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The Catfish Fishing in the Amazon Floodplain Lakes



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Abstract

This study is about the spatial and temporal variability of the Hypophthalmus catfish fishery in the Amazonian floodplain lakes and the relationship among commercial CPUE, environmental and economic variables. The fishing productivity varies according to the fishing ground which varies due to the contribution of a set of variables. The most outstanding environmental variables are the Amazon River flow, the large-scale ENSO and GITA events. This catfish productivity was related to the dynamics of the hydrological cycle, ENSO events and economic factors in Óbidos, mainly with economic variables in Santarém and the dynamics of sea surface temperature, ENSO events and economic factors in Monte Alegre. Regarding this fishing profitability, the main economic factors are the distance to the nearest buyer market location and boat types – ice storage capacity and fuel required. The present study is a contribution to the development of a more sustainable small-scale fishery management policy for Amazon and other floodplain regions around the world. To monitor and deepen understanding of this resource fishing dynamics, we strongly encourage additional studies to offer long-term fishery data set, analyze the fishermen behaviour with changes in the exploitation form and intensity in the floodplain lakes, and address other essential data such as use of floodplain, local community, land and vegetation cover as well as landscape changes.

Keywords: Amazon; Catfish; Climate change; Floodplain lake; Hypophthalmus fishing; Mapará

Introduction

The complex Amazon River drainage and its main tributaries are accompanied along their courses by extensive flood zones, known as the floodplain [1]. That area occupies 92,400km² and represents approximately 2% of the Brazilian Amazon territory [2], of which 11% is covered with lakes [3]. These wetlands (forests, fields and lakes) are seasonally flooded forming a landscape mosaic very rich in biodiversity and productivity [4]. During the rainy season, these lakes are filled, intercommunicated with each other and rivers, and often overflow up forming a single system.

The floodplains have a great order and repetition of physical and chemical processes in this environment, suggesting order and predictability in the abiotic components of this system [5] although indicate a high ecological complexity. The hydrologic cycle is an ecological factor essential for the life in the floodplain region because it alternates terrestrial and aquatic phases, expands and contracts the aquatic environments and food availability [6]. During the year, most of this lowland is either a part of the aquatic (submerged for four to five months) or the terrestrial environment (seven to eight months). As a result of these deep oscillations, the Amazon biota and local communities face severe stress and develop a wide variety of adaptive behaviours [7].

The flood and the ebb season relationship is critical to the multiple and in some cases predictable substantial hydrographic changes (such as evaporative inundation) and their subsequent linked processes, directly or indirectly [5]. Several authors have already studied the flood variability [3,6,8-18] but none of them included the above mentioned relationship analysis.

Despite the social and ecological relevance [19,20], there are few studies on the genus Hypophthalmus (mapará) and none of them are related to the fishery productivity in lakes and its relationship with the environmental and climate variables. Understanding how species respond to climate change is critical for their management and conservation [21]. The meteo-oceanographic variability affects fish populations in different ways for each species [18,22]. The drought season characterized by a lower water level, minimum monthly precipitation and maximum insolation occurs from August to October and ends in the November-January period with the standardization of precipitation and soil moisture recovery. The vegetation suffers from water stress due to the intense soil evaporation in years of prolonged drought season.

The Amazon floodplain is an extremely favourable environment for fishing. Depending on the hydrologic cycle, local fishermen change the fishing gear, the target species and the explored aquatic environment to continue fishing efficiency [23,24]. The riverine populations depend on fishing activity for quick access to income and source of protein contributing to a healthy diet [25]. Despite the rich Amazon fish fauna, 80% of the commercial landings are only based on six to twelve species which adapt to seasonal river and lake environment changes [26]. Moreover, strong relationships have been found between the hydrological cycle and the variability of catches during the year [6,9,17,18,27].

The commercial fishing mainly focuses its productivity on the migratory species in the river channels [28] during the drought season, and explores the lakes focusing mainly on the genus *Hypophthalmus* species [29]Isaac, V.J. during the flooding period, when fishing in the river channel is poor and technically difficult.

The South American catfish *Hypophthalmus marginatus* (Valenciennes, 1840) and *H. edentatus* (Spix & Agassiz, 1829) are medium sized Siluriformes of the Pimelodidae family [30], known as mapará in Portuguese language. They are considered reofilic fish since they depend on the flow of the natural environment to perform their reproduction and have a short life expectancy [20] with a high growth rate and natural mortality.

