Drivers of change in the spatial dynamics of the Amazon artisanal fishing fleet.

Samantha Aquino Pereira[1], Nídia Noemi Fabré[2], Vandick da Silva Batista[3], Sophie Lanco[4]

Corresponding author: Samantha Aquino Pereira*
Email: samanthaaquino@ufam.edu.br

Abstract

The way artisanal fishermen use natural resources is highly adaptable in space and time. In the Amazon region, the spatial distribution of the tropical fishing fleet is influenced by various environmental and anthropogenic variables. Environmental variables include river level variation, which affects accessibility to different habitats and species during seasonal changes, such as the flood pulse characterized by dry and wet phases, and interannual variability, influenced by ENSO (El Niño and La Niña) events in the Pacific Ocean. Anthropogenic variables, such as rising fuel prices and the creation of protected areas, also impact the distribution of the fishing fleet by limiting access to distant fishing grounds. This study investigated whether and how the spatial distribution of the Central Amazon Fishing Fleet (CAFF) was affected by a series of environmental and anthropogenic variables over an 11-year period (1994-2004). We analyzed an 11-year dataset of landings (1994-2004) from the artisanal commercial fishery in Manaus. Identifying habitat types, target species, hydrological anomalies, fuel price variation and the increase in Protected Area areas. In addition, we evaluated the drives that determine the distribution of CAFF. The results showed that there have been substantial changes in the spatio-temporal distribution of CAFF fishing effort due to the interaction between various environmental and anthropogenic factors, acting at various temporal and spatial scales.

Keywords: environmental variables; anthropogenic variables; spatio-temporal distribution; fishing fleet

Highlights:

- From 1998 onwards, the distance traveled by CAFF and the number of fishing grounds exploited decreased;
- Considering the time scales, we observed that the seasonal scale (month) showed the highest percentage of explanation for the intensification of CAFF fishing

---

[1] Postgraduate Program in Animal Science and Fisheries Resources, Faculty of Agrarian Sciences. Federal University of Amazonas. Manaus, Amazonas, 69067-005, Brazil * Present address: Institute of Exact Sciences and Technology –ICET/UFAM. R. Nossa Sra. do Rosário, 3863 - Tiradentes, Itacoatiara - AM, 69100-00, Brazil.

[2, 3] Institute of Biological and Health Sciences, Federal University of Alagoas, Maceió, 57072-900, AL, Brazil.

[4] Institut de Recherchepour Le Développement (IRD),MARBEC (Univ. Montpellier, Ifremer, CNRS, IRD), Centre de Recherche Halieutique, Avenue Jean Monnet - BP171 - 34203 Sète Cedex – France.

near the port of landing, highlighting the CPUE variables of the river-lacustrine species and the increase in the price of fuel;

- It is necessary to establish strategies for the use of fishing grounds and continuous stock assessments of the jaraqui species, since since the 1990s, the jaraqui stock has been considered overexploited and to date there has been no monitoring.

1. Introduction

The way artisanal fishers use natural resources is highly adaptive in space and time (e.g.Lambin et al., 2003; Perry and Sumaila, 2007; Vierros et al., 2020). Resource availability and accessibility are continuously changing due to the variability of local environmental and ecological conditions(e.g.Alho et al., 2015; Badjeck et al., 2010),resource management, anthropogenic pressures, cultural practices and other external processes(e.g. Cinner and Aswani, 2007; Malsale et al., 2018). These changes in resource use have diverse socioeconomic and environmental impacts, and their understanding is essential for the design of sustainable fisheries management policies.The impacts of environmental and anthropogenic variability are particularly critical in the Amazon region, where a high fish biodiversity is ensuring nutritional security, income and livelihood sustainability (Welcomme et al., 2010) to numerous artisanal fishing communities (Batista 1998a; Cerdeira et al., 1997).

In the gigantic Amazonian basin, 70-80 % of fish catches come from white-water rivers and their nutrient-rich floodplains (Barletta et al., 2015; Bayley and Petrere Júnior, 1989). The central Amazon fishing fleet (CAFF)exploiting this basin is composed of>3000 boats performing relatively long fishing trips(average duration of 13±11 days). This fleet exploits the Amazon River floodplain which is a complex network that includes: the main stem river, permanent lakes of various sizes, large river branches that receive the contributions of major tributaries and small streams that drain riparian areas, and canals that connect floodplain lakes to the main stem and its branches depending on the water level (Batista et al., 2012; Batista and Petrere Júnior, 2003; Melack, 1984; Nolan et al., 2009).

The Amazonian region is submitted to intense seasonal changes, mainly related to the variation of the flood pulse characterized by dry phases with low water levels and wet phases with high water levels (e.g. Junk et al., 1989).In addition to this seasonal environmental variation, these freshwater habitats are submitted to interannual variability(Ficke et al., 2007), partly driven by the regional effects of ENSO events (El Niño and La Niña) originating in the Pacific ocean. Those events differ in terms of magnitude, spatial extent and temporal evolution. And the effects of those extreme climatic events are not homogeneous within the Amazon basin due to differences in local landscape and climate, including precipitation, evapotranspiration and flood size (Sorribas et al., 2016). In addition, climate change is expected to affect this interannual variability, by modifying the frequency and typology of these ENSO events(FAO, 2020).Consequently, changes in habitat accessibility, availability and productivity, already acute under current variability, are expected to increase under the pressure of climate change, including: (1) disruptions in the migratory routes of the main Amazonian fish resources(Jackson and Marmulla, 2011); (2) decreases in fish species diversity and abundance (Freitas et al., 2013); (3) changes in assemblage structure (Röpke et al., 2017); (4) changes in target species and habitat types exploited by fisheries (Pinaya et al., 2016); and (5) decreases in the abundance of larger fishes in extreme drought periods (Fabré et al., 2017).

Together with the impacts of seasonal, interannual and climate change induced variability, habitats are also subject to the direct pressure from human activities, such as deforestation, overfishing (Pauly and Zeller, 2016) and land-use change, which influence the spatial dynamics of the CAFF. To limit the effect of these anthropogenic pressures, Protected Areas (PA) are being increasingly implemented as a partial solution to contain the degradation of habitats and conserve the biodiversity of freshwater environments and fishing resources(Sousa et al., 2015). Many works demonstrated the efficiency of the implementation of these areas for conservation and for ensuring the sustainability offishery resources (Arantes et al., 2008; Barnes and Sidhu, 2013; Campos-Silva and Peres, 2016; Huntington, 2000; Keppeler et al., 2017; Roberts et al., 2001). However, in marine environments, the rapid expansion of a network of protected areas frequently triggers changes in fishing behavior, with displacement and increased fishing effort outside PAs, adoption of new methods and target species, and adaptation in the spatial pattern of resource use (Greenstreet et al., 2009; Vaughan, 2017). In the inland tropical freshwaters, little attention has been paid to the effect of area closure/delimitation from Protected Area implementation on fishermen's behavior, particularly on the spatial dynamics of the CAFF.

