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Amazon commercial fishing dynamics: a space macroscale analysis on fishing variables

A dinâmica da pesca comercial amazônica: uma análise em macroescala espacial sobre variáveis da pesca

Giulia Cristina dos Santos Lopes
PhD student in Freshwater Biology and Inland Fisheries by the National Institute for
Amazonian Research
National Institute for Amazonian Research
André Araújo Avenue, 2936 - Aleixo, Manaus - AM, Brazil
E-mail: giuliacristinaa@gmail.com

Michel Fabiano Catarino
PhD in Biological Sciences by the National Institute for Amazonian Research
Amazon Leaf Fish
André Araújo Avenue, 2151 - Aleixo, Manaus - AM, Brazil
E-mail: michelcatarinofish@gmail.com

Leandro Castello
PhD in Conservation Biology from the State University of New York
Virginia Tech
West Campus Drive Cheatham Hall, RM101 Blacksburg - VA, United States
E-mail: leandro@vt.edu

Carlos Edwar de Carvalho Freitas
PhD in Environmental Engineering Sciences from the University of São Paulo
Federal University of Amazonas
Rodrigo Otávio Avenue, 6200 – Coroado, Manaus - AM, Brazil
E-mail: freitasc50@gmail.com

ABSTRACT

The landscape and the dynamics of seasonal flooding should be considered in the development of fishery management measures in the Amazon, as these factors determine the distribution and ecology of fishery resources and consequently the behavior of fisherman and fishery. In this context, the spatial dynamics of commercial fishing in the upper and lower reaches of the Solimões River were analyzed and the hypothesis that fishing is homogeneously developed by the Amazonian landscape was discussed. Catch data, number of fishers per trip, duration of fisheries and fishing locations were collected in 2012 at the main landing centers of the

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municipalities of Benjamin Constant and Iranduba. The geographical coordinates of fishing locations were recorded in 2018 using a hydrographic map of municipalities, a list of fishing locations documented in 2012 and the help of fishermen. The spatialization of fishery information was performed by municipality, by fishing location and by river regime period using the QGIS software (2.18). Thirty-two fishing sites were identified in the municipalities. The fishermen operated within a 175 km radius of Benjamin Constant during both periods of the river regime. In Iranduba the area of operation was 28 km in high water and 35 km in low water. In Benjamin Constant the Solimões River recorded the highest catches in both periods. In Iranduba the Iranduba coast and Manaquiri beach recorded the highest catches during periods of high and low waters, respectively. In Benjamin Constant the highest yields were recorded in the 35 km zone far from the municipal headquarters in both periods. While in Iranduba, in the high water period the highest yield was recorded in locations closer to the municipal headquarters than in the low water period. With the analysis of the spatial dynamics of commercial fishing we reject the hypothesis that fishing is homogeneously distributed throughout the Amazonian landscape and we propose to consider the spatial aspects of this activity in management systems.

Keywords: Inland fishing, fishing landing, fishing grounds.

RESUMO

A paisagem e a dinâmica de alagação sazonal devem ser consideradas no desenvolvimento de medidas de manejo pesqueiro na Amazônia, pois esses fatores determinam a distribuição e a ecologia dos recursos pesqueiros e consequentemente o comportamento do pescador e da pesca. Nesse contexto, foi analisada a dinâmica espacial da pesca comercial nos trechos superior e inferior do rio Solimões e discutida a hipótese de que a pesca é desenvolvida homogeneamente pela paisagem amazônica. Dados de captura, número de pescadores por viagem, duração das pescarias e locais de pesca foram coletados em 2012 nos principais centros de desembarque dos municípios de Benjamin Constant e Iranduba. As coordenadas geográficas dos locais de pesca foram registradas em 2018 utilizando um mapa hidrográfico dos municípios, uma lista dos locais de pesca documentados em 2012 e o auxílio dos pescadores. A espacialização das informações pesqueiras foi realizada por município, por local de pesca e por período do regime fluvial utilizando o software QGIS (2.18). Trinta e dois locais de pesca foram identificados nos municípios. Os pescadores operaram em um raio de 175 km em Benjamin Constant durante os dois períodos do regime fluvial. Em Iranduba a zona de operação foi de 28 km em águas altas e de 35 km em águas baixas. Em Benjamin Constant o rio Solimões registrou as maiores capturas em ambos os períodos. Em Iranduba a costa do Iranduba e a praia do Manaquiri registraram as maiores capturas durante os períodos de águas altas e baixas, respectivamente. Em Benjamin Constant os maiores rendimentos foram registrados na zona de 35 km distante da sede municipal em ambos os períodos. Enquanto em Iranduba, no período de águas altas o maior rendimento foi registrado em locais mais próximos da sede municipal do que no período de águas baixas. Com a análise da dinâmica espacial da pesca comercial rejeitamos a hipótese de que a pesca é distribuída de maneira homogênea pela paisagem amazônica e propomos considerar os aspectos espaciais dessa atividade nos sistemas de gerenciamento.

