuação da frota pesqueira e a quantificação das variáveis da paisagem foram elaborados para períodos de águas altas e baixas e as análises de escalonamento multidimensional não-métrico (nMDS) com as capturas por espécie, por região e período hidrológico foram realizadas. O maior raio de atuação da frota pesqueira foi de 1.028 km e foi identificado no Baixo rio Amazonas provavelmente devido ao maior tamanho do mercado consumidor, características das embarcações e nível de explotação das espécies próximo do centro de desembarque. A proporção de cobertura de vegetação teve uma redução de 87% no trecho superior do rio Solimões para 46% no trecho inferior. As regiões do Alto e Baixo rio Solimões apresentaram maior variedade de espécies na composição dos desembarques. Foi identificada que a composição dos desembarques entre as três regiões analisadas variou possivelmente conforme a disponibilidade de hábitats, indicando a importância das variáveis da paisagem para os desembarques de pescado.

Palavras-chave: pesca artesanal, peixes comerciais, variáveis da paisagem, Amazônia.

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1. Introduction

The landscape of the Solimões-Amazon River is quite heterogeneous along its course (Mertes et al., 1995; Junk et al., 2011). The differences possibly result from the topography, convergence of different rivers and water types, landforms, and extent of the adjacent floodplain (Mertes et al., 1995, 1996). In addition, the structure of the landscape has been affected by human activities. Mertes et al. (1995) observed that the flooded forest comprised 70% of the floodplain vegetation in the upstream and middle stretches of the Amazon River, in contrast to 37% of forest in the wetlands of the downstream stretch and attributed this difference to agricultural activities. Recently, Renó and Novo (2019) also observed the existence of an east-west gradient of depletion of vegetation cover in the Amazon floodplain that keeps pace with human occupation and government policies in the region.

Commercial fishing in the Amazon is artisanal, employs different fishing equipment and methods, and captures several species of fish (Matos et al., 2021). This activity has high social, economic and cultural importance for the region, and contributes to more than 170,000 tons of fish (Barthem and Goulding, 2007). Although there are 2,716 fish species in the Amazon basin (Dagosta and De Pinna, 2019), landings are of fewer than 200 species (Hallwass and Silvano, 2015; Matos et al., 2021). Among the most important species in the landings in the region, the following can be cited: curimatã (*Prochilodus nigricans* Spix and Agassiz, 1829), jaraqui (*Semaprochilodus insignis* Jardine, 1841; *S. taeniurus* Valenciennes, 1821), matrinxã (*Brycon amazonicus* Spix and Agassiz, 1829; *B. cephalus* Cuvier, 1816), tambaqui (*Colossoma macropomum* Cuvier, 1816), pacú (*Mylossoma aureum* Spix and Agassiz, 1829; *M. duriventre* Cuvier, 1818; *Catoprion* spp.; *Metynnis* spp.; *Myleus* spp.), aracú (*Leporinus* spp., *Rhytiodus* spp. and *Schizodon* spp.), sardinha (*Triportheus albus* Cope, 1872; *T. angulatus* Spix and Agassiz, 1829; and *T. elongatus* Günther, 1864), branquinha (*Cyphocharax* spp.; *Curimata* spp.; *Potamorhina* spp.; *Psectrogaster* spp.; *Steindachneria* spp.), mapará (*Hypophthalmus edentates* Spix and Agassiz, 1829; *H. marginatus* Rüppell, 1835; *H. fimbriatus* Kner, 1858), surubim/caparari (*Pseudoplatystoma fasciatum* Linnaeus, 1766; *P. tigrinum* Valenciennes, 1840; *P. reticulatum* Eigenmann and Eigenmann, 1889), dourada (*Brachyplatystoma rousseauxii* Castelnau, 1855) and piramutaba (*Brachyplatystoma vaillantii* Valenciennes, 1840) (Goulding et al., 2018). Although the type of movement varies, these species are migratory and eating habits vary between detritivores, omnivores, herbivores, planktivores and carnivores (Goulding et al., 2018; Arantes et al., 2019). Most species use the floodplain as a feeding, spawning, nursery and refuge area against predators, indicating the importance of this environment, are periodic strategists with maturation at small and large size, no parental care (Goulding et al., 2018; Arantes et al., 2019).

The behavior of the commercial fishers and the capture of the species can be shaped according to the fluctuation of the river level, the preferences of the consumer market, the type of environment and the fishing site (Matos et al., 2021; Tregidgo et al., 2021). In addition, the use of certain fishing sites by fishers may be related to the accessibility and availability of the aquatic environment (Sousa et al., 2009). Thus, the spatial complexity of Amazonian commercial fishing needs to be considered in the management of the activity.