The spatial dynamics of fisheries may also be driven by an economic component, like the variation of fuel price for instance. For example, the Honduran artisanal coral reef fishery decreased the number of fishing grounds with rising fuel prices, favoring sites near the harbor, what induced local depletions of fish stocks (Chollett et al., 2014). Davies et al.(2014) also demonstrated that increasing fuel price led to a decrease in fuel consumption, especially for more powerful, larger vessels. However, in inland water environments, the absence of records over time of both fuel price and consumption by vessels makes it difficult to investigate the influence of this factor on the spatial dynamics of the fleet.

The high diversity and heterogeneity of exploited habitats, conditioning the way fishers use space, is a typical feature of tropical artisanal fisheries (Daw, 2008; Lopes et al., 2020; Nolan et al., 2009; Pet-Soede et al., 2001; Petrere Jr, 1978). However, the location of fish catches is generally overlooked in fisheries statistics and often not even reported (Goethel et al., 2011). Yet, analyzing the spatial dynamics of fisheries can be used both to infer trends in the distribution of fish (Booth, 2000) and the fishing fleet efficiency (Bertrand et al., 2008), as well as revealing fleet responses to variations in habitats generated by climate change (Pinaya et al., 2016). Understanding the spatial dynamics of fisheries can serve as a thermometer of the possible effects of climate and anthropogenic changes on resource uses, especially when the fleet presents high mobility within the scale of the fishing area: The fleet that lands in Manaus for instance, Central Amazon, has autonomy for weeks of travel, and deploys itself in rivers and lakes at a spatial scale larger than 2000 km from the port (Freitas et al., 2003; Petrere Jr, 1978).

Here we investigate if and how the spatial distribution of CAFF was affected by a series of environmental and anthropogenic variables,over an 11-year period (1994-2004).We expect environmental factors, such as anomalous river level variation, and anthropogenic factors, such as increases in Protected Areas and oil prices, to influence the spatial dynamics of CAFF by affecting the accessibility and availability of fishing grounds. Based on the analysis of changes in the spatial patterns of fishing, we explore the effects of possible drivers on the behavior of the fishing fleet.

2. Material and methods

2.1 Study area, fish community and fishing fleet

Our study area is the Amazon River basin and its main tributaries, both white (Amazonas-Solimões, Purus, Madeira and Juruá rivers), and black waters (Negro river), and its flood plains. The Amazon basin river-flooded area system has about 8,500 lakes, corresponding to approximately 11% of the 62,000 km^2 of Amazonian floodplains (Hess et al., 2015; Melack, 1984). This area is among the most biodiverse ecosystems in the world, with about 2200 registered fish species (Albert and Reis, 2011). This rich environment provides the basis for high fish production and extensive fishing activity (Batista and Petrere Júnior, 2003; Goulding et al., 2018; Nolan et al., 2009; Ruffino et al., 2012) (Figure 1).

Figure 1.Amazon basin study area, highlighting the main rivers and exploited fishing grounds (pink dots) by the fishing fleet that lands in Manaus.

River-lacustrine species perform migrations that depend fundamentally on the rhythm of the flood pulse (Barletta et al., 2010), what is reflected in the dynamics of their landing sin Manaus (Batista, 2012). These species, represented in the catches by the Prochilodontidae family, have their reproductive cycle closely associated with seasonal flood cycles. Because they have a short life cycle (6 years of longevity on average) and a high growth and mortality rates, they are considered high turnover species (Bayley et al., 2018; Winemiller and Jepsen, 1998).Lacustrines species have generally k-strategy. Some species have limited movement, for example cichlids, which lay their eggs on the bottom and both parents share care for weeks after hatching (Kullander and Ferreira, 2006). These species have a maximum total length (LT) of 20-200 cm and develop their entire life cycle in flooded environments with similar limnological characteristics. These species perform daily or seasonal movements on a local scale (1-5 km) in order to use different lakes or flooded environments. This is the case of *Arapaima* spp, a k-strategy species that moves between flooded forest habitats (Castello, 2008). Riverine species account for only 3% of the catches and for this reason they were not considered in subsequent analyses.

The fleet operating in this vast region is composed of approximately 3 000 wooden boats with engine power ranging from 20 to 60HP (Batista, 1998b), boat length ranging from 8 to 27 meters, with an average of 14±3m, and ice storage capacity varies from 2000 to 14500 kg, with an average of 7,000±3 kg. Each fishing trip is operated by an average of 8±3 fishers and lasts 13±11 days. The predominant fishing gear is purse seine (91.4%), followed by gill net (8.25%) (Batista, 2012). Vessels that land in Manaus have diverse ports of origin from which they explore fishing grounds (Hanry et.al, 2019).This fleet is mainly composed of two categories of boats: *commercial fishing boats* that take a more or less fixed team of commercial fishermen to the fishing locations and have the autonomy to explore fishing environments further away from urban centers, with appropriate structures for fish storage and conservation, shelter for the fishermen and transportation of large quantities of fishing gear; and *purchasing boats* that go around riverside communities and Sustainable Development Reserves (SDR), buying fish from riverside fishermen (Matos et al.,2021 e Isaac et. al.,1996).

2.2 Fishery activity and scales of analysis

We analyzed an 11-years dataset of landings (1994-2004) by the artisanal commercial fishery in Manaus. The database provided information on a total of 27613 fishing trips made along the main Amazonian rivers (Amazonas-Solimões, Madeira, Purus, Negro and Juruá, see Figure 1). The variables recorded for each fishing trip were: year, month, vessel identifier ("vessel name"), vessel length (small, medium and large, as established by Batista, 1998), total catch per species group (kg), based on common name, not by species (see Supplementary Material 1), latitude and longitude of the fishing ground, duration of the fishing trip (days), number of fishermen, name of the fishing ground (when reported), type of habitat of the fishing ground (lake or river), amount of ice on board (liters). The catch per unit effort (CPUE) of the trip was calculated by dividing the total landings (kg) by the trip duration (number of fishing days). Captured species group (40) were categorized according to their mobility and life strategy into 'lacustrine', 'river lacustrine' and 'riverine' species (Barletta et al., 2010) (see Supplementary Material 1).