The mapará fish growth presents two rings in the otholits, one during the flooding period [19] for the reproductive migration

(February and March) and spawning (April), and the other (June - August) when zooplankton is scarce [19,20].

In the Amazon aquatic ecosystem, phytoplankton and zooplankton amount depends on the climatic variability and conservation of the forest vegetation and increases when the load of suspended solids is decanted and the floodplain lakes water is clear [15]. The erosion and deposition of sediments exert a differential effect on the physical and biological processes, including transport and transformation of organic matter and primary production [10,31]. This explains how important the hydro-meteorological system influence is on the success of this species life.

Hypophthalmus spp. (mapará) fishing occurs in the flooded forest and shallow floodplain lakes of open water, where forest is scarce [14] and takes place almost all year long, but with greater intensity at the beginning of the flood period [28]. These species account for over 50% of the total landings in the Lower Amazon [18,22], rank among the most economically important fishery resources in the region [8] and play an important ecological function in the food chain because they are pelagic planktivorous resources and serve as food for several top predator fishes.

This study analyzes the possible relationships among hydrological, meteorological, oceanographic and economic variables and the variability of the mapará fishing through its productivity (CPUE).

Material and Methods

Data

The study area is rich in floodplain lakes comprising the Lower Amazon region (Pará State, Brazil) along with approximate 250km of Amazon river which we divided into three zones or fishery grounds: Óbidos, Santarém and Monte Alegre (Pinaya et al. 2016) with two main lakes: Grande de Curuaí and Grande de Monte Alegre (Figure 1).



How to cite this article: Pinaya W H D, Pita P, Souza R B, Lobon-Cérvia F J, Freire J, Isaac V J. The Catfish Fishing in the Amazon Floodplain Lakes. Oceanogr Fish Open Access J. 2018; 7(4): 555720. DOI: 10.19080/OFOAJ.2018.07.555720 On a daily basis from January 1993 to December 2004, interviews were conducted with skippers and persons responsible for the landings of vessels docked at fishery ports in the studied area. We obtained series of fishing data for each fishing trip from the study performed by Isaac, Milstein & Ruffino [9] and selected landings and fishing efforts of *H. marginatus* and *H. edentatus*, grouped under the genus Hypophthalmus (mapará), caught by

- a. Motorized boats with
- b. Their own crew of fishermen ("fishery boat") and
- c. Using gill nets.

These criteria which resulted in a new series of 7,645 records for catches in the lake environment are justified because gill net is the most commonly used fishing gear for these species and the fishing boats are the most representative of this artisanal fleet in the Lower Amazon, responsible for over 80% of the fishery production in the region [32]. For this study economic analysis, the fishing efforts data are monthly average of the maximum ice storage capacity in the boat (IC), the ice on board on the fishing in boat (IB) and the fuel consumption by fishing trip (Fuel).

For the same fishing data period, we obtained monthly hydrological data such as the Amazon River flow (m³·s⁻¹), level (cm) and rainfall (mm) from ANA (Brazilian National Water Agency - www.ana.gov.br). In addition, we obtained meteorological data from the National Centers for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR- http:// www.cdc.noaa.gov), Reanalysis Project, N/N Reanalysis [33] and Reanalysis 2 [34]. We used monthly averages in a distributed Gaussian grid with a spatial resolution of 1.8758° x 1.9058° and included data anomalies of the zonal (u) and meridional (v) wind surface (10m), surface specific humidity (SPFH) (fraction), soil temperature (TMPsfc), latent heat flux (LHF) and runoff (Runoff). The meteorological data is publicly available on-line (http:// www.esrl.noaa.gov/psd/data/gridded/).

We also obtained monthly sea surface temperature (°C) in a 4 × 4km grid along the North Brazilian Continental Shelf, from the "Optimum Interpolation Sea Surface Temperature Version 2 - first guess SST Field" dataset, processed with the Non Linear Sea Surface Temperature (NLSST) algorithm, and available on the Pathfinder project v.5. (PV5) database developed by the National Oceanographic Data Center (NODC - ftp://podaac.jpl.nasa. gov/sea_surface_temperature/avhrr/ pathfinder/data_v5) and RSMAS (Rosenstiel School of Marine and Atmospheric Science, -University of Miami)

Climatological indexes

We used temporal series of climatological indexes, namely the Multivariate ENSO Index (MEI) and the Gradient Inter-hemispheric SST in the Atlantic Index (GITA). The MEI index is associated with the phases of ENSO, El Niño events - warm phase and La Niña cold phase [35]. We obtained the MEI time series from www.esrl. noaa.gov/psd/data/ climate indexes/list/. The GITA index was calculated by the difference between SST anomalies in the North and the South Atlantic Ocean [36].