In the Amazon, although there is a limitation in relation to the identification of geographical fishing patterns that allow us to determine the rules for the use of fishery resources, it is recognized that most commercial fisheries are carried out in the floodplain, which have a high level of animal biomass (Goulding et al., 2018). Some studies spatialized the fishing activity (Sousa et al., 2009) and analyzed the influences of landscape variables, such as flooded forest, aquatic macrophytes and open water, on fishing yield (Castello et al., 2017). Castello et al. (2017) identified that the removal of floodplain forests reduces fishery yields per unit effort, and Arantes et al. (2019) observed that floodplain land cover affects biomass distribution of fish functional diversity in the Amazon River. More recently, Pereira et al. (2022) also showed the importance of land cover and was able to discriminate flooded shrub habitats as the most influential landscape component to the fishing yield. In this study, the landscape is characterized according to the river level measured in the area of operation of the fishing fleet of three regions of the Solimões-Amazon River, and the landscape characteristics are analyzed as possible drivers in the composition of landed catches. Considering that floodplain land cover is highly important for several species of fish (Arantes et al., 2019), it is hypothesized that the greatest variety of species landed by commercial fishing are recorded in regions with a higher proportion of forest cover.

2. Materials and Methods

2.1. Study area

The Solimões-Amazon River flows from the Peruvian Andes until it reaches the Atlantic Ocean, and has wetland area of 8.4×10^5 km^2 (Hess et al., 2015). In addition, it possesses different environments that are widely exploited by fishers for the capture of several fish species (Goulding et al., 2018). In this study, commercial fisheries were evaluated in three regions of the Brazilian stretch, corresponds to approximately 1,627.25 km, namely the upper, and lower Solimões River and the lower Amazon River, and the landings of the municipalities of Benjamin Constant, Tabatinga, Iranduba and Parintins were analyzed (Figure 1). These municipalities are important fishery landing centers in the Amazon. The municipalities of the upper Solimões River (Benjamin Constant and Tabatinga), located in the border region between Brazil, Peru and Colombia, constitute one of the main hubs of the commercial sector of regional fisheries (Paiva and Silva, 2020). While Iranduba (lower Amazon River) is responsible for 11% of the fishing production that is landed in the Central Amazon, and is considered the second main fishing port in this region (Barthem and Goulding, 2007), Parintins (lower Amazon River) is responsible for 6.4% of the fishery production that is landed in the Amazon

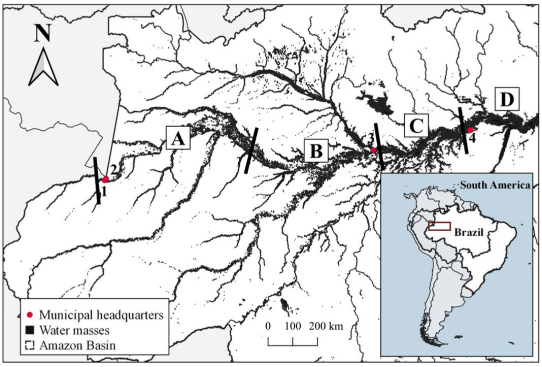

Figure 1. Municipal headquarters of the upper Solimões River, lower Solimões River and lower Amazon River regions. A= upper Solimões River; B= lower Solimões River; C= upper Amazon River; D= lower Amazon River; 1= Benjamin Constant; 2= Tabatinga; 3= Iranduba; 4= Parintins.

(Batista et al., 2012). The different regions vary according to hydrology, soil fertility, vegetation cover, plant diversity and animal species, and also have distinct histories of land use and fisheries resources (Junk et al., 2011).

2.2. Data collection

The river level data were collected on the Hidroweb platform of the National Water Agency (ANA) available at: https://www.snirh.gov.br/hidroweb/. Catch data by species, environments and fishing sites were collected through semi-structured questionnaires within the scope of the Amazonas Fishery Statistics and Landing project. The questionnaires investigate landings and were applied between January and December 2012 in the main landing centers in the cities of Benjamin Constant (270 questionnaires), Tabatinga (603 questionnaires), Iranduba (198 questionnaires) and Parintins (396 questionnaires).

The geographical coordinates of the fishing sites were obtained using the list of fishing sites registered in 2012. Subsequently, in 2018 and 2020, the list of registered fishing sites and hydrographic maps of the regions shown to fishers and the civil defense department with the aim of geographic identification. The geographic information from maps elaborated in the Fronteiras Project (Projeto Fronteiras, 2018), Google Earth Pro 7.3 aquatic masses layer (Google Earth, 2020) and the available literature (Petrere, 1978; Pantoja, 2006; Sousa et al., 2014; Cardoso et al., 2016) were also considered to confirm the geographic location of fishing sites. Information about landscape variables was obtained from the database of Hess et al. (2015). In this study, the image file was used in the Albers Conical Equal Area system with a pixel size of 100 m.

2.3. Data analysis

The flood periods were divided into high-water and low-water, which were defined according to the river level for the year 2012. The grouping of fisheries was carried out considering the river level recorded in Tabatinga for the upper Solimões River, in Iranduba for the lower Solimões River and in Parintins for the lower Amazon River.

A total of 873 fisheries were analyzed in the upper Solimões River, 198 in the lower Solimões River and 396 in the lower Amazon River. Regarding fisheries without records of fishing sites, a total of 188 fisheries in the upper Solimões River, 6 fisheries in the lower Solimões River and 3 fisheries in the lower Amazon River were not included in the analyses.