Fishing grounds were mapped using the name of the fishing ground, the river it belongs to and the nearest town, available in the database. The name of the fishing ground exploited was recorded for each travel (207 different fishing grounds in total). The 207 locations identified were classified into river or lake environments (see Supplementary Material 2). We used this information for calculating the distance traveled by the vessel, from leaving the central fishing terminal in Manaus to each fishing ground. For such purpose, we used Google Earth to geolocate each fishing ground and then, estimated the approximate path of the vessel along the river, in kilometers (variable 'Dist'). To visualize the interannual spatial expansion or contraction of the area used by the fleet we constructed maps highlighting the registered fishing grounds, and calculated kernel density estimates using the stat_density2d function of the ggplot2 R package (Wickham and Chang, 2016).

From this database, the spatial distribution of the fishing activity was evaluated at three scales: The *first scale* was that of the fishing trip, and was characterized by the distance covered by the vessel; the *second and third scales* were that of the fleet behaviour at the seasonal and annual scales respectively. For those last two scales, we evaluated the spatial behavior using two metrics: (1) the center of gravity of the fishing grounds visited, determined from the average of their spatial coordinates and weighted by the number of trips concerned; and (2) the surface of the ellipse of dispersion of the fishing grounds, which semi-axes are calculated from the standard deviation of the center of gravity. The spatial direction of the ellipse is determined by the direction of greatest spatial variability and its angle of rotation (Wang et al., 2015; Yuill, 1971).At these seasonal and annual scales, we also computed: The proportion of trips per boat size category (small, medium and large), the proportion of trips to river and lake, the total number of trips, the proportion of fishing grounds visited, the global Catch per unit effort (CPUE), that was calculated by dividing the catch (kg) by fishing trip days; and the CPUE by species category, for which we selected only vessels that reported catching only river lacustrine species and vessels that caught lacustrine species.

2.3 Exploring drivers of change

2.3.1 Hydrology

We obtained the daily river levels, in meters, from the National Water Agency from 1994 to 2004,forthe Negro river station. This data was used to calculate a river level climatology over the study period, as the average monthly value (amv) of the river level and the corresponding standard deviation (sd).

To estimate hydrological anomalies, we compared for each month the observed value with the climatology value for the same month. The anomaly was considered significant if the observed value lied outside the range amv ± 2sd (Figure 2).

Figure 2. River level climatology (red curve, representing the average value and error bar indicating the 2sd interval) and monthly observations (average and sd based on daily data, black curve).

2.3.2 Protected areas (PAs)

We identified the Federal and States Conservation Units (CUs) and Indigenous Lands (ILs) created during our study period from a series of websites (uc.socioambiental.org; www.icmbio.gov.brand meioambiente.am.gov.br) and denominated their ensemble as Protected Areas. The protected areas are managed by specific environmental agencies: the Chico Mendes Institute for Biodiversity Conservation (ICMbio) for Federal Conservation Units (CUs) and the Secretary of the Environment (Secretaria do MeioAmbiente) for State CUs, both of which follow the guidelines established by the National System of CUs (Law No. 9985/2000)and the National Indian Foundation - FUNAI, for Indigenous Lands, which establishes the laws for the occupation of Indigenous territory. In these PAs, zones and norms are established for governing the use of the area and the management of natural resources identified in the management plan. In both CUs and ILs, zones are defined for subsistence fishing for residents, fishing gear authorized, and the amount of fish that can eventually be commercialized. Thus, in these PAs, subsistence fishing is authorized while commercial fishing is prohibited. For each year, we estimated the cumulative surface of these protected areas(CSPA)(Figure 3).

Figure 3.Cumulated surface (hectare) of the protected areas.

2.3.3.Oil Price

Due to the unavailability of the oil prices applied locally in the State of Amazonas at the time the data were collected, we used as a proxy the monthly variation of the price of crude oil calculated by the World Bank and available online at the website: www.indexmundi.com.Figure 4 provides a summary (annual average and standard deviation among months) of these oil price fluctuations.

Figure 4.Annual world crude oil price movements.

2.4 Data analyses

2.4.1 Random Forest (RF)

RF (Breiman, 2001; Prasad et al., 2006)are flexible and robust models, based on regression or classification trees. Randomization procedures on the data and the variables allow to build a forest of trees, robust to data and predictor specificities, and then allowing a more robust result. They allow the use of a mix of continuous and/or categorical values, are robust to collinear variables, interactions between variables and non-linear relationships between predictive and response variables. These models identify the most important variables to explain the response variable using mean square error - MSE. The percentage increase in the mean square error indicates the most important variable.To examine the type of effect of the most important variables detected in the RF model on the response variable (fishery spatial behaviour), we used the partial dependency plot, from the pdp R package (Greenwell, 2017).

2.4.2 Exploring the drivers of fishing behaviour changes at different scales

Random Forest (RF) were used to identify the factors that explained space-time patterns of the fishing activity, using the randomForest Rpackage (Friedman et al., 2001). We considered three models, to address the question at three different scales (Table 1):

- ✓ Fishing trip scale- Predict the variability of distance traveled per fishing trip as a function of numerical and categorical variables.
- ✓ Month and Year scales - Predict the variability of the spatial dispersion of the fishing trips as a function of numerical variables.

Table 1.Explanatory variables used in RF models at thefishing trip scale,year and month scales.

Three parameters needed to be defined in the RandomForest regression model: *ntre*e, the number of bootstrap samples from the original data (the default value is 500, but we used 1000); *nodesize,* the minimum number of data on each end node and *mtry*,the number of different predictors tested at each node, we used the default parameter (total predictors/3) for each scale.

T-tests were performed to test for significant differences between distances traveled between years, considering 5% significance level. The calculations and the statistical analysis were performed with R 3.6.3 (R Development Core Team, 2017).

3. Results

3.1 Typology of the captured species

Among the species groups captured by the CAFF, 13 are lacustrine species, where the most representative were: tucunaré (*Cichla* sp), pescada (*Plagioscion squamosissimus* e *P. auratus*), aruanã (*Osteogloss umbicirrhosum*), and pirarucu (*Arapaima* spp.). And 28 river lacustrine species, highlighting jaraqui (*Semaprochilodus insignis/ Semaprochilodus taeniurus*), curimatã (*Prochilodus nigricans*), pacu (*Mylossoma* sp.), matrinxã (*Brycon amazonicus*), and tambaqui (*Colossoma macropomun*). Our results show that the river-lacustrine species are the main target of the CAFF fishery, highlighting the increase in the catch of the jaraqui, curimatã, pacu and matrinxã (Figure 5A). Among lacustrine species, we observed an increase in the capture of tucunaré, pescada, and aruanã (Figure 5B).