We estimated normalized anomalies of all environment parameters for the January 1993 to December 2004 period so the non-dimensional data can be comparable among themselves. The climatology calculation of the hydrological variables was based on the 1975 to 2006 period while the meteorological and oceanographic variables considered the period between 1979 and 1995. This climatology data was made available by the Climate Data Assimilation System (CDAS).

Commercial catch per unit of effort-CPUE

The CPUE is an index of productivity defined as the volume of fishery resource captured by a unit of effort employed in the fishery. For each fishery ground, we estimated the monthly CPUE by using the sum of the catch (in kg) and the effort (number of fishermen per fishing day). The estimate for CPUE was calculated using the equation suggested as best estimator by Petrere, Giacomini, & De Marco Jr [37]:

$$CPUE = \frac{\sum_{i=1}^{n} CiEi}{\sum_{i=1}^{n} E_i^2}$$

Where, *C* is the catch per trip in one month and one fishing area; *E* is the effort for the same month and fishery ground, and *i* is each fishing trip. The time series of CPUE was estimated from January 1993 to December 2003 for the Óbidos fishery grounds and to December 2004 for the Santarém and Monte Alegre fishery grounds.

Market index

The market index (MKT) for the monthly mapará production was obtained to account the fishery destination, industrial fish processing companies (set to be one) or local consumption markets (set to be zero), aiming to take into consideration the economical drivers of the Lower Amazon fisheries [18].

Statistical Analysis

We used wavelet transform to examine the variability of the catfish mapará productivity along with spatial and temporal domains and estimated coefficients of cross-correlations (r) between the catch productivity by fishery ground and meteorologic, hydrographic, oceanographic and economic variables. In addition, we performed crosswavelet analysis and wavelet coherence according to the methodology proposed by Grinsted, Moore & Jevrejeva [38]. To identify significant results, we used a cone of influence (p>0.05) from the red noise.

The cross wavelet spectrum analysis emphasized the common power of the two-time series while the wavelet coherence emphasized correlations between variations of two series, i.e., coherence fluctuations. This analysis determine the local correlation of significant oscillations observed among the CPUE and environmental variables. We used STATISTICA7.0[®] and Matlab7.0[®] softwares to perform the cross-correlations and wavelet and crosswavelet, respectively.

We used Generalized Additives Models (GAM) [39,40] for an analysis of the influence of hydrological, meteorological, oceanographic and economic variables on the commercial CPUE variability of mapará. We made three simulations,

i. The first simulation used only environmental variables as independent variables;

ii. The second one used only economic variables and

iii. The third simulation used environmental and economic variables together

The GAM models were adjusted, selected and evaluated with the mgcv package of the statistical package R version 3.3.2 [41].

We selected the most appropriate models based on the Akaike criterion [42] whenever possible, and secondarily on the

percentage of variance explained. Models with dispersed and/or anomalous distributed residues were discarded.

Results

Fishing production

The catch in the Óbidos fishing ground is the main contributor to the fishing in the floodplain lake environment, with 18,200kg·month⁻¹ and an average CPUE of 16.4kg·fisherman⁻¹·day⁻¹. In Santarém, the mapará contribution to the fishery production was 12,745kg·month⁻¹ with an average CPUE of 15.10kg·fisherman⁻¹·day⁻¹. The Monte Alegre fishing grounds contributed with 10,000kg·month⁻¹ and an average yield of 16.33kg·fisherman⁻¹·day⁻¹ (Figure 2a). The average fishing effort for the Lower Amazon during the January 1993 to December 2004 period was six fishermen per trip and five fishing days for each expedition (Figures 2b & 2c) with a standard deviation of two for both efforts.