The geographical coordinates of the fishing sites exploited by the fishers of the three fishing areas were entered into Google Earth Pro, later transferred to Q-Gis and transformed into shapefiles. Subsequently, a buffer was defined around the municipal headquarters with the value of distance from the furthest fishing site used by fishers in periods of high and low-water. The buffer generated was considered as the operating radius of the fishing fleet. The municipal headquarters of Tabatinga was chosen for the upper Solimões River because it is considered an important fishing landing port in this region (Paiva and Silva, 2020). The maps were prepared with the geographical coordinates of the fishing sites used by the fishers, the radius of action of the fishing fleets of each region for the periods of high and low-water and with the data base of Hess et al. (2015). The maps of the upper Solimões River and lower Amazon River regions were made in two geographical scales due to the greater radius of operation of the fleet. The analyses were performed using the software QGIS Desktop 3.4.2 (QGIS Development Team, 2018) and the Multi-Distance Buffer plugin (Tveite, 2018).

The raster image provided by Hess et al. (2015) was cropped from the area of the fishing fleets' operating radius in both flood periods. Subsequently, landscape variables (Hess et al., 2003) were calculated using the software Q-Gis desktop 3.4.2 with GRASS 7.4.2 (QGIS Development Team, 2018). The following classes were disregarded: land outside the basin, non-humid area in the Amazon basin, elevation ≥ 500 m and ocean. The areas were calculated in square kilometers, and were later converted into percentage values and represented graphically. The Albers Conic Equal Area projection system was used in the analyses.

The possible associations between exploited fish species and fishing regions in each hydrological period were investigated using non-metric multidimensional scaling analysis (nMDS). The analyses were performed on a Bray-Curtis distance matrix, estimated from the capture data by species, (Bocard et al., 2011). The vegan package (Oksanen et al., 2016) in the software R 4.0 (R Core Team, 2020) version 4.0.5 was used. Species total catch lower than 300 kg were ignored in the analyses. The removal of these species allowed a better adjustment of the analyses in all regions. The different number of records between regions has little impact on the analyzes that were carried out. Since we performed spatial analysis of fishing sites and an nMDS, which allows exploring the data from an ordering based on a distance matrix and does not need to have the same number of samples between groups.

3. Results

A total of 126, 38 and 122 fishing sites were exploited by fishers from the upper Solimões River, lower Solimões

River and lower Amazon River, respectively. Among these, 49 in the upper Solimões River, 19 in the lower Solimões River and 46 in the lower Amazon River were identified. In the three regions, in both hydrological periods, the lake is the most-used habitat as a fishing environment. The rivers were also heavily exploited by fishers on the upper Solimões River and the lower Amazon River. While in the lower Solimões River, there was a greater amount of fishing on islands and coasts.

In the upper Solimões River, 36 sites were exploited in the high-water period, 33 sites were exploited in the low-water period and 23 sites were exploited in both periods. The operating radius of the fishing fleet was 243 km during the high-water season (Figure 2) and 237 km in the low-water season (Figure 3). 50% of the fishing sites used were observed at a distance of about 28 km and 25 km from Tabatinga during the high-water and in the low-water seasons, respectively.

In the lower Solimões River, 14 sites were exploited during the high-water period, 17 sites were exploited during the low-water period and 12 sites were exploited in both periods. The operating radius of the fishing fleet was 58 km in both hydrological periods (Figure 4). 50% of the fishing sites used were observed at a distance of about 8.5 km from Iranduba in both hydrological periods.

In the lower Amazon River, 44 sites were exploited in the high-water period, 23 sites were exploited in the period of low-waters and 18 sites were exploited in both periods. In the period of high-water, the fleet's radius of action was 896 km (Figure 5) and, during the low-water period, it was 1,028 km (Figure 6). 50% of the fishing sites used were observed at a distance of about 75.5 km and 83 km from Parintins during the high-water and in the low-water seasons, respectively.

In the three regions, flooded forest and non-flooded forest were the dominant components in the landscape, while non-flooded herbaceous and flooded shrubs represented the lowest proportion (Table 1). In the high-water period, the highest proportion of flooded and non-flooded forest was identified in the upper Solimões River and the lowest in the lower Solimões River (Table 1). The highest proportion of flooded shrubs was observed in the lower Amazon River and in the lower Solimões River (Table 1). Non-flooded shrubs were identified only in the lower Solimões River and non-flooded herbaceous plants were not recorded in this period. The highest proportions of flooded herbaceous plants and open water were found in the lower Solimões and lower Amazon Rivers (Table 1).

In the low-water period, the highest proportions of flooded and non-flooded forest were observed in the upper Solimões River and in the lower Amazon River (Table 1). Flooded and non-flooded shrubs were recorded in higher proportions in the lower Amazon River and lower Solimões River (Table 1). While in the lower Solimões River, the highest proportions of flooded herbaceous, non-flooded herbaceous and open water were observed (Table 1).

The stress values of the nMDS were 0.02 and the adjustments were greater than 90%. Thirty species or groups of fish species were exploited by fishers in the high-water period and twenty-seven in the low-water period. Some fish species were exploited only in a certain hydrological period (Table 2).