Figure 5. CPUE time series of river-lacustrine species (A) andCPUE time series of lacustrine species (B).

3.2Spatial dynamics of the fishery

Vessels covered in average 357±257km per trip. At annual scale, longest distances covered were observed in 1995, 1996 and 1997. After this period, distances travelled were smaller, with significant difference between those before and after 1998 ($t = 4.0123$, $df = 9$, p-value= 0.003053)(Figure 6). In the same sense, we observed a decrease in the number of exploited fishing grounds after 1997.

Figure 6.Total distance travelled by the fleet over years (boxplots) and number of fishing grounds exploited by the fleet per year (red curve).

We observed an increase in the number of Protected Areas along the Solimões-Amazonas River and the Negro River; a decrease in the number of fishing points used, especially the fishing grounds farther from the port of Manaus, and from 98,we observed a concentration of fishing trips near the port of Manaus (Figure 7).

Figure 7. Kernel density(green to red color scale) of the fishing grounds used by the fisheryover 11 years. Additional information are: the landing port of Manaus (black dot), fishing grounds (black, blue and pink dots, those in pink lying >1500km from Manaus), protected areas (brown surfaces), synthesis of the spatial dispersion of fishing grounds (black ellipses).

3.3Drivers of change of the space use by the fishery

At the fishing trip scale, the model explained 53% of the variability of the distance traveled. The variables with the highest percentage increase MSE are the most important predictors, which are: habitat type, rivers and river level (Figure 8A). At the month scale, the model explained 58% of the variability of spatial dispersion (area of the ellipse) by the fleet from the fishing grounds to the port of landing (Manaus). The most important variables were: Global CPUE, river-lacustrine species and price of Oil (Figure8B). At the scale of the year, the model explained 32% of the variability of spatial dispersion traveled by the fleet from the fishing grounds to the port of landing (Manaus). The most important variables were: total fishing grounds, rivers and lakes (Figure 8C).

Figure 8. RF results at the trip, month and annual scales (panels A, B and C respectively). The most important variables are those with the largest percentage increase in the mean square error (%IncMSE).

In the partial dependence plots for the *fishing trip scale*, we observed that the fleet traveled longer distances to lake-type fishing grounds, for the Juruá and Purus rivers and when the river level was at its minimum (Figure 9).

Spatial dispersion

Figure 9. Partial dependence plots showing the influence of important explanatory variables, Habitat type, rivers and river level on the variability of the distance traveled by the fleet per fishing trip.

The partial dependence model at month scale shows that low dispersion is associated to high global CPUE, high catches of river-lacustrine species and highest oil price (Figure 10).

Figure 10. Plots of partial dependence showing the influence of important explanatory variables, global CPUE, and CPUE of river-lacustrine species and price of oil of the spatial dispersion by the fleet per month.

In the partial dependence plot at the annual scale, we observed that the fleet exhibited greater dispersion to explore numerous fishing grounds mainly more distant lakes. At closer distances to port, the CAFF exploits mainly rivers. And there was an increase in the CPUE of river-lacustrine species with low fleet dispersal (Figure 11).

Figure 11.Plots of partial dependence showing the influence of important explanatory variables, total fishing grounds, total rivers, total lakes and river-lacustrine species CPUE of the spatial dispersion by the fleet per year.

4. Discussion

To our knowledge, this research represents the first study illustrating how data of fishing recorded over 11 years can be used in combination with data of the hydrological anomalies, protected areas and oil price in Random Forest models to assess the spatial distribution of the Amazonian commercial artisanal fishing fleet (CAFF) and its response to environmental and anthropogenic drivers of change. Our results showed that substantial changes in the spatio-temporal distribution of CAFF fishing effort occurred due to the interaction between various environmental and anthropogenic factors, acting at multiple temporal and spatial scales.

Our data show that understanding the synergistic impact of environmental and anthropogenic factors in determining the dynamics of CAFF has important implications for fisheries management and the conservation of aquatic ecosystems and the livelihoods of riverine populations that depend on fisheries resources. It helps to identify critical areas for fishing and to guide policies for managing the use of and access to fishing territories, as well as the conservation of fisheries resources.

4.1 Drivers of change: ‘Macro’ adaptive responses

Our results showed that CAFF's spatial dynamics were particularly affected by two factors: the average river level variation and fuel price increase. Both factors triggered substantial macro-scale changes in the dynamics of CAFF fishing effort, which were reflected in the notable reduction of the distance traveled and the number of fishing grounds exploited by CAFF.

This sequence of events started in 1997-1998, a period when negative hydrological anomalies were recorded. These anomalies were caused by El Nino events (Marengo, 2009; Marengo et al., 2012) stimulating prolonged droughts in Amazonia (Cavalcanti et al., 2013).We expected that hydrological anomalies, particularly the negative anomaly, which represents more severe drought periods, would influence the dynamics of the CAFF, promoting a retraction of the distance traveled, due to the difficulty of access of important fishing grounds.However, although we show the spatial retraction of CAFF, the negative anomalies do not explain it at any temporal scale, fishing days, month and year. And, this retraction was maintained in the years without negative hydrological anomalies.

However, our results reinforce the importance of seasonal hydrological variability for the spatial dynamics of fishing, since the response of fishing effort distribution to the variability of flood pulses varies according to the fish feeding strategy and access to the fishing ground (Castello et al., 2015; Isaac et al., 2016; Pinaya et al., 2016). This seasonal variability is known to fishermen who rotate their use of the space. Isaac et. al., (2016) demonstrated four strategies of fishers to minimize seasonal variability of CPUE according to the seasonality of flood pulses. Fishers target fish from floodplain lakes during rising waters (e.g., *Hypoththalmus* spp.), Characiform fish that migrate out of floodplains during high and low waters (e.g., *Semaprochilodus* spp.), and migratory catfish that migrate upstream in river channels during low waters (e.g., *Brachyplatystoma rouseauxii*).