Palavras-chave: Pesca interior, desembarque pesqueiro, locais de pesca.

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1 INTRODUCTION

The freshwater fisheries have high social, economic and environmental relevance, mainly at developing countries (Youn et al., 2014; Lynch et al., 2016). Welcomme et al. (2010) estimated that more than 90 % of the fish caught by freshwater fisheries are from human consumption. Approximately 21 million of fishers are engaged in these fisheries (FAO, 2014). Although its importance, freshwater fisheries are less studied than marine fisheries, probably due the predominance of small-scale fisheries in rivers and lakes around the world (Allan et al., 2005; Bartley et al., 2015). And some basic information to fishing management, as the fisheries the distribution by habitats of a basin remain unavailable.

In large river basins with adjacent floodplains, as at the Congo and Amazon basins, the extension of the flooded floodplain and the hydrological cycle have been assumed as the main drivers of the fishing yield (Welcomme, 1995; Isaac et al, 2016). Nevertheless, other studies showed the influence of dissolved oxygen, depth, area and connection of the lakes on the fish abundance (Petry et al., 2003; Arantes et al., 2013). And more recently, several studies have demonstrating the riparian vegetation influence on fish diversity and fishing yield at the Amazon basin (Arantes et al., 2017; Castello et al., 2017; Freitas et al., 2018).

Since environmental factors drive the fish distribution and the fishing yield, it is expected that these factors also are the key factors to explain the fishing fleet distribution, with implications to the successful of fishing management proposals. In a study on the spatial dynamic of the fishery toward *Cynoscion othonopterus*, at the Gulf of California, Erisman et al. (2012) observed highest fishing intensity and catch into a protected area. Similar results were observed for a small-scale fishery performed to exploit *Colossoma macropomum* in an Amazonian floodplain lake of the lower stretch of the Solimões River. Highest captures were registered in a protected area of the lake (Sousa & Freitas, 2011).

The Solimões river is a white water river and its middle and lower stretch can be divided into three geomorphologic units: the scroll-dominated floodplain with origin at the late Pleistocene, the impended floodplain that is an active alluvial system and the channel-dominated floodplain that is composed by channels, active sandbars, levees, islands and abandoned channels (Latrubesse & Franzinelli, 2002). These geomorphologic characteristics, coupled with the flood pulse, are key drivers of environmental factors such as soil fertility, forest cover and fish diversity and abundance (Junk et al., 1989; Ab'Saber, 2002; Junk et al., 2011).

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The Amazonian fishers have a high knowledge of these environmental patterns and its interaction with the fish biology (Freitas et al., 2002; Batistella et al., 2005; Lima & Batista, 2012; Doria et al., 2014) and develop their fisheries toward target species, knowing its preferential habitat and the most profitable fishing gear (Freitas et al. 2002; Batista et al., 2004; Batista & Petrere, 2007). Analysis of the spatial dynamic of commercial fisheries based on fisher's knowledge could be essential to build public policies associated with the resource exploitation and use of the fishing territories, mainly in inland small-scale fisheries (Furtado, 2002; Begossi, 2004; Erisman et al., 2012). These analyses also could be useful to identify the expansion of the fishing area as a consequence of the depletion of fishing stocks in areas near the urban centers (Berkes et al., 2006).

Taking into account the high diversity of fisheries performing at the Amazon basin, its importance to riverine people and the great variety of environments explored by the fishers at the main stem of the Solimões-Amazonas River (Ab'Saber, 2002; Isaac et al., 2015; Lopes et al., 2016), we performed a spatial analysis of the commercial fishery and discussed the hypothesis that the fishery is developed homogeneously by the landscape, independent of its physiography.