In the period of high-water, barba-chata, bacú-liso (*Pterodoras granulosus* Valenciennes, 1821), jandiá

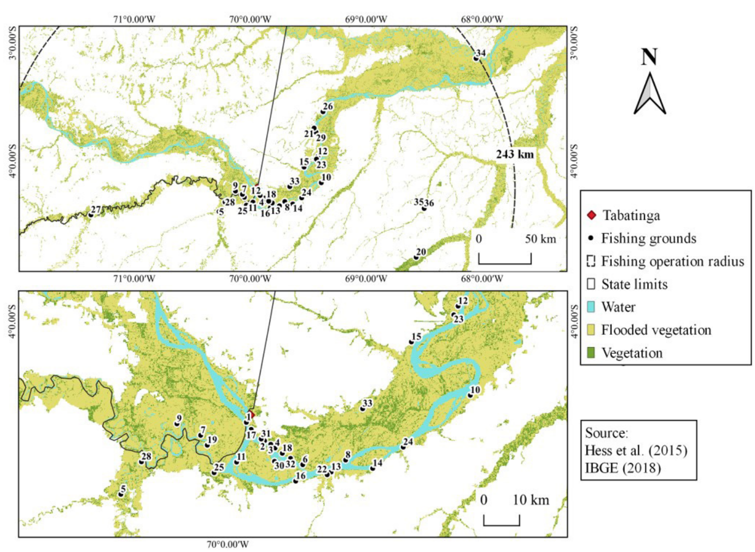

Figure 2. Radius of operation of the fishing fleet of the upper Solimões River during the high-water season on a large and small scale. 1= Solimões River*; 2= Fátima Beach*; 3= Vila Eternidade Lake*; 4= Vila Nova Lake*; 5= Quixito River; 6= Terezina II Lake*; 7= Tucano Lake*; 8= Bom Futuro Lake*; 9= Sacambu Lake*; 10= Tauarú Lake*; 11= Saraiva Lake*; 12= Bananal Lake*; 13= Capacete Lake*; 14= Bom Pastor Lake*; 15 = Belém do Solimões Lake*; 16= Niterói Lake; 17= Umariaçu Lake*; 18= Grossa Beach; 19= Javari River*; 20= Jutaí River*; 21= Cajari Creek*; 22= Palhal Creek; 23= Palmares Creek; 24= Feijoal Creek*; 25= Javarizinho River; 26= Santa Rita Creek; 27= Curuçá River; 28= Itaquaí River; 29 = Cojoari Lake; 30 = Aramaçá Lake; 31= Limeira Lake*; 32= Terezina Lake*; 33= Santa Rosa Lake*; 34= Içá River; 35= Aratituba Lake; 36= Comprido Lake*. *Sites exploited in both hydrological periods.

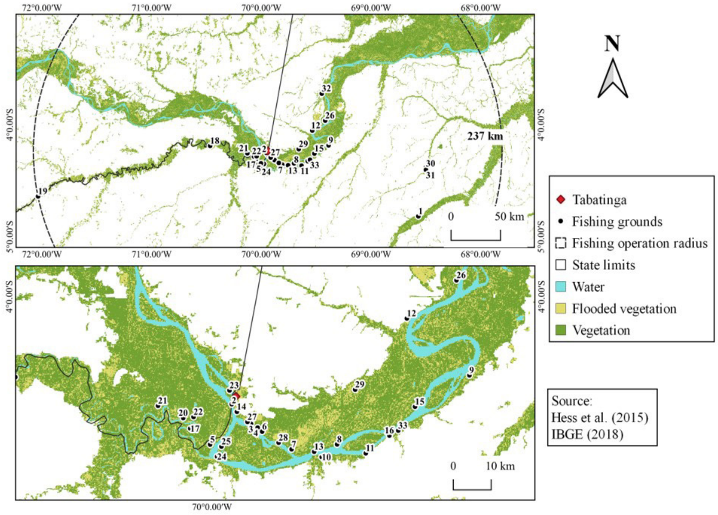

Figure 3. Radius of action of the fishing fleet of the upper Solimões River during the low-water season on a large and small scale. 1= Jutaí River*; 2= Solimões River*; 3= Fátima Beach*; 4= Vila Eternidade Lake*; 5= Bom Intento Creek; 6= Vila Nova Lake*; 7= Terezina II Lake*; 8= Bom Futuro Lake*; 9= Tauarú Lake*; 10= Capacete Lake*; 11= Bom Pastor Lake*; 12= Belém do Solimões Lake*; 13= Terezina III Community; 14= Umariaçu Lake*; 15= Sapotal Lake; 16= Prosperidade Lake; 17= Javari River*; 18= Piranha Lake; 19= Santa Fé Lake; 20= Tucano Lake*; 21= Sacambu Lake*; 22= Jacaré Lake; 23= Peruano Lake; 24= São Miguel Lake; 25= Saraiva Lake*; 26= Bananal Lake*; 27= Limeira Lake*; 28= Terezina Lake*; 29= Santa Rosa Lake*; 30= Paraná Creek; 31= Comprido Lake*; 32= Cajari Creek*; 33= Feijoal Creek*. *Sites exploited in both hydrological periods.