Linked to river level variability, the increase in fuel prices from 2000 onwards affected CAFF's response by shifting their fishing effort closer to the main port in order to increase or maintain profit. This strategy was also observed by fishermen from Puerto Ayora, in Galapágos, who also intensified their fishing effort close to the port of origin, aiming to reduce fuel costs, as an adaptive response to the global financial crisis of 2007-2009 (Castrejón and Charles, 2020).This strategy reflects the importance of the economic factor for the spatial dynamics of CAFF, as the costs of a fishing boat can involve more than U$ 632,47 with the purchase of fuel, ice and the advance payment of auxiliaries who will go fishing (Illenseer and Pereira, 2010).Study in Central Amazonia demonstrated that fuel expenses range from 30 to 64% of the operational costs of the expedition (Cardoso and Freitas, 2004; Inomata and Freitas, 2015).Thus, our results demonstrate how fuel costs can affect the dynamics of space and resource use by causing fishing intensification in a few fishing grounds close to the port of landing.

Another factor that we expected to affect the dynamics of CAFF was the increase in protected areas. Differently from what was expected, the increase in protected areas was not a determining variable in the spatial dynamics of the CAFF. Our results showed an increase in protected areas over these 10 years. Then, we expected that this increase in protected areas would cause a retraction in the spatial distribution of the fleet, since it would no longer have access to the traditional fishing grounds that now were delimited within the protected areas.

Thus, it is suggested that CAFF fishermen have articulated new agreements for the use of fishing grounds by establishing new arrangements with local actors and social agents involved directly and indirectly in fishing, both with residents living within protected areas and with residents living in rural communities on the banks of rivers and establishing community fishing agreements.For example, Tregidgo et al. (2021) observed that riverine fishers living in communities along the Purus River maintain fisheries for pirarucu (*Arapaima* spp.) and tambaqui (*Colossoma macropomum*) in the lakes and sell to larger fishing boats. Another example was the establishment of partnerships between commercial fishermen with local fishermen in the Anavilhanas National Park on the Negro River to access and use fishing grounds (Illenseer and Pereira, 2010).

Our results reinforce the importance of PSAs for the conservation of fisheries resources (Hermoso et al., 2016; Keppeler et al., 2017), but also for the maintenance and survival of riverine livelihoods by strengthening local arrangements(Campos-Silva et al., 2021; Nagl et al., 2021). As well, they reveal the importance of identifying and understanding the strategies of use and access of space and fishery resources between commercial fishermen and riverine fishermen promoted by different and simultaneous territorial, political, economic and environmental changes.

4.2 Drivers of change: 'Micro' adaptive responses

The macro-scale changes in the spatial dynamics of CAFF described above have in turn altered the micro-scale dynamics of CAFF fishing patterns, which is reflected in intensification in habitat and fishery resource use, mainly at the seasonal scale. According to the RF models, the distance traveled by CAFF was influenced by the type off is hing ground habitat exploited and the target species. CAFF exploite drivers in search of river-lacustrine species.

We suggested that the preference of CAFF for river environment may be related to the greater availability of migratory species, throughout the hydrological cycle, as they are species that have their life or part of it associated with the river channel and their spawning occurs in lotic environment as for example, jaraqui (*Semaprochilodus* spp)(Barthem, R., & Goulding, 2007; Barthem et al., 2019; Isaac et al., 2016).Another species, represented in catches by the curimatã, of the family Prochilodontidae also have their reproductive cycle closely associated with seasonal flood cycles. Because they have a short life cycle (6 years of longevity on average) and a high growth rate and high mortality, they are considered special high turnover species (Winemiller& Jepsen, 1998; Bayley et al., 2018). These characteristics are known to commercial fishermen and are reflected in fishing productivity throughout the hydrological cycle (Batista, 2012).So, adding the fisherman's knowledge of the biology of the species and the need to reduce fuel costs, CAFF adopted as a strategy the use of traditionally productive fishing grounds close to the port of landing and that can be accessed throughout the hydrological cycle.

Thus, our results signal the need to establish strategies for the use of fishing grounds and assessments on the fish stocks of these species on a continuous basis to propose management actions for these species, since the 1990s the stock of jaraqui is considered overfished (Batista et al., 2012; Ribeiro and Petrere Jr, 1990) and the lack of data since then, leaves the current situation unclear (Goulding et al., 2018).

Although river environments are intensively used by CAFF, lake environments are particularly important for most exploited species (Martelo et al., 2008) and fisheries production(Nolan et al., 2009). Our results demonstrated that the more distant lakes remain important fishing grounds for the CAFF because they are home to lake species, which have a high market value, such as tucunaré (*Cichla* sp.), aruanã (*Osteogloss umbicirrhosum)*, and pirarucu (*Arapaima* spp.) (Isaac et al., 1996). Making lake environments more attractive to commercial fishermen.This condition suggests that the lakes are fishing points of relevant importance for the CAFF commercial fishery (Nolan et al., 2009), especially for the buying boats, which possibly maintain a communication network with the riverside fishermen living near these environments for the commercialization of these species (Illenseer and Pereira, 2010; Tregidgo et al., 2021).

However, pirarucu, has its fishing prohibited throughout the year, and can be caught and sold only in areas with community management (Decree No. 36083 of 07/23/2015). And the tambaqui, has the closed season regulated by law, as well as, minimum capture size (IBAMA ORDINANCE No. 08, FEBRUARY 2, 1996). But, due to the lack of inspection, these species are also fished illegally in many areas until today (Cavole et al., 2015). Thus, our results corroborate the strategies used by commercial fishermen operating in the Rio Negro after the emergence of protected areas that limited the use of traditional fishing grounds. One strategy adopted was agreements with riverine fishermen who carry out community management and sell their fish to commercial fishing boats and those who risk fishing illegally.

Acknowledgements

This work was supported by the National Council for Scientific and Technological Development-CNPq (Process No. 141441/2017-8), Faculty of Agrarian Sciences, of the Federal University of Amazonas, the Laboratory for the Conservation and Management of Renewable Resources - LACOM, of the Federal University of Alagoas and the Federal University of Alagoas and the Marine Ecology Laboratory - LEMAR, of the Federal Rural University of Pernambuco - UFRPE.

Funding Federal University of Amazonas and Conselho Nacional de Desenvolvimento Cientı´fico e Tecnolo´gico—CNPq

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

Conflicts of interest The authors declare no conflict of interest.

Consent for publication The authors declare their agreement for publication

5. References

Albert, J.S., Reis, R.E., 2011. Introduction to Neotropical Freswaters, in: Biogeography Ictiology Neotropical.