2 MATERIALS AND METHODS

Study Area

Data were collected in two cities of the Solimões River: Benjamin Constant, placed at the right margin of higher stretch of the Solimões River, in the boundary of Brazil with Colombia and Peru; and Iranduba, located at the left margin of the lower stretch of Solimões River, near its confluence with the Negro River (Figure 1). Fisheries at the Solimões River are very productive and both cities harbor important fishing fleets (Batista et al., 2004).

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Figure 1. Study Area. 1= Benjamin Constant; 2= Iranduba.
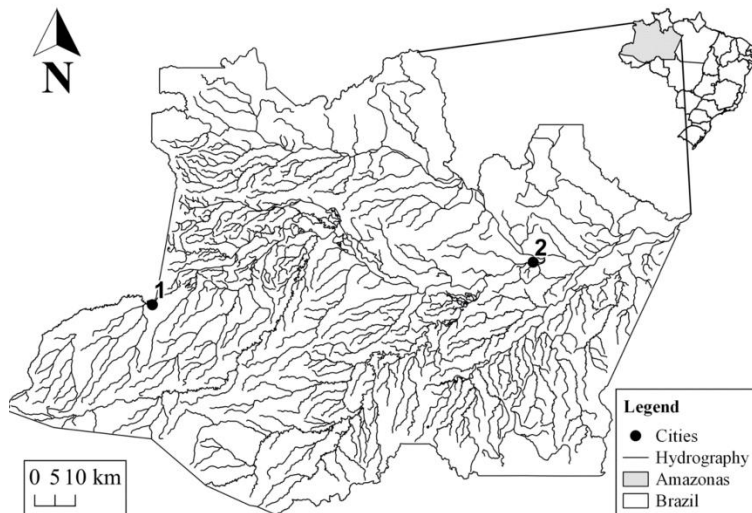
Data Collection

Fishing landing data were collected daily, using semi-structured questionnaires, from January to December of 2012. The questionnaires were applied to the crew lead, at the time that fish were sold, at the main fishing landings places of Benjamin Constant (472 questionnaires) and Iranduba (277 questionnaires). No questionnaires were applied in Benjamin Constant at the months of September and October. The information collected by the questionnaires were catch per species (kg), number of fishers by trip, number of days per fishing trip and fishing grounds. The geographic localization of the fishing grounds were obtained by interviews applied in March and May of 2018. These interviews were made with experienced fishers using the list of the fishing grounds registered in 2012 and hydrographic maps of the region. Data on the water system, in shapefile format, and water level were obtained from the National Water Agency (ANA).

Data Analysis

Monthly averages of the water level were estimated for the areas around both cities and these averages were employed to define two distinct seasons of the hydrological cycle: high water and low water seasons. In Benjamin Constant, the months from October to April were defined as high water and the months from May to September were associated with low water season. In Iranduba, the months from December to June represented the high water season and the months from July to November were the low water season. The Google Earth Pro (version 7.1) was employed to annotate the geographic coordinates of the fishing grounds

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in the map and converted to kml files to work on the Q-Gis (version 2.18) and converted to shapefiles. Fishing grounds with only one register were assumed as episodic events and excluded from the analysis.

We established buffers to limit the explored area by the fishing fleet of each municipality. These buffers were constructed taking the fishing ground most distant from the municipality as reference in each season of the hydrological cycle. The fisheries frequencies per fishing ground and per season of the hydrological cycle were estimated counting the number of fishing trips to each fishing ground. The catches per unit of effort per fishing ground and per season were estimated following Petrere (1978), as the division of the catch (kg) by the fishing effort, assumed as the product of the fisher's number by the fishing days. All estimated values were registered at the DBF file of the geographic coordinates to each municipality and maps were building per season of the hydrological cycle employing the Q-Gis software. The Datum WGS84 was used in all geo-processing analysis.