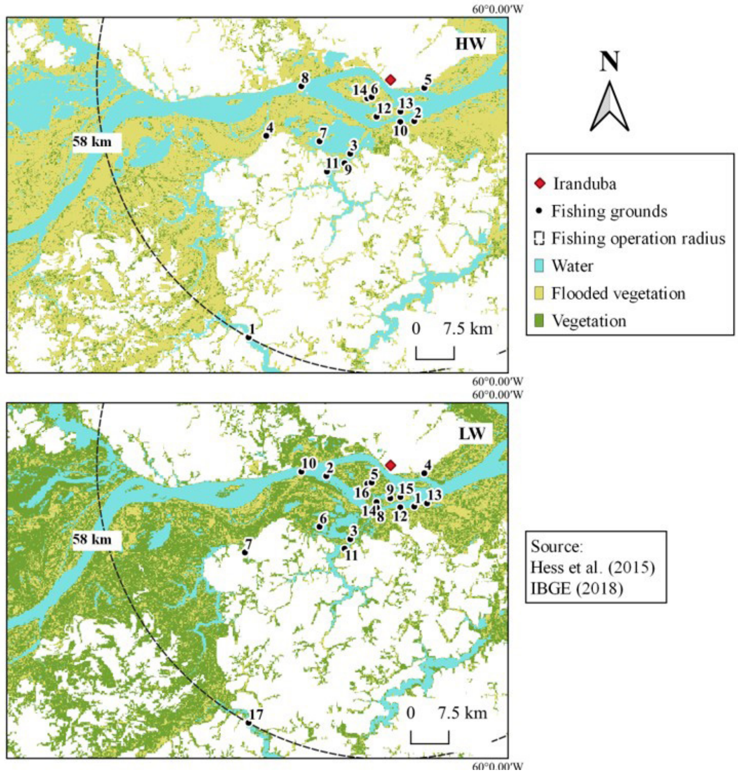

Figure 4. Radius of operation of the fishing fleet in the lower Solimões River. High-water season (HW): 1= Castanha Lake*; 2= Curarizinho Coast*; 3= Janauacá Lake*; 4= Manaquiri Coast; 5= Iranduba Coast*; 6= Preto Lake*; 7= Laguinho*; 8= Solimões River*; 9= Tilheiro Lake*; 10= Curuçá Coast*; 11= Grande Lake; 12= Moratu Island*; 13= Jacurutu Island*; 14= Paciência Island*. Low-water season (LW): 1= Curarizinho Coast*; 2= Aruanã Coast; 3= Janauacá Lake*; 4= Iranduba Coast*; 5= Preto Lake*; 6= Laguinho*; 7= Manaquiri Beach; 8= Moratu Lake; 9 = Jacurutu River; 10= Solimões River*; 11= Tilheiro Lake*; 12= Curuçá Coast*; 13= Maria Antônia Beach; 14= Moratu Island*; 15= Jacurutu Island*; 16= Paciência Island*; 17= Castanha Lake*. *Sites exploited in both hydrological periods.

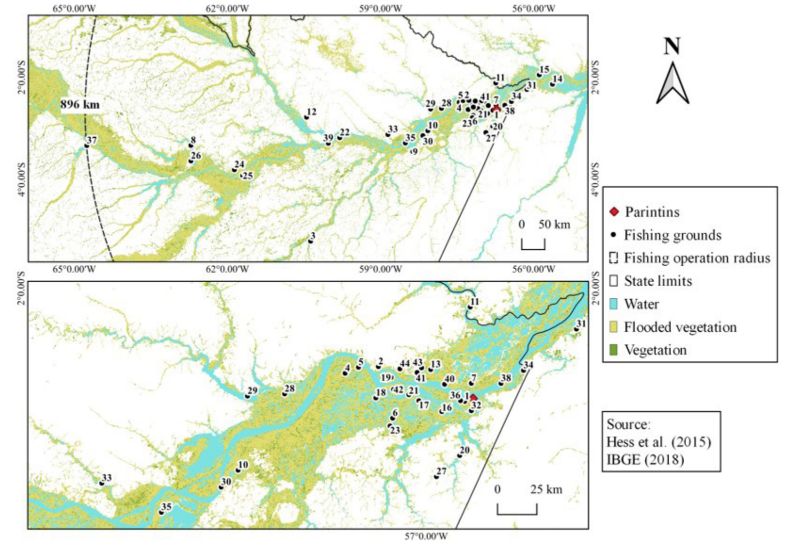

Figure 5. Operating radius of the fishing fleet in the lower Amazon River during the high-water season on a large and small scale. 1= Aningal Lake*; 2= Mocambo Lake; 3= Acari River; 4= Grande Lake*; 5= Comprido Lake*; 6= Mapará Lake; 7= Paraná Espirito Santo*; 8= Badajós River; 9= Arari River; 10= Arrozal Lake; 11= Nhamundá River; 12= Cuieiras River; 13= Acari Lake; 14= Grande do Poção Lake; 15= Marrecas Lake; 16= Piranhas Lake; 17= Meratinga Lake; 18= Limão Lake; 19= Arari Lake*; 20= Uaicurapá River*; 21= Saracura Lake; 22= Arroz Lake*; 23= Paraná Ramos*; 24= Mureru Lake; 25= Lake of the Primeiro Lake; 26= Acará Lake*; 27= Araçatuba Lake*; 28= Urucará Lake; 29= Uatumã River*; 30= Paraná do Urucurituba*; 31= Araçá Lake; 32= Paraná Parananema; 33= Urubu River*; 34= Parintins Hill; 35= Juquiri Lake*; 36= Paraná Limão*; 37= Tefé River; 38= Amazon River*; 39= Solimões River*; 40= Boto Grande Lake; 41= Buiuçu Lake; 42= Onças Lake; 43= Botinho Lake*; 44= Mato Grosso Lake. *Sites exploited in both hydrological periods.