Alho, C.J.R., Reis, R.E., Aquino, P.P.U., 2015. Amazonian freshwater habitats experiencing environmental and socioeconomic threats affecting subsistence fisheries. Ambio 44, 412–425. https://doi.org/10.1007/s13280-014-0610-z

Arantes, C.C., Garcez, D.S., Castello, L., 2008. DENSIDADES DE PIRARUCU (*Arapaima gigas*, TELEOSTEI, OSTEOGLOSSIDAE) EM LAGOS DAS RESERVAS DE DESENVOLVIMENTO SUSTENTÁVEL MAMIRAUÁ E AMANÃ, AMAZONAS, BRASIL. Sci. Mag. UAKARI 2, 37–44. https://doi.org/10.31420/uakari.v2i1.13

Badjeck, M.C., Allison, E.H., Halls, A.S., Dulvy, N.K., 2010. Impacts of climate variability and change on fishery-based livelihoods. Mar. Policy 34, 375–383. https://doi.org/10.1016/j.marpol.2009.08.007

Barletta, M., Cussac, V.E.V.E., Agostinho, A.A.A.A., Baigún, C., Okada, E.K.E.K., Catella, A.C., Fontoura, N.F.N.F., Pompeu, P.S.P.S., Jiménez-Segura, L.F.L.F., Batista, V.S.V.S., Lasso, C.A.C.A., Taphorn, D., Fabré, N.N.N., Carlos Catella, A., Fontoura, N.F.N.F., Pompeu, P.S.P.S., Jiménez-Segura, L.F.L.F., Batista, V.S.V.S., Lasso, C.A.C.A., Taphorn, D., Fabré, N.N.N., 2015. Fisheries ecology in South American river basins, in: Freshwater Fisheries Ecology. John Wiley & Sons, Ltd, Chichester, UK, pp. 311–348. https://doi.org/10.1002/9781118394380.ch27

Barletta, M., Jaureguizar, A.J., Baigun, C., Fontoura, N.F., Agostinho, A.A., Almeida-Val, V.M.F., Val, A.L., Torres, R.A., Jimenes-Segura, L.F., Giarrizzo, T., Fabré, N.N., Batista, V.S., Lasso, C., Taphorn, D.C., Costa, M.F., Chaves, P.T., Vieira, J.P., Corrêa, M.F.M., 2010. Fish and aquatic habitat conservation in South America: A continental overview with emphasis on neotropical systems. J. Fish Biol. 76, 2118–2176. https://doi.org/10.1111/j.1095-8649.2010.02684.x

Barnes, B., Sidhu, H., 2013. The impact of marine closed areas on fishing yield under a variety of management strategies and stock depletion levels. Ecol. Modell. 269, 113–125. https://doi.org/10.1016/j.ecolmodel.2013.08.012

Barthem, R., & Goulding, M., 2007. An unexpected ecosystem: the Amazon as revealed by fisheries.

Barthem, R.B., Silva-Júnior, U.L. da, Raseira, M.B., Goulding, M., Venticinque, E., 2019. Bases para a conservação e o manejo dos estoques pesqueiros da Amazônia. Mus. Goeldi 150 anos ciência na Amaz. pp.148-178.

Batista, G.S., Freitas, C.E.C., 2006. Descrição da pesca com redinha e escolhedeira na área do Ayapuá, RDS Piagaçu-Purus, rio Purus, Amazonas. Biol. Água Doce e Pesca Inter. 56.

Batista, V. da S., 1998a. Distribuição, dinâmica da frota e dos recursos pesqueiros da Amazônia Central 291.

Batista, V. da S., 1998b. Distribuição, dinâmica da frota e dos recursos pesqueiros da Amazônia Central 291.

Batista, V.S., 2012. Peixes e Pesca Solimões - Amazonas: uma avaliação integrada.

Batista, V.S., Petrere Júnior, M., 2003. Characterization of the commercial fish production landed at manaus, amazonas state, brazil 33.

Bayley, P.B., Castello, L., Batista, V.S., Fabré, N.N., 2018. Response of prochilodus nigricans to flood pulse variation in the censtral Amazon. R. Soc. Open Sci. 5. https://doi.org/10.1098/rsos.172232

Bayley, P.B., Petrere Júnior, M., 1989. Amazon Fisheries: assessment methods, current status and management options, in: Dodge, D.P. (Ed.), Proceedings Ofthe Lnternational Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. Dept. of Fisheries and Oceans, Honey Harbour, Ontario, Canada, pp. 385–398.

Bertrand, S., Díaz, E., Lengaigne, M., 2008. Patterns in the spatial distribution of Peruvian anchovy (Engraulis ringens) revealed by spatially explicit fishing data. Prog. Oceanogr. 79, 379–389. https://doi.org/10.1016/j.pocean.2008.10.009

Booth, A.J., 2000. Incorporating the spatial component of fisheries data into stock assessment models. ICES J. Mar. Sci. 57, 858–865. https://doi.org/10.1006/jmsc.2000.0816

Breiman, L., 2001. Random Forests. Mach. Learn. 45, 5–32. https://doi.org/10.1007/978-3-030-62008-0_35

Campos-Silva, J.V., Peres, C.A., 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Sci. Rep. 6, 1–13. https://doi.org/10.1038/srep34745

Campos-Silva, J. V., Peres, C.A., Hawes, J.E., Haugaasen, T., Freitas, C.T., Ladle, R.J., Lopes, P.F.M., 2021. Sustainable-use protected areas catalyze enhanced livelihoods in rural Amazonia. Proc. Natl. Acad. Sci. U. S. A. 118. https://doi.org/10.1073/pnas.2105480118

CARDOSO, R.S., FREITAS, C.E.C., 2004. A composição dos custos de armação e a renda das expedições de pesca da frota pesqueira artesanal da região do Médio rio Madeira, Amazonas, Brasil 1 36, 519–524.

Castello, L., 2008. Nesting habitat of Arapaima gigas (Schinz) in Amazonian floodplains. J. Fish Biol. 72, 1520–1528. https://doi.org/10.1111/j.1095-8649.2007.01778.x

Castello, L., Isaac, V.J., Thapa, R., 2015. Flood pulse effects on multispecies fishery yields in the Lower Amazon. R. Soc. Open Sci. 2, 150299. https://doi.org/10.1098/rsos.150299

Castrejón, M., Charles, A., 2020. Human and climatic drivers affect spatial fishing patterns in a multiple-use marine protected area: The Galapagos marine Reserve, PLoS ONE. https://doi.org/10.1371/journal.pone.0228094

Cavole, L.M., Arantes, C.C., Castello, L., 2015. How illegal are tropical small-scale fisheries? An estimate for arapaima in the Amazon. Fish. Res. 168, 1–5. https://doi.org/10.1016/j.fishres.2015.03.012

Cerdeira, R.G.P., Ruffino, M.L., Isaac, V.J., 1997. Consumo de pescado e outros alimentos pela população ribeirinha do lago Grande de Monte Alegre, PA-Brasil. Acta Amaz.