3 RESULTS

The fishing fleet of Benjamin Constant, at the higher stretch of the Solimões River explored 12 fishing grounds over the year, eight during high water season and the same number during low water season. Fisheries at the lower stretch of the Solimões explored a total of 20 fishing grounds, 17 during high water and 13 during lower water. In both seasons of the hydrological cycle, taking the municipality of Benjamin Constant in the center, were defined five buffers with rays of 35 km to encompass the fisheries performed at the high stretch of the river. In the low stretch, taking Iranduba in the center, were established four and five buffers of 7 km, during high and low water seasons, respectively. On both seasons, the Comprido lake, placed at 170.17 km far away Benjamin Constant, was the more distant fishing ground at the higher stretch of the river. The Janauacá island, 21.62 far away Iranduba, was the more distant fishing ground explored during high water season by the fishing fleet acting in the lower stretch of the river. And the Manaquiri beach, located a distance of 34 km than municipality, was the more distant fishing ground during low water season.

At the higher stretch of the river, the lakes Peruano, Sacambu and Tucano are in the Peruvian Amazon. And the lakes Aratituba and Comprido, explored exclusively during high water season, are located in indigenous areas of the Cocama ethnicity. The rivers Solimões and Javari were the most exploited fishing grounds explored by fishers of Benjamin Constant

in both seasons of the hydrological cycle (Figure 2). During high water season, 43 fisheries were performed at the Solimões River and 9 at the Javari. Janauacá Lake, with 47 fisheries, and Iranduba Coast, with 17 fishing trips, were the most explored fishing grounds by Iranduba's fishers during high water season. While the Curuça Coast, with 19 fisheries, and Janauacá Lake, with 12 fisheries, were the most explored during low water season in the lower stretch of the River (Figure 3).

Figure 2. Fishing frequency in Benjamin Constant.
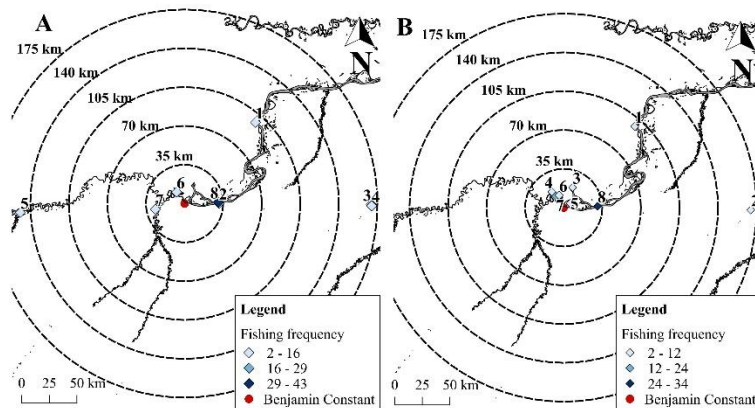
A= High waters. 1= Igarapé Cajari; 2= Igarapé Palhal; 3= Aratituba Lake; 4= Comprido Lake; 5= Curuçá River; 6= Javari River; 7= Quixito River; 8= Solimões River. B= Low water. 1= Igarapé Cajari; 2= Comprido Lake; 3= Peruano Lake; 4= Sacambu Lake; 5= Saraiva Lake; 6= Tucano Lake; 7= Javari River; 8= Solimões River.

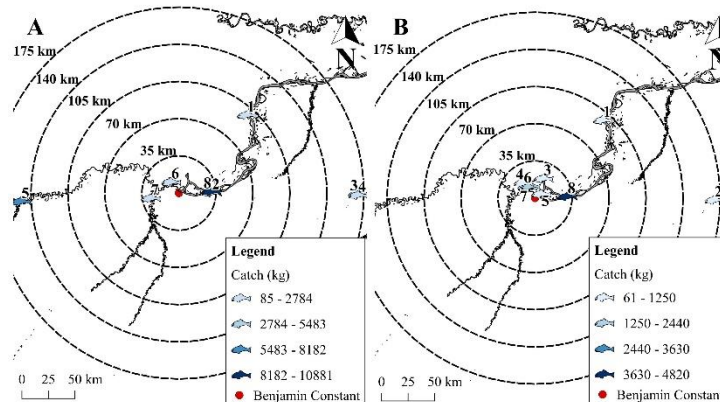Figure 3. Fishing frequency in Iranduba.
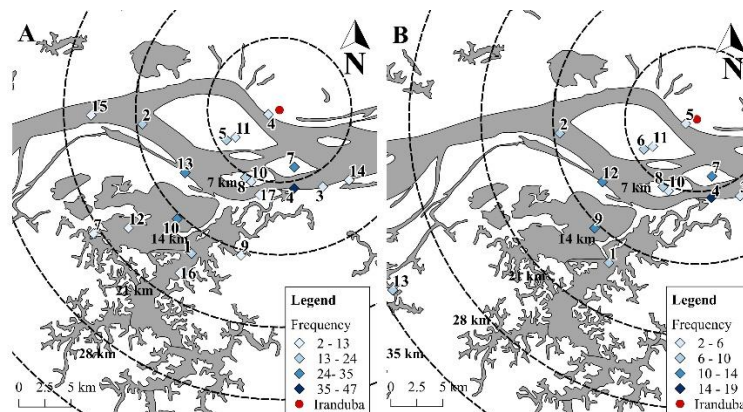
A= High waters. 1=Janauacá Mouth; 2= Curarizinho Coast; 3= Curuçá Coast; 4= Iranduba Coast; 5= Paciência Island; 6= Jacurutu Island; 7= Janauacá Island; 8= Moratu Island; 9= Castanha Lake; 10= Janauacá Lake; 11= Preto Lake; 12= Janauacá Lakelet; 13=