Cross-correlation

004

The CPUE is mainly correlated with seven hydro-meteooceanographic variables. In all fishing areas, the mapará productivity showed a high correlation with the variance of the ENSO events, with an average lag of 34 months. The CPUE was also significantly correlated (r) with other variables, i.e. the

Amazon River flow (ARD) and surface runoff (Runoff) for the Óbidos fishing ground, the Amazon River level (WL) and the zonal wind component at Santarém (u), and soil temperature (Table 1) at Monte Alegre.

Table 1: Cross-correlation (r) between CPUE of *Hypophthalmus spp.* by the fishing grounds of Óbidos, Santarém and Monte Alegre: the Amazon River discharge (ARD), the Amazon River level (WL), zonal wind component (u), soil temperature (TMPsfc), surface runoff (Runoff), and multivariate index of ENSO events (MEI).

| | Óbidos | | Santarém | | Monte Alegre | |
|--------|--------|-----|----------|-----|--------------|-----|
| | r | lag | r | lag | r | lag |
| ARD | 0.5 | 10 | | | | |
| WL | | | 0.5 | 17 | | |
| u | | | 0.5 | 4 | | |
| TMPsfc | | | | | 0.4 | 12 |
| Runoff | 0.4 | 31 | | | | |
| MEI | 0.5 | 34 | 0.7 | 23 | 0.6 | 35 |
| | | | | | | |

Wavelet

The wavelet transform of the CPUE of mapará shows two main power centres: annual and interannual (three years) (Figure 3). The annual signal is significant for the fishing grounds of Óbidos and Santarém. That is the case mainly in the 1995-1998 period when the interannual signal (34-36 months) is stronger for Santarém and Monte Alegre.



Figure 3: Continuous wavelet power spectrum for CPUE of mapará in fishing grounds of Óbidos, Santarém and Monte Alegre, from January 1993 to December 2004. Thick black contour indicates the 95% confidence level against the red noise and the cone of influence, and where edge effects may distort, the picture is shown in a lighter shade.

Crossed wavelet

005

The common variability between CPUE of mapará in Óbidos and the ENSO events (MEI) indicated in the cross-wavelet shows a predominantly annual peak energy which is in the opposite phase (Figure 4). In Santarém and Monte Alegre, the main energy core is interannual (34-36 months). In Santarém, the CPUE signal is 135° forward in relation to the ENSO events so the CPUE responds in approximately 12 months (3/8 of the period) to those events. In Monte Alegre, the CPUE phase is advanced 45° in relation to the variability of the ENSO events, i.e., the CPUE responds in nine months (fourth period) to the ENSO variability. The coherence spectrum shows the same phases as those observed in the cross-wavelet.



Figure 4: Cross wavelet between CPUE of mapará obtained in lakes at Óbidos, Santarém and Monte Alegre and ENSO events (MEI) environments. The left side is the crosswavelet power (CW) and the right represents wavelet coherence (WC). The contours are for variance units. The 5% significance level against red noise is shown as a thick contour (cone of influence). The relative phase is shown as vectors.

GAM model

Óbidos

Considering only the environmental variables as independent variables, the "Ecology" GAM explains 43.70% of the total fishery productivity variance of CPUE of the mapará in Óbidos fishing ground. The time, zonal wind component, specific humidity and ENSO events are the best explanatory variables. However, when using just economic variables the "Economy" GAM explains 56.40% for the CPUE variance and 25.10% for the mapará first sale price variability. In this case, the time, the market index, the total ice on board and the fuel consumption result the best explanatory for the CPUE variability while the market index, ice on board and fuel consumption are the best explanatory for the first sale price variance.

Finally, considering both environmental and economic variables, the GAM explains 68.9% of the total mapará fishing variance. Therefore, the model with the best fit included the Amazon River level (p-value<0.001), the zonal component of wind (p-value=0.013), surface runoff (p-value=0.047), latent heat flux (p-value<0.001), multivariate ENSO index (p-value=0.012), market index (p-value<0.001), ice on board in the boat (p-value<0.001) and fuel consumption per fishing trip (p-value<0.001) as the most explanatory variables (Table 2).