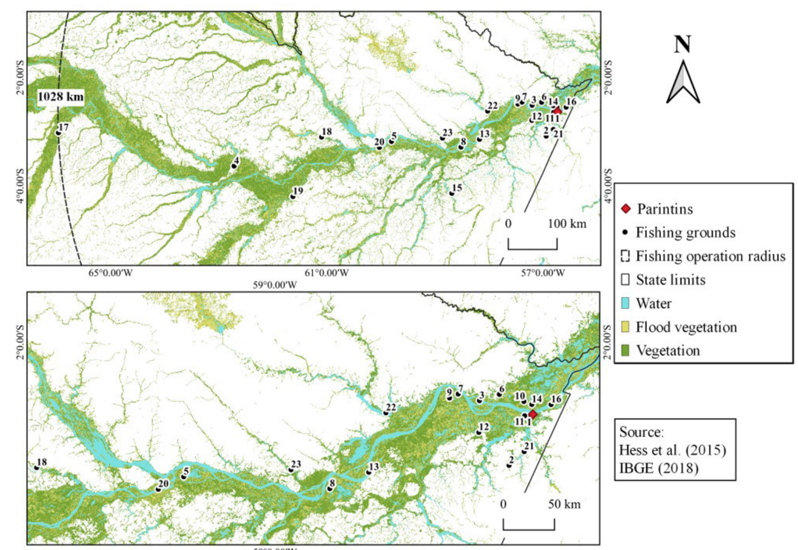

Figure 6. Operating radius of the fishing fleet in the lower Amazon River during the low water season on a large and small scale. 1= Aningal Lake*; 2= Araçatuba Lake*; 3= Arari Lake*; 4= Acará Lake*; 5= Arroz Lake*; 6= Botinho Lake*; 7= Comprido Lake*; 8= Juquiri Lake*; 9= Grande Lake*; 10= Macuricanã Lake; 11= Paraná Limão*; 12= Paraná Ramos*; 13= Paraná Urucurituba*; 14= Paraná Espírito Santo*; 15= Abacaxis River; 16= Amazon River*; 17= Juruá River; 18= Manacapuru River; 19= Purus River; 20= Solimões River*; 21= Uaicurapá River*; 22= Uatumã River*; 23= Urubu River*. *Sites exploited in both hydrological periods.

(*Leiarius* spp.), mandi (*Pimelodus blochii* Valenciennes, 1840; *Pimelodina flavipinnis* Steindachner, 1876), aruanã (*Osteoglossum bicirrhosum* Cuvier, 1829), apapá (*Pellona* spp.), traíra (*Hoplias malabaricus* Bloch, 1794), peixe-cachorro and sardinha were associated with the upper Solimões River region (Figure 7). Dourada, acari-bodó (*Pterygoplichthys pardalis* Castelnau, 1855), caparari/surubim, cuiú-cuiú, aracu, pirapitinga (*Piaractus brachypomus* Cuvier, 1818), pacú, piranha (*Pygocentrus nattereri* Kner, 1858; *Serrasalmus* spp.),

Table 1. Percentage of landscape variables in each region and hydrological period analyzed (%).

Class	High-waters period			Low-waters period		
	USR (36)	LSR (14)	LAR (44)	USR (33)	LSR (17)	LAR (23)
OW	6.87	36.86	17.31	6.25	31.45	12.26
NH	0	0	0	1.61	7.97	4.81
FH	4.01	9.13	5.70	2.42	5.83	2.83
NS	0	1.96	0	2.86	7.74	9.52
FS	2.27	5.78	9.41	0.05	0.73	0.76
NF	22.07	9.33	17.18	62.50	31.37	48.45
FF	64.79	36.94	50.41	24.31	14.90	21.37

USR= upper Solimões River; LSR= lower Solimões River; LAR= lower Amazon River; OW= open water; NH= non-flooded herbaceous; FH= flooded herbaceous; NS= non-flooded shrubs; FS= flooded shrubs; NF= non-flooded forest; FF= flooded forest. In parentheses is the number of fishing sites exploited.

Table 2. Fish species caught only in one hydrological period.

High-waters period	Low-waters period
Barba-chata (*Pinirampus pirinampu* Spix and Agassiz, 1829)	Braço de moça (*Hemisorubim platyrhynchos* Valenciennes, 1840)
Cara de gato (*Platynematichthys notatus* Jardine, 1841)	Mandubé (*Ageneiosus* spp.)
Charuto (*Anodus* spp.; *Hemiodus* spp.)	Piramutaba (*Brachyplatystoma vaillantii* Valenciennes, 1840)
Cuiú-cuiú (*Oxydoras niger* Valenciennes, 1821)	
Peixe-cachorro (*Acestrorhynchus* spp.)	
Piracatinga (*Calophysus macropterus* Lichtenstein, 1819)	