Paraná Januacá; 14= Maria Antônia Beach; 15= Solimões River; 16= Tilheiro; 17= Janauacá Village. B= Low water. 1= Janauacá Mouth; 2= Aruanã Coast; 3= Curarizinho Coast; 4= Curuçá Coast; 5= Iranduba Coast; 6= Paciência Island; 7= Jacurutu Island; 8= Moratu Island; 9= Janauacá Lake; 10= Moratu Lake; 11= Preto Lake; 12= Paraná Janauacá; 13 = Manaquiri Beach.

At the high stretch of the river, the highest catches during the high water season were obtained in the rivers Solimões (10.88 tons) and Curuçá (7.05 tons). During the low water season, the Solimões river also was the most productive (4.82 tons), but the Tucano lake shows the second with 2.28 tons (Figure 4). The landings at the Iranduba city showed that the most productive areas in the lower stretch were the Iranduba coast (44.40 tons) and Janauacá Lake (15.78 tons), during high water season. While Manaquiri beach (22.0 tons) and Curuça coast (20.82 tons) were the most productive fishing grounds during low water season (Figure 5).

Figure 4. Catch in Benjamin Constant.

A= High waters. 1= Igarapé Cajari; 2= Igarapé Palhal; 3= Aratituba Lake; 4= Comprido Lake; 5= Curuçá River; 6= Javari River; 7= Quixito River; 8= Solimões River. B= Low water. 1= Igarapé Cajari; 2= Comprido Lake; 3= Peruano Lake; 4= Sacambu Lake; 5= Saraiva Lake; 6= Tucano Lake; 7= Javari River; 8= Solimões River.
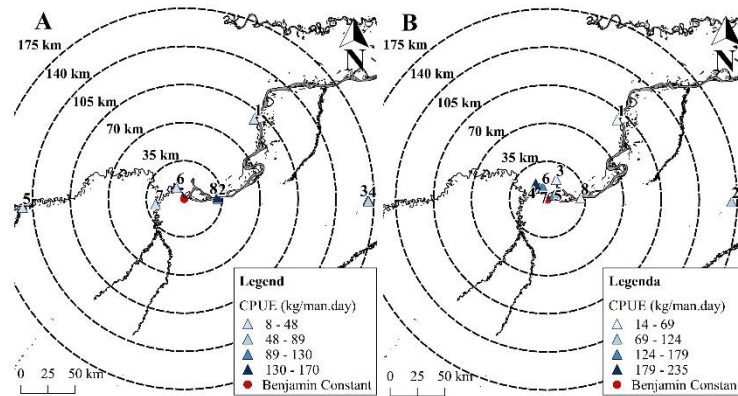
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Figure 5. Catch in Iranduba.
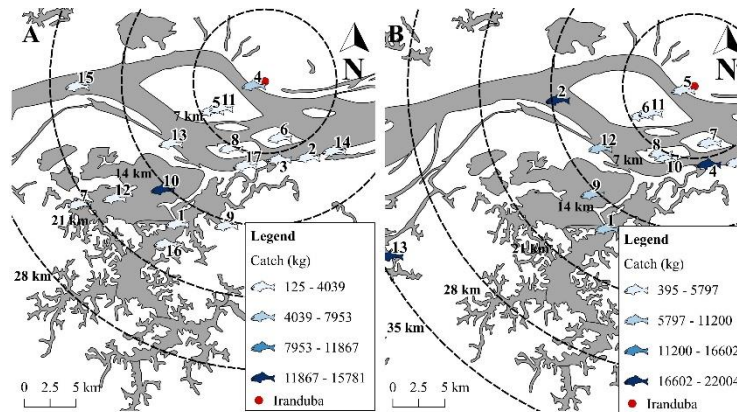
A= High waters. 1=Janauacá Mouth; 2= Curarizinho Coast; 3= Curuçá Coast; 4= Iranduba Coast; 5= Paciência Island; 6= Jacurutu Island; 7= Janauacá Island; 8= Moratu Island; 9= Castanha Lake; 10= Janauacá Lake; 11= Preto Lake; 12= Janauacá Lakelet; 13= Paraná Januacá; 14= Maria Antônia Beach; 15= Solimões River; 16= Tilheiro; 17= Janauacá Village. B= Low water. 1= Janauacá Mouth; 2= Aruanã Coast; 3= Curarizinho Coast; 4= Curuçá Coast; 5= Iranduba Coast; 6= Paciência Island; 7= Jacurutu Island; 8= Moratu Island; 9= Janauacá Lake; 10= Moratu Lake; 11= Preto Lake; 12= Paraná Janauacá; 13 = Manaquiri Beach.