Table 2: Results of GAM fitted on the productivity of *Hypophthalmus spp.* in floodplain lakes in the fishing grounds of Óbidos, Santarém and Monte Alegre. Significant variables (explanatory), number of observations (N), the percentage of explained deviance (%), degrees of freedom (df) are shown. Error distribution is Gaussian and link is identity for all models,(WL) Amazon River level, (u) zonal component of the wind, (Runoff) surface runoff, (SPFH) surface specific humidity, (LHF) latent heat flux, (MEI) Multivariate ENSO Index, (GITA) Inter-Hermispheric SST Gradient of the Atlantic, (MKT) Market index, (IceCap) total ice storage and (IceBoard) total ice on board in the boat, (Fuel) total fuel consumption per fishing trip.

| Response | Explanatory | N | Deviance | df | | | | |
|-------------|---|-----|----------|-------|--|--|--|--|
| Environment | | | | | | | | |
| CPUE_O | Time + u + SPFH + MEI | 95 | 43.70 | 9.25 | | | | |
| CPUE_S | Time + Runoff + MEI + GITA | 124 | 31.30 | 7.34 | | | | |
| CPUE_M | MEI | 102 | 15.80 | 2.75 | | | | |
| Economy | | | | | | | | |
| CPUE_O | Time + MKT_0 + IceBoard_0 + Fuel_0 | 94 | 56.40 | 10.41 | | | | |
| FP_O | MKT_O + IceBoard_O + Fuel_O | 95 | 25.10 | 8.00 | | | | |
| CPUE_S | MKT_S + IceCap_S + IceBoard_S | 122 | 68.50 | 3.37 | | | | |
| FP_S | Time + MKT_S + IceCap_S + Fuel_S | 118 | 54.60 | 18.54 | | | | |
| CPUE_M | MKT_M | 108 | 51.70 | 1.99 | | | | |
| FP_M | Time + IceCap_M + Fuel_M | 93 | 34.40 | 10.12 | | | | |
| Total | | | | | | | | |
| CPUE_O | WL + u + Runoff + LHF + MEI + MKT_0 + IceBoard_0 + Fuel_0 | 84 | 68.90 | 13.57 | | | | |
| CPUE_S | MKT_S + IceCap_S + IceBoard_S | 122 | 68.50 | 3.37 | | | | |
| CPUE_M | Time + MEI + GITA + MKT_M + IceCap_M + Fuel_M | 90 | 65.80 | 9.49 | | | | |



Figure 5: Graphic representation of the GAM model for the CPUE for mapará in the fishery grounds of Óbidos, considering the Amazon River level (WL), zonal component of wind (u), runoff (Runoff), latent heat flux (LHF), Multivariate ENSO index (MEI), market index (MKT), the ice on board in the fishing boat (IceBoard) and total fuel consumption per fishing trip (Fuel) as the explanatory variables the model. The CPUE prediction is showed with a continuous line and the dotted line shows the standard deviation.

The CPUE was inversely and almost linear related with the zonal component of wind, latent heat flux, ENSO events and the fuel consumption. The total ice on board showed a direct and quite linear relation with the CPUE. Likewise, the CPUE was directly related with Amazon River level and market index (Figure 5).

007

Santarém

The "Ecology" GAM results for Santarém with just environmental variables explain 31.30 % of CPUE variance using the time, runoff, MEI and GITA as explanatory variables in the final model. From the *Ecology* model, the highest annual CPUE average (21.04±1.66kg•fisherman•day⁻¹) occurred in 1996. From that year on, there has been a progressive decline in the number of catches, reaching the minimum (9.93±1.70 •fisherman•day⁻¹) in 2004 which is the last year of the analyzed temporal series (Figure 6).

Using only economic variables, the resulted "Economy" GAM explains 68.5% of the mapará fishing variance and 54.60% of the variance of its first sale price in Santarém. The best set of variables in these cases are the market index, total ice storage capacity and on board in the fishing boat for CPUE economic model and the time, market index, the total ice storage capacity on boat and fuel

consumption for explaining the variance of the first sale price in Santarém.

However, when using environmental and economic variables together, the total variance of the CPUE of mapará explained by the GAM was also 68.50%. So, the CPUE in Santarém was best related with the market index (p-value<0.001), total ice storage capacity in the boat (p-value<0.001) (p-value=0.003) and ice on board (p-value=0.035; Table 2). The explanatory variables (market index, ice storage capacity and ice on board) showed a direct and quite linear relation with the CPUE in Santarém (Figure 6).