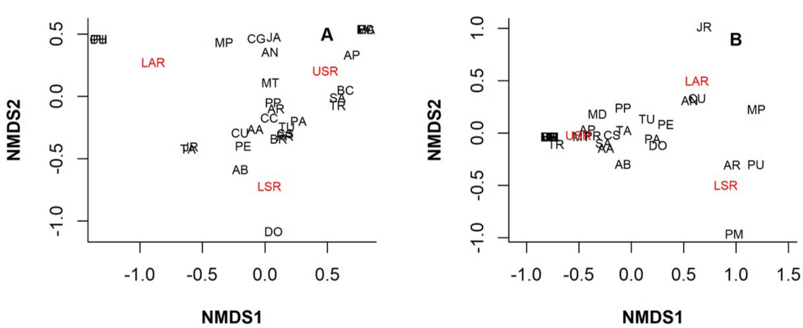

Figure 7. Relationship between fish and fishing regions. A= high-water period; B= low-water period. USR= upper Solimões River; LSR= lower Solimões River; LAR= lower Amazon River; AA= acará-açú; AB= acari-bodó; AP= apapá; AR= aracu; AN= aruanã; BL= bacú-liso; BM= braço de moça; BC= barba-chata; BR= branquinha; CS= caparari/surubim; CG=cara de gato; CH= charuto; CC= cuiú-cuiú; CU= curimatã; DO= dourada; JA= jandiá; JR= jaraqui; MA= mandi; MD= mandubé; MP= mapará; MT= matrinxã; PA= pacú; PC= peixe-cachorro; PE= pescada; PI= piracatinga; PM= piramutaba; PR= piranha; PP= pirapitinga; PU= pirarucu; SA= sardinha; TA= tambaqui; TR= traíra; TU= tucunaré.

tambaqui, jaraqui, branquinha, curimatã, acará-açu (*Astronotus* spp.), pescada (*Plagioscion squamosissimus* Heckel, 1840) and tucunaré (*Cichla* spp.) were associated with the lower Solimões river region (Figure 7). Cara de gato, mapará, piracatinga, charuto and pirarucu (*Arapaima gigas* Schinz, 1822) were associated with the lower Amazon River region (Figure 7), while the matrinxã was associated with the regions of the upper Solimões River and lower Amazon River (Figure 7).

In the low-water period, braço de moça, jandiá, mandi, acari-bodó, caparari/surubim, apapá, sardinha, traíra, branquinha, matrinxã, piranha, acará-açu, tucunaré, pescada and tambaqui were associated with the upper Solimões River region (Figure 7). Dourada, piramutaba, pirarucu, aracu, pirapitinga and pacú were associated with the region of the lower Solimões River (Figure 7). The mapará, aruanã, jaraqui and curimatã were associated with the region of the lower Amazon River (Figure 7).

4. Discussion

Accessing fishing information with fishers in the years after the fisheries were carried out can be useful, especially when there is no systematic data collection, as is the case with freshwater fisheries in Brazil. Other studies conducted via interviews with fishers to obtain the amount of fish caught and the composition of the species, which fish are more valued, and how fish abundance and sizes vary over time have shown that this methodology is accurate (Silvano and Hallwass, 2020; Tregidgo et al., 2021; Rabuffetti et al., 2022).

The greater number of fishing sites and the greater radius of action of the fishing fleet observed in the lower Amazon River in both hydrological periods is probably related to the size of the cities that were analyzed, the characteristics of the vessels used and a higher level of exploitation of the species in the environments near each urban center (Tregidgo et al., 2017; Faria Junior and Batista, 2019; IBGE, 2021). Parintins, in the lower Amazon River, is the municipality with the largest population (116,439) in relation to Tabatinga (68,502 people) and Benjamin Constant (44,873) in the upper Solimões River and Iranduba (49,718) in the lower Solimões River, and demanded a greater landing (IBGE, 2021). In addition, the municipality of Parintins has the second largest number of fishing boats, which have greater storage and transport capacity than other vessels, and which consequently allow fishers to travel greater distances (Faria Junior and Batista, 2019). Keppeler et al. (2018), when evaluating indicators of Amazonian fish communities, identified that the distance from the lake to the urban center was positively related to the average size of fish and the dominance of large fish, thus indicating direct human effects caused by fishing or indirect effects by habitat alteration. Therefore, considering the east-west degradation gradient of the vegetation cover identified by Renó and Novo (2019), it is possible that fishers from Parintins on the lower Amazon River need to travel greater distances to catch fish.

The use of fishing sites closer to the landing site by fishers on the lower Solimões River reflects how fishers use their traditional knowledge of the environment and species (Silvano and Hallwass, 2020; Tregidgo et al., 2021). Generally, fishers choose the fishing site located at the shortest distance and with a high density of fishery resources (Corrêa et al., 2012; Pereira et al., 2019).

In the three analyzed regions, in both hydrological periods, the greater predominance in the use of lakes in relation to other fishing environments is possibly related to the importance of the adjacent plain for commercial fisheries (Matos et al., 2021). In the Amazon, as observed in the municipality of Manaus lakes have an important contribution to landed catches (Matos et al., 2021). In the lower Solimões River, the use of a greater diversity of environments in fisheries highlights the geomorphological and, consequently, the landscape differences of the adjacent river-floodplain system (Mertes et al., 1996).