At the upper stretch of the Solimões River, the Javari River (170.32 kg / fisher.day) and the Palhal stream (50.41 kg / fisher.day) were the fishing grounds with highest CPUE during high water season. While Sacambu and Tucano lakes, with 235 kg / fisher.day and 173.91 kg / fisher.day, respectively, were the most productive place during low water (Figure 6). At the lower stretch, the Januacá village (87.5 kg / fisher.day) and Janauacá Lake (73.66 kg / fisher.day) exhibited the greatest CPUE during high water. While Manaquiri beach (321.83 kg / fisher.day) and Moratu island (197.37 kg / fisher.day) showed highest CPUE during low water season (Figure 7).

Figure 6. Catch Per Unit Effort (CPUE) in Benjamin Constant.

A= High waters. 1= Igarapé Cajari; 2= Igarapé Palhal; 3= Aratituba Lake; 4= Comprido Lake; 5= Curuçá River; 6= Javari River; 7= Quixito River; 8= Solimões River. B= Low water. 1= Igarapé Cajari; 2= Comprido Lake; 3= Peruano Lake; 4= Sacambu Lake; 5= Saraiva Lake; 6= Tucano Lake; 7= Javari River; 8= Solimões River.

Figure 7. Catch Per Unit Effort (CPUE) in Iranduba.
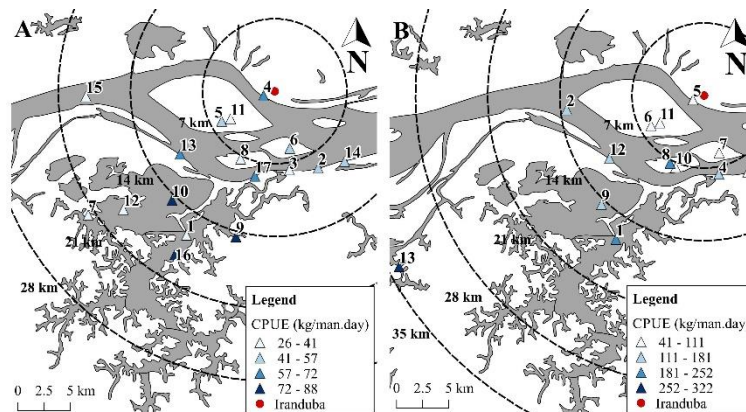
A= High waters. 1=Janauacá Mouth; 2= Curarizinho Coast; 3= Curuçá Coast; 4= Iranduba Coast; 5= Paciência Island; 6= Jacurutu Island; 7= Janauacá Island; 8= Moratu Island; 9= Castanha Lake; 10= Janauacá Lake; 11= Preto Lake; 12= Janauacá Lakelet; 13= Paraná Januacá; 14= Maria Antônia Beach; 15= Solimões River; 16= Tilheiro; 17= Janauacá Village. B= Low water. 1= Janauacá Mouth; 2= Aruanã Coast; 3= Curarizinho Coast; 4= Curuçá Coast; 5= Iranduba Coast; 6= Paciência Island; 7= Jacurutu Island; 8= Moratu Island; 9= Janauacá Lake; 10= Moratu Lake; 11= Preto Lake; 12= Paraná Janauacá; 13 = Manaquiri Beach.