Figure 6: Graphic representation of the GAM model for the CPUE for mapará in the fishery grounds of Santarém, considering the market index (MKT), the total ice capacity storage (IceCap) and the ice on board (IceBoard) in the fishing boat as explanatory variables. The CPUE prediction is showed with a continuous line and the dotted line shows the standard deviation.

Monte alegre

The "Ecology" GAM with only environmental variables as explanatory variables showed 15.80% explanation of the mapará fishing productivity variance in Monte Alegre. From the complete set of environmental variables tested only the MEI was significant for this model.

Using only economic variables in the "Economy" GAM, the total mapará fishing variance explained is 51.70% while 34.40% is the explained variance of the first sale price of the fish. In the GAM "Economy" for the mapará CPUE, the total explained is 51.70% while 34.40% is the explained variance of the first sale

price. The variables that best fit the model were the market index for CPUE and the time, ice storage capacity in the boat and fuel consumed for the first sale price.

However, when considering the environmental and economic variables together in the GAM for the mapará in Monte Alegre, 65.80% of the variance of the fishery productivity is explained. In this model, the CPUE was better related to time (p <0.001), the variability of ENSO events (p-value = 0.019). Inter-Hemispheric SST gradient in the Atlantic Ocean (p <0.001), market index (p <0.001), total ice storage capacity in the boat (p-value = 0.019) and fuel consumption (p-value <0.001, Table 2).



The highest annual CPUE average (22.12±2.37kg•fisherman•day-1) was estimated for 1999 (Figure 7). Furthermore, the CPUE was inversely related with the time, ENSO events variability, and fuel consumption. However, the CPUE showed a direct relationship with the market index, the Inter-Hemispheric Gradient of the Sea Surface Temperature in the Atlantic Ocean and, overall, with the total of the ice storage capacity in the boat (Figure 7).

Discussion

009

The complex dynamics behavior of fish that inhabits the floodplain lakes is reflected in the fishing techniques and productivity in the Lower Amazon [15]. In seasonal tropical systems, the temperature is relatively constant and periodic flooding is the main factor driving ecological dynamics. The access to the floodplain aquatic environments is important for the successful recruitment of many fish species in the seasonal tropical rivers.

The interannual variability in the recruitment of fish is generally more associated with the flooding length than its magnitude [11]. The flood pulse of the great rivers in the Amazon generates many ecological processes in the floodplain by seasonality between the expansion and retraction of the aquatic environment. In addition, many economic activities are restricted to the dynamics of the hydrological cycle [13].

The results of this research show that the climate variability and the hydrological cycle of the Amazon River Basin can influence differently the floodplain yield of mapará fishing in the Lower Amazon lakes. The annual signal in the spectrum of the wavelet is related to the flood pulse and the discharge of the Amazon River, while the interannual signal is related to the ENSO events. The mapará fishing season coincides with the flood period [9], mainly for the months of May-June-July. The smaller catches are associated with the drought season (October-November-December), when the Amazon River level is lower.

With the floods, the fish has access to a wide variety of habitats [11]. Dissolved inorganic nutrients and terrestrial allochthonous materials are transported through runoff to the floodplain lakes stimulating the production of phytoplankton and zooplankton [5]. In the drought season, fish mortality is increased in the floodplain lakes due to predation.

Succession and seasonal floodplain dynamics are influenced by all these mechanisms [11] which also determine the success of the reproductive and recruitment events. Due to its short life cycle, anomalies or any change in the environment will be quickly felt in the success of the mapará fishing production. The mortality rates tend to increase in years with warm phase of ENSO and river with level lower than normal because some lakes can completely dry in those conditions. A combined effect between the positive ENSO and GITA might occur during extreme events such as the one in 2005 when thousands of tons of fish died in the Amazon [43].

Several studies have noted the relationship of the Amazon hydrologic cycle, ENSO events and the anomaly of sea surface temperature in the tropical Atlantic Ocean [18,22,44,45]. The ENSO warm phase reduces the flooded area shortening the mapará fishing period and increasing the fish catchability because the water level is low while the cold phase prolongs the flood period [13] and favors fishing. The years with the larger (1995, 2000 to 2002) and smaller (1993, 1994, 1997 and 1998) catches coincide respectively with the cold and warm phases of ENSO.