Chollett, I., Canty, S.W.J., Box, S.J., Mumby, P.J., 2014. Adapting to the impacts of global change on an artisanal coral reef fishery. Ecol. Econ. 102, 118–125. https://doi.org/10.1016/j.ecolecon.2014.03.010

Cinner, J.E., Aswani, S., 2007. Integrating customary management into marine conservation. Biol. Conserv. 140, 201–216. https://doi.org/10.1016/j.biocon.2007.08.008

Davies, T.K., Mees, C.C., Milner-Gulland, E.J., 2014. Modelling the spatial behaviour of a tropical tuna purse seine fleet. PLoS One 9, 1–18. https://doi.org/10.1371/journal.pone.0114037

Daw, T.M., 2008. Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. Fish. Res. 90, 17–25. https://doi.org/10.1016/j.fishres.2007.09.027

Fabré, N.N., Castello, L., Isaac, V.J., Batista, V.S., 2017. Fishing and drought effects on fish assemblages of the central Amazon Basin. Fish. Res. 188, 157–165. https://doi.org/10.1016/j.fishres.2016.12.015

FAO, AQUACULTURE, F.A., 2020. El Niño Southern Oscillation (ENSO) effects on fisheries and aquaculture, El Niño Southern Oscillation (ENSO) effects on fisheries and aquaculture. https://doi.org/10.4060/ca8348en

Ficke, A.D., Myrick, C.A., Hansen, L.J., 2007. Potential impacts of global climate change on freshwater fisheries, Reviews in Fish Biology and Fisheries.

https://doi.org/10.1007/s11160-007-9059-5

Freitas, C.E.C., Batista, V.S., Inhamus, A.J., 2003. Strategies of the small-scale fisheries on the central amazon floodplain. Acta Amaz. 32, 101–108.

Freitas, C.E.C., Siqueira-Souza, F.K., Humston, R., Hurd, L.E., 2013. An initial assessment of drought sensitivity in Amazonian fish communities. Hydrobiologia 705, 159–171. https://doi.org/10.1007/s10750-012-1394-4

Friedman, J., Hastie, T., Tibshirani, R., 2001. The elements of statistical learning, 1st ed. New York.

Goethel, D.R., Quinn, T.J., Cadrin, S.X., 2011. Incorporating spatial structure in stock assessment: Movement modeling in marine fish population dynamics. Rev. Fish. Sci. 19, 119–136. https://doi.org/10.1080/10641262.2011.557451

Goulding, M., Venticinque, E., Forsberg, B., Ribeiro, M.L. d. B.R., Barthem, R., Petry, P., Hess, L., Durigan, C., Cañas, C., 2018. Ecosystem-based management of Amazon fisheries and wetlands 1–21. https://doi.org/10.5063/F1BG2KX8

Greenstreet, S.P.R., Fraser, H.M., Piet, G.J., 2009. Using MPAs to address regional-scale ecological objectives in the North Sea: Modelling the effects of fishing effort displacement. ICES J. Mar. Sci. 66, 90–100. https://doi.org/10.1093/icesjms/fsn214

Greenwell, B.M., 2017. pdp: An R package for constructing partial dependence plots. R J. 9, 421–436. https://doi.org/10.32614/rj-2017-016

Hermoso, V., Abell, R., Linke, S., Boon, P., 2016. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 3–11. https://doi.org/10.1002/aqc.2681

Hess, L.L., Melack, J.M., Affonso, A.G., Barbosa, C., Gastil-Buhl, M., Novo, E.M.L.M., 2015. Wetlands of the Lowland Amazon Basin: Extent, Vegetative Cover, and Dual-season Inundated Area as Mapped with JERS-1 Synthetic Aperture Radar. Wetlands 35, 745–756. https://doi.org/10.1007/s13157-015-0666-y

Huntington, H.P., 2000. Using traditional ecological knowledge in science: Methods and applications. Ecol. Appl. 10, 1270–1274. https://doi.org/10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2

Illenseer, R., Pereira, H. dos S., 2010. Territórios fluídos: estratégias de adaptabilidade no acesso e uso de recursos pesqueiros no mosaico de áreas protegidas do baixo Rio Negro, AM. Encontro Nac. da ANPPAS.

https://doi.org/10.13140/2.1.3112.0965

Inomata, S.O., Freitas, C.E.C., 2015. A pesca comercial no m??dio rio negro: Aspectos econ??micos e estrutura operacional. Bol. do Inst. Pesca 41, 79–87.

Isaac, V.J., Castello, L., Santos, P.R.B., Ruffino, M.L., 2016. Seasonal and interannual dynamics of river-floodplain multispecies fisheries in relation to flood pulses in the Lower Amazon. Fish. Res. 183, 352–359. https://doi.org/10.1016/j.fishres.2016.06.017

Isaac, V.J., Milstein, A., Ruffino, M.L., 1996. Characterization of the commercial fish production landed at Manaus, Amazonas State, Brazil. Acta Amaz. 26, 185–208. https://doi.org/http://dx.doi.org/10.1590/1809-4392200331066

Jackson, D.., Marmulla, G., 2011. THE INFLUENCE OF DAMS ON RIVER FISHERIES, Ecology and Conservation of Estuarine Ecosystems: Lake St Lucia as a Global Model. https://doi.org/10.1017/CBO9781139095723.017

Junk, W.J., Bayley, P.B., Sparks, R.E., 1989. The flood pulse concept in river - floodplain systems.

Keppeler, F.W., Hallwass, G., Silvano, R.A.M., 2017. Influence of protected areas on fish assemblages and fisheries in a large tropical river. Oryx 51, 268–279. https://doi.org/10.1017/S0030605316000247

Kullander, S.O., Ferreira, E.J.G., 2006. A review of the South American cichlid genus Cichla, with descriptions of nine new species (Teleostei: Cichlidae). Ichthyol. Explor. Freshwaters 17, 289–398.

Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of land-use and land-cover change in tropical regions. Annu. Rev. Environ. Resour. 28, 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Lopes, G.C. dos S., Catarino, M.F., Castello, L., Freitas, C.E. de C., 2020. Amazon commercial fishing dynamics: a space macroscale analysis on fishing variables. Brazilian J. Dev. 6, 6025–6044. https://doi.org/10.34117/bjdv6n2-053

Malsale, P., Sanau, N., Tofaeono, T.I., Kavisi, Z., Willy, A., Mitiepo, R., Lui, S., Chambers, L.E., Plotz, R., 2018. Protocols and partnerships for engaging pacific island communities in the collection and use of traditional climate knowledge. Bull. Am. Meteorol. Soc. 99, 2471–2489. https://doi.org/10.1175/BAMS-D-17-0163.1

Martelo, J., Lorenzen, K., Crossa, M., Mcgrath, D.G., 2008. Habitat associations of exploited fish species in the Lower Amazon river-floodplain system. Freshw. Biol. 53, 2455–2464. https://doi.org/10.1111/j.1365-2427.2008.02065.x

Melack, P., 1984. Amazon fllodplain lakes: shape, fetch ans stratification.

Nagl, P., Hallwass, G., Tomazoni-Silva, L.H., Nitschke, P.P., Rowedder, A.R.P., Romero-Martinez, A.T., Silvano, R.A.M., 2021. Protected areas and frugivorous fish in tropical rivers: Small-scale fisheries, conservation and ecosystem services. Aquat. Conserv. Mar. Freshw. Ecosyst. 31, 2752–2771. https://doi.org/10.1002/aqc.3673

Nolan, K.S., Fabré, N.N., Batista, V.S., 2009. Landscape variables affecting fishery yield in lake systems of the Central Amazon region, Brazil. J. Appl. Ichthyol. 25, 294–298. https://doi.org/10.1111/j.1439-0426.2008.01122.x

Pauly, D., Zeller, D., 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat. Commun. 7. https://doi.org/10.1038/ncomms10244

Perry, R.I., Sumaila, U.R., 2007. Marine ecosystem variability and human community responses: The example of Ghana, West Africa. Mar. Policy 31, 125–134. https://doi.org/10.1016/j.marpol.2006.05.011

Pet-Soede, C., Van Densen, W.L.T., Hiddink, J.G., Kuyl, S., Machiels, M.A.M., 2001. Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia. Fish. Manag. Ecol. 8, 15–36. https://doi.org/10.1046/j.1365-2400.2001.00215.x

Petrere Jr, M., 1978. Pesca e esforço de pesca no Estado do Amazonas. Acta Amaz. 3, 439–454.

Pinaya, W.H.D., Lobon-Cervia, F.J., Pita, P., De Souza, R.B., Freire, J., Isaac, V.J., 2016. Multispecies fisheries in the lower amazon river and its relationship with the regional and global climate variability. PLoS One 11, 1–29. https://doi.org/10.1371/journal.pone.0157050

Prasad, A.M., Iverson, L.R., Liaw, A., 2006. Newer classification and regression tree techniques: Bagging and random forests for ecological prediction. Ecosystems 9, 181–199. https://doi.org/10.1007/s10021-005-0054-1

R Development Core Team, 2017. R: A language and environment for statistical computing. The R Foundation for Statistical Computing, Vienna, Austria.

Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P., Goodridge, R., 2001. Effects of marine reserves on adjacent fisheries. Science (80-.). 294, 1920–1923. https://doi.org/10.1126/science.294.5548.1920

Röpke, C.P., Amadio, S., Zuanon, J., Ferreira, E.J.G., De Deus, C.P., Pires, T.H.S., Winemiller, K.O., 2017. Simultaneous abrupt shifts in hydrology and fish assemblage structure in a floodplain lake in the central Amazon. Sci. Rep. 7, 1–10. https://doi.org/10.1038/srep40170

RUFFINO, M.., BATISTA, V.., ISAAC, V.., FABRE, N.N., ALMEIDA, O.., 2012. Gestão e Pesca na AMazônia e seu Monitoramento, in: Peixes e Pesca Solimoes.

Sorribas, M.V., Paiva, R.C.D., Melack, J.M., Bravo, J.M., Jones, C., Carvalho, L., Beighley, E., Forsberg, B., Costa, M.H., 2016. Projections of climate change effects on discharge and inundation in the Amazon basin. Clim. Change 136, 555–570. https://doi.org/10.1007/s10584-016-1640-2

Sousa, M.M.O., Lopes, S.I.M., da Costa, R.S., Novaes, J.L.C., 2015. Population structure and reproductive period of two introduced fish species in a Brazilian semiarid region reservoir [Estructura poblacional y período reproductivo de dos especies introducidas de peces en una represa de una región semiárida brasileña]. Rev. Biol. Trop. 63, 727–739. https://doi.org/10.15517/rbt.v63i3.15669

Tregidgo, D., Parry, L., Barlow, J., Pompeu, P.S., 2021. Urban market amplifies strong species selectivity in amazonian artisanal fisheries. Neotrop. Ichthyol. 19, 1–20. https://doi.org/10.1590/1982-0224-2021-0097

Vaughan, D., 2017. Fishing effort displacement and the consequences of implementing Marine Protected Area management – An English perspective. Mar. Policy 84, 228–234. https://doi.org/10.1016/j.marpol.2017.07.007

Vierros, M.K., Harrison, A.L., Sloat, M.R., Crespo, G.O., Moore, J.W., Dunn, D.C., Ota, Y., Cisneros-Montemayor, A.M., Shillinger, G.L., Watson, T.K., Govan, H., 2020. Considering Indigenous Peoples and local communities in governance of the global ocean commons. Mar. Policy 119. https://doi.org/10.1016/j.marpol.2020.104039

Wang, B., Shi, W., Miao, Z., 2015. Confidence analysis of standard deviational ellipse and its extension into higher dimensional Euclidean space. PLoS One 10. https://doi.org/10.1371/journal.pone.0118537

Welcomme, R.L., Cowx, I.G., Coates, D., Béné, C., Funge-Smith, S., Halls, A., Lorenzen, K., 2010. Inland capture fisheries. Philos. Trans. R. Soc. B Biol. Sci. 365, 2881–2896. https://doi.org/10.1098/rstb.2010.0168

Wickham, H., Chang, W., 2016. Package ggplot2: An Implementation of the Grammar of Graphics.

Winemiller, K.O., Jepsen, D.B., 1998. Effects of seasonality and fish movement on tropical river food webs. J. Fish Biol. 53, 267–296. https://doi.org/10.1111/j.1095-8649.1998.tb01032.x

Yuill, R.S., 1971. The Standard Deviational Ellipse; An Updated Tool for Spatial Description. Geogr. Ann. Ser. B, Hum. Geogr. 53, 28–39. https://doi.org/10.1080/04353684.1971.11879353