At the upper stretch, in both seasons of the hydrological cycle, the highest frequency of fisheries (57 and 65 fishing trips), catches (13.94 and 9.11 tons) and CPUE's (69.99 ± 68.34 and 108.9 ± 85 kg / fisher.day) were registered in the area between the municipality and a limit of 35 km far away. At the lower stretch of the Solimões River, during the high water season, the greatest frequency of fisheries (70 fishing trips), catches (21.2 tons) and CPUEs (323.2 ± 22.12 kg / fisher.day) were obtained on fishing grounds located between 14 and 21 km far away the municipality. While at the low water season, the highest frequency of catches and catches were registered between 7 and 14 km and the highest CPUEs (321.83 ± 341.48 kg / fisher.day) were obtained at fishing grounds placed between 28 and 35 km distant from the municipality.

4 DISCUSSION

The high heterogeneity and quantity of fishing grounds explored by Amazonian fisheries is a worldwide characteristic of small-scale fisheries (Petrere, 1978; Allan et al. 2005; Bartley et al., 2015). In general, this pattern has been associated with the large traditional knowledge of the fishers, which ability them to explore successfully the surrounding environment (Souza et al., 2018). The differences in the quantity explored fishing grounds and rays of actuation between the upper and lower stretches of the Solimões River could be related with specific geomorphological characteristics, market preferences, fishery history, land use strategies and operational characteristics of the fishing fleet acting in each area. The lower stretch of the Solimões River shows more intense hydrodynamic pressure due the confluence with large rivers as Purus and Negro (Martinelli, 1986; Ab'Saber, 2002). This process results in a larger extension of floodplain here, at the lower stretch, than in the upper stretch of the river, surrounding Benjamin Constant city (Barthem & Fabré, 2004). Composing this large floodplain could be found a higher diversity and quantity of habitats used as fishing grounds as beaches, oxbow lakes, scroll-bars, channels and streams.

Nevertheless, the landscape at this floodplain is drastically changed between low and high water seasons. During low water season, some aquatic habitats of the floodplain could became isolated and reduced in dimension. At this season, the access of fishers to isolated lakes could be very difficult and several fish species could migrate to the main stem of the rivers to avoid adverse environmental conditions (Junk et al., 1989; Cox-Fernandes, 1997). As consequence, as observed in the lower stretch of the Solimões River, the fishers need to

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perform longer trips to find appropriate environments for fishing. By the other hand, during high water season aquatic habitats of the floodplain are connected (Hurd et al., 2016) and re-colonized by fish species that explore the newly flooded habitats (e.g. forests) looking for food and shelter (Noveras et al., 2012). These recently flooded and expanded aquatic habitats of the floodplains (Fink and Fink, 1978) could be located nearest the urban centers and more intensively explored by fishers during this season.

The western portion the Amazon basin, including the upper stretch of the Solimões River, is one of most pristine regions in this ecosystem (MIN, 2005) and hosts several indigenous protected areas, corresponding to more than 8.5 million of hectares of areas where commercial fishery is forbidden (Baines, 2001). The Comprido Lake, fishing ground more distance used by the fleet landed at Benjamin Constant on both seasons, is located within an indigenous area belonging to the Cocama ethnic group. That lake was possibly used by indigenous people that when needing services restricted to the municipality, catch fish for commercialization. In contrast, there are not protected areas at the lower stretch of the Solimões River and Iranduba city host one of the most important harbor for fish landings at main stem of the Solimões-Amazonas River (Barthem & Goulding, 2007). The Janauacá island, fish ground most distant exploited by the Iranduba fishing fleet in high water season has not importance documented in the literature, however Manaquiri beach, the most distant local exploited in low waters season was important in this study with high catch and CPUE records. The lakes located outside the Brazilian territory that were used by the fishing fleet of Benjamin Constant can indicate the fishing relations existing in the border between Brazil, Colombia and Peru. Some commerce interactions between the three countries have already been documented, especially for catfish fishing, where Leticia is the main fishing port (Barthem & Goulding, 2007; Moraes et al., 2010).