The higher proportion of flooded forests in the three regions studied and the absence of non-flooded herbaceous plants in the high-water period shows the influence of the flood pulse in the area exploited by fishers (Junk et al., 2020). This is considered an important regulator of the Amazon landscape and functioning of the ecosystem (Junk et al., 2020). In this study, as observed by Mertes et al. (1995) and Renó and Novo (2019), the highest proportion of forest was recorded in the radius of operation of the fishing fleet of the upper Solimões River. The three regions studied have distinct occupation processes. The upper Solimões River consists of twenty-six officially recognized indigenous lands, which represent 46% of the indigenous population of the state of Amazonas (CIAMA, 2020). Indigenous populations probably contribute to the maintenance of the forest in the upper Solimões River region due to their way of life based on the realization of resource management (Schmidt et al., 2021).

In the lower Solimões River, a greater distribution of landscape variables was observed, which characterizes this stretch as more heterogeneous. The lower regions of the Solimões-Amazon River have larger lateral areas when compared to the upper Solimões River, thus favoring the occupation of other plant communities (Hess et al., 2003). In the lower Solimões River, the aquatic herbaceous plants that are observed in greater proportions than in the other analyzed regions may be related to the accumulation of nutrients due to the contribution of sediments from several tributaries of the Solimões-Amazon River that fertilize extensive floodplain areas (Junk et al., 2020).

In the lower Amazon River, the greater number of shrubs than in other regions is dominated by woody plants of low stature (0.5-5 m) (Hess et al., 2003). This vegetation has great importance for fishery resources that migrate laterally to these habitats regardless of the hydrological period when seeking areas for reproduction, feeding and/or refuge (Freitas et al., 2018).

The composition of the landings and the amount caught varies according to the level of the river, the preferences of the consumer market, the geographical distance from large urban centers, the vegetation cover present in the exploited environment and the population density (Goulding et al., 2018; Keppeler et al., 2018; Arantes et al., 2019; Tregidgo et al., 2021). The greater variety of fish in the landings in both hydrological periods was associated with the fisheries of the upper and lower Solimões River, which presented a higher proportion of forest cover and greater heterogeneity of the landscape in its radius of action, respectively. However, the lower variety of species was associated with fisheries in the lower Amazon River, possibly indicating the influence of availability and/or proportion of landscape variables on the composition of landings. The unequal distribution of Amazonian fish species was also evidenced through a richness model that evaluated environmental and historical factors with the identification of a negative downstream gradient (Oberdorff et al., 2019).

Analyzing different lakes in the central Amazon, Freitas et al. (2018) identified that the richness of fish species is related to the shrub vegetation during the high-water period, which in this study was found in greater proportion in the lower Amazon River region and which presented less variety in landings. During low-waters, Freitas et al. (2018) associated the richness of fish species with the extension of herbaceous and open water regions, which in this study were found in greater proportion in the region of the lower Solimões River and which had a greater variety of species in the landings in this hydrological period.

Fish use certain habitats according to their reproductive behavior, migration and feeding (Sánchez-Botero and Araújo-Lima, 2001). The flooded forest found predominantly in the radius of operation of the fleet of the upper Solimões River is of great relevance for fish such as herbivores, omnivores and detritivores (Claro Junior et al., 2004; Arantes et al., 2019). Forests provide food via plant material, fruits, seeds and invertebrates, as well as organic matter via fungi and bacteria of high nutritional value for prochylodontids and loricarids (Arantes et al., 2019). In addition, habitats in regions with greater forest cover tend to have higher total biomass and possess species that are important for commercial fisheries (Arantes et al., 2019), as observed in the upper Solimões River in both hydrological periods.

In this study, the greatest variety of species that depend on the flooded forest for their life cycle in the fisheries of the upper and lower Solimões River was evidenced. Fish, such as branquinha, which can select forest areas with detritus of higher nutritional value, and the bodó, which feeds on organic matter derived from decomposed forest vegetation, related in this study to the landings of the upper and lower Solimões have been strongly associated with forest cover (Goulding, 1980; Arantes et al., 2019). In addition, cichlids, such as tucunaré and acará which are well adapted in structurally complex flooded forest habitats have also been associated with fisheries in the upper and lower Solimões (Ribeiro et al., 2016; Arantes et al., 2017, 2019). However, the presence of planktivores, such as mapará, and piscivores such as piracatinga, which have not been related to forest cover (Arantes et al., 2017, 2019), was identified in the lower Amazon River. These species may exploit other habitats such as open water and herbaceous areas. Agostinho et al. (1994) identified a high capture rate of Mapará that was favored by the increase in zooplanktonic biomass in a dammed region of the Paraná River with extensive open areas. Furthermore, Arantes et al. (2019) found a weak and negative relationship between planktivores and forest cover and associated this with the barrier imposed by dense forest canopies that limit zooplankton abundance, since they prevent the entry of light and the maintenance of phytoplankton production.

Considering the three regions studied, only 40% of the fishing sites were identified, which demonstrates the difficulty involved in accessing fishery information with fishers in the years after the fisheries were carried out, in addition to the knowledge gap related to understanding the patterns of Amazonian fisheries. Thus, our results should be used with caution since some fisheries could be performed beyond the estimated radius of action of each fishing fleet. Despite this, the analyses are valid and through them it was possible to observe that the landscape variables and the river level are drivers in the composition of landed catches. As a result, it was found that the greatest variety of captures were idenfied in regions with the highest proportion of forest cover during low water periods and those with aquatic herbaceous vegetation cover in high water periods.

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