Moreover, negative precipitation anomalies occur in warm ENSO years. The opposite occurs in cold ENSO years [35]. For the 1979-2000 period, Marengo [6] observed that the Amazon rainfall, runoff and moisture convergence levels reduce during warm and increases during cold ENSO phases. Previous studies have shown that variations in the Amazon rainfall are also related to the SST in tropical Atlantic [18,22,46,47].

Expanded droughts occurred in more than one of the four Amazon regions during the 1971-2010 period (1982/83, 1991/92, 1994/95, 1997/98, 2004/05 and 2010) and indicated the influence of the already known warm ENSO phase on precipitation in the tropical region of South America as well as the influence of the anomalous sea surface temperature warming of the tropical Atlantic which is also known but less common [16].

The temperature increase may enhance the drought effect on the evaporation [48] and negatively impact the ecology and dynamics of fishes that inhabit the Amazon floodplain lakes and as a result all fishery activity in the Lower Amazon region. This effect should be more visible in Monte Alegre where the GAM indicates that the mapará fishing productivity is related to the anomalous temperature variability. Other floodplain regions with open water lakes and less shadow area should also have the fishery activity influenced by the temperature.

Some studies have emphasized the importance of climate variability and the hydrological cycle for fishing in the Amazon. Other researches consider the socio-economic aspects to understand fishing in this region. Pinaya et al. [18] considered environmental variables and the final destination of the fishery product either to the local market or to the fish factories, with the market index as an option to use environmental and economic aspects together in their analysis. In this research, we observed that the percentage of the variance of the mapará fishing explained by the GAM is significantly higher when considering the environmental along with the economic variables, such as amount of ice on board and ice storage capacity in the boat, distance between fishing point and market buyer and fuel used in fishing trips. Virtually, all fishery production of fishing boats in the Amazon is conditioned, transported and sold in ice. Moreover, due to the lack of infrastructure, second-category fish caught are discarded and replaced by fish of the most important species caught simultaneously or at a later time. Informally, there is a belief that up to 30% of fish damage occurs in that operation [1].

Agriculture, livestock and deforestation change the landscape (especially, riparian wetlands) and not only contribute to the destruction of the spawning and fish nursery areas, but also affect the fish diversity and fishery production [49] of mapará and other fish species. Some of the challenges for future research on the conservation of biodiversity, the ichthyofauna and the fishing activity in the Amazon will be gaining deeper understanding on how the impacts of climate change will act on these themes. Changes in temperature and precipitation may lead to loss of total aquatic habitat influencing the distribution and migration of fish species, even within the limits of environmental protection area [50].

Conclusion

In Óbidos, the GAM model shows that the variance of fishing productivity is mainly influenced by regional and local hydrological and climatic cycle variability, such as Amazon river level, wind, runoff and latent heat flux, together with some economic variables as distance from the fishing plant, total ice on board and fuel used. In Santarém, the fishery variance of mapará is explained more by economic than environmental variables since the city is the main consumer market for this fish and has fishing plant in the neighborhood. Thus, the GAM model showing the best explanation considered only economic variables such as ice and the distance of the consumer market. In Monte Alegre, the variance of this fishery is mainly related to large scale events, ENSO and GITA, and economic variables as ice, fuel and the distance between the fishing grounds and the fishing plant.

This research should contribute to manage sustainable small-scale fisheries and enhance policies for Amazon and other floodplain regions around the world. For future studies, we strongly encourage analysis of the frequent landscape changes and the floodplain lakes morphology to sum up to this study results for each fishing ground, continuous generation of long term fishery statistical data to increase awareness of the interannual and interdecadal variability of this fishery resource, and incorporation of biotic interactions in biohydroclimatic, ecological and fishing models based on specific processes of each target species.

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Conflict of Interest

I WHDP and any of the co-authors have no conflict of interest with the policy of the Oceanography & Fisheries Open Access Journal to be declared.

Data Accessibility

The environmental data and climate indexes are available in public repositories as follows: Meteorological data are available on-line www.esrl.noaa.gov/psd/data/timeseries/. The sea surface temperature data are available in the website: https://www.nodc. noaa.gov/SatelliteData/pathfinder4km/ . The hydrological data are available in the website: http://www.snirh.gov.br/hidroweb/.

Climate indexes are available in the website: www.esrl.noaa. gov/psd/gcos_wgsp/Timeseries/http://www.snirh.gov.br/ hidroweb/

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