The importance of the rivers for the fisheries in upper stretch of the Solimões River was evidenced in this study with the high values of frequency of fishing, catch and CPUE in these environments in the period of high water season. The high utilization of this environment occurs mainly due to the capture of catfish (fish of the order Siluriformes), which are destined for export and have a high proportion of landings at the extremity of the Solimões - Amazonas River channel (Cruz, 2007; Batista et al., 2012). In addition, in the region of Benjamin Constant the riverside communities are located mainly on the banks of the Solimões River facilitating the fisheries in this environment (Fronteiras, 2018). The higher CPUE in lakes in the low water season are possibly associated with fish densities in these environments due to

the decrease in river level. The high waters seasons make fish populations and fishing activities able to move to floodplain habitats, while low waters seasons cause fish when they are not migrating in the channel of the river are retained in the lakes, increasing the productivity of the fisheries in these environments (Barthem & Goulding, 1997; Freitas & Rivas, 2006; Isaac et al., 2016).

In Iranduba during the high waters season, the high importance of the lake Janauacá was observed for the fisheries of this region with the high registries of frequency of fishing and capture. The Janauacá Lake is a typical floodplain environment and is one of the regions oldest and most traditional fishing grounds (Petrere, 1978; Batistella et al., 2005). This place has been widely exploited by fishermen, possibly because it is situated closer to urban centers than other places. In 1976 production was quantified at 1,277.5 t (Petrere, 1978), and the observed decrease in this production is possibly related to the development of communities around the lake (Miranda, 2013). Although in the low water season in Iranduba, the highest frequency of fishing was recorded on the coast of Curuçá, no records were identified that showed the importance of fishing in this place in the years prior to this study. However, the region stands out for its high agricultural production (Frota Filho et al., 2011), which should be carefully observed since deforestation due to agriculture and livestock has increased in recent years (Rennó et al., 2011; Nobre et al., 2016). And because fish depend on flooded forests for their abundance and fishery yields would decrease (Lobón-Cerviá et al., 2015, Castello et al., 2017). The highest catch and CPUE recorded in the Manaquiri beach in the low water season reflect the relevance of this environment during this phase of the flood pulse. The importance of beaches has also been reported in the fisheries of the Madeira, Purus and Juruá rivers (Cardoso & Freitas, 2008; Lopes et al., 2016). Possibly the fishery production in these environments is related to the formation of shoal for the process of dispersion migration (Araújo-Lima & Ruffino, 2003).

The highest frequencies, catches and CPUEs were recorded in a few fishing grounds, indicating that fishermen in the Amazon region know the fishing area well and have some preferential fishing grounds. Probably, these locations are likely to be where fish populations are present in greater abundance or density, and fishermen using the local ecological knowledge they have guide their fisheries to ensure greater catches and yields. Due to the concentration of fisheries in a few places, our results are consistent with previous studies showing that several species perform a strong selection of habitats and differentiate abundance between environments, and fishermen knowing the order of selection benefit from it in the

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fishery (Castello, 2008; Arantes et al., 2013; Lobón-Cerviá et al., 2015; Castello et al., 2015). The flood pulse did not influence the choice of fishing grounds in the upper stretch of the Solimões River possibly, due to the higher fishing frequencies, catches and CPUEs observed in the 35 km zone in the two hydrological periods and especially in the rivers. While in the lower stretch of the Solimões River, the possible influence of the flood pulse in the choice of fishing sites was evidenced where other environments such as lakes and beaches were important in the fisheries. In addition, there was a difference in the choice of fishing grounds between the zones of operation and between the hydrological periods.

With the analysis of the spatial dynamics of fishing in the two regions of the Amazon basin, we reject the hypothesis that the fishery is homogeneous distributed over the Amazonian landscape. Thus, it is proposed to consider the spatial aspects of commercial fishing activity in decision making for the implementation of fisheries management in the system. Because the spatial context is of great importance for the understanding of the behavior of the fishing fleet, it may indicate the origins of changes in the quantity and quality of production that may be motivated not only by the dynamics of fishing but also by factors such as climate change, deforestation or use of the environment in conflict with other activities.

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