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Article

The Hydrological Cycle of the Lower Amazon in Brazil Determines the Variation in Local Fishing Patterns

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Abstract: Fishery catches on the Lower Amazon River were analyzed in relation to the hydrological cycle, temporal shifts in fishing effort, and the use of nets or lines in lakes and rivers. The study was based on a temporal series of catch data collected between January 1993 and June 2011. The variables analyzed were the total catch, use of gillnets or lines, the environment targeted (lakes or rivers), and fishing effort. Temporal trends in the data series were analyzed using the Mann–Kendall test. An Analysis of Covariance (ANCOVA) was used to evaluate whether gillnet and line catches had independent effects on the catch data. Duncan's test was applied to identify the groups (months) of means that were significantly different from each other. The majority of the catch landings were taken with gillnets (98.65%) in a lake environment (64.98%). The temporal series showed a significant decline over time in the gillnet catches from both lakes and rivers, as well as in fishing effort. The influence of the annual flood cycle was reflected in the catches and the flood pulse regulated fishing productivity patterns in the region. The fishers who adapt their activities to this flood pulse have good traditional knowledge of the environment. The results of the study also indicated that any changes in this dynamic system may impact traditional local fisheries and affect the economic wellbeing of local fisher populations.

Keywords: Amazonia; artisanal fishery; fishing grounds; fishing technique; hydrological pattern; sustainable development

Key Contribution: The empirical knowledge of the fishers of the Lower Amazon region supports the selection of fishing techniques and grounds appropriate to the stage of the hydrological cycle. Eventual shifts in this cycle will likely impact this dynamic, affecting both the productivity of fishing and the local communities that depend on this activity.

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1. Introduction

With more than 2400 species [1], Amazonia has the greatest diversity of freshwater fish in the world [2,3]. This biological richness supports the region's artisanal fisheries, which are one of its principal economic sectors [4,5]. These fisheries are responsible for the majority of the fish products sold regionally, nationally, and even for export [6], and are also the principal source of subsistence for the region's traditional riverside populations, whose per capita consumption of fish is among the world's highest [7].

Artisanal fishing is also an important source of full-time or seasonal employment for the population of the Brazilian Amazon region [8,9], where job opportunities are limited, and alternative sources of income are scarce. However, this activity is extremely variable, and the income derived from a fishing trip can be affected by a range of factors, both endogamous and exogenous, including the fishing season, target species, and fluctuations in the climate and river levels. A few previous studies have focused on the productivity of fisheries in the Lower Amazon basin [10,11], and the factors that determine the oscillations in the income generated by this activity [4,6,10].

The biological cycles of the local species are adapted to the natural cycle of the rivers' hydrological regime. The fish of the Amazon region have three principal life history strategies [12]: (i) species that undertake extensive longitudinal migrations along the channels of the region's principal rivers; (ii) species that migrate locally, across the floodplain between lakes and rivers, and (iii) sedentary fish, which do not migrate or move only short distances over the course of the year. The gilded and Goliath catfish (*Brachyplatystoma vaillantii*) are two examples of the long-distance migrants, which migrate from the nursery zone, in the estuary, to spawn in the upper Amazon [13,14]. The second group includes a large number of species, which shoal at low water to migrate along the principal river channels from their principal habitats to their spawning grounds. After spawning, the shoals wait until the subsequent flood pulse to occupy floodplain lakes or swamps in search of shelter from predators and abundant feeding resources [13]. These species include the tambaqui (*Colossoma macropomum*), curimatã (*Prochilodus nigricans*), and pacus (*Mylossoma* spp.) [15]. The sedentary species, such as peacock bass (*Cichla temensis* and *Cichla monoculus*), croakers (*Plagioscion squamosissimus* and *Plagioscion auratus*), and janitor fish (*Pterygoplichthys pardalis*), normally only travel short distances when feeding resources are locally scarce [14].

The present study evaluated a long-term series of fishery catch data in the context of the hydrological cycle and the type of fishing gear and environment, using a covariance approach (ANCOVA) approach [16]. Longitudinal studies that evaluate long-term trends in the intensity and productivity of the region's artisanal fisheries are still scarce. This is due to the general lack of official fishery statistics in Brazil—in particular, those that provide continuous, long-term data [14,17,18]. In addition to the lack of any government policy for the monitoring of fisheries, the paucity of data reflects the unique characteristics of artisanal fisheries, which tend to be informal in most cases, cover large areas, and employ a variety of fishing techniques, while also landing their catches in relatively small and isolated localities that are difficult to monitor [19,20]. Brazilian fishery agencies only collect data from industrial fisheries. While some specific projects run by public or private institutions have collected data in the past, none are currently active. The only source of fishery data from the Brazilian Amazon at the present time are licensed hydroelectric projects, which are required to monitor fishing activities as part of their environmental obligations. The data analyzed in the present study were obtained by two projects financed by the German government, which were concluded in 2012. Overall, Amazonian fisheries are complex, and the few available data are invaluable for the understanding of the exploitation of different environments and productivity levels, in the context of the annual flood cycle [10,21–23].

In the specific case of the Lower Amazon, no previous study has associated the variation in fishing techniques with the hydrological cycle, although data are available on the fluctuations in the productivity of certain species, and the relationships between this variation and both river levels and rainfall rates [10,11,24,25]. In this context, the present study focuses on the variation in the total fishery catches associated with the hydrological cycle, trends in fishing effort, and the patterns of use of gillnets and lines in floodplain lakes and river environments on the Lower Amazon.

The present study focused on four principal questions: How do fishing effort and catches vary over time? How does the hydrological cycle affect the distribution of fishing effort between lakes and rivers? Which factors determine the choice of fishing gear? When and how were the highest yields obtained?

2. Materials and Methods

2.1. Study Area

The fishery data analyzed in the present study were collected along a stretch of approximately 480 km (in a straight line) of the Lower Amazon River, including the principal course of the river, its lateral channels, creeks, and marginal and floodplain lakes, between the municipality of Parintins in the Brazilian state of Amazonas and Almeirim in the state of Pará (Figure 1). In this region, the river is extremely wide, and its margins are lined with extensive, shallow floodplain lakes and other seasonally flooded areas—some of which are forested, while others have more open vegetation. Over the course of the year, the level of the river rises and falls by approximately seven meters, leading to the flooding of land margins during the periods of peak rainfall and river discharge [26]. These fluvial environments and floodplain areas are exploited extensively by artisanal fishing vessels, which land their catches in the ports of the municipalities of Parintins, Oriximiná, Óbidos, Alenquer, Santarém, Monte Alegre, Prainha, and Almeirim [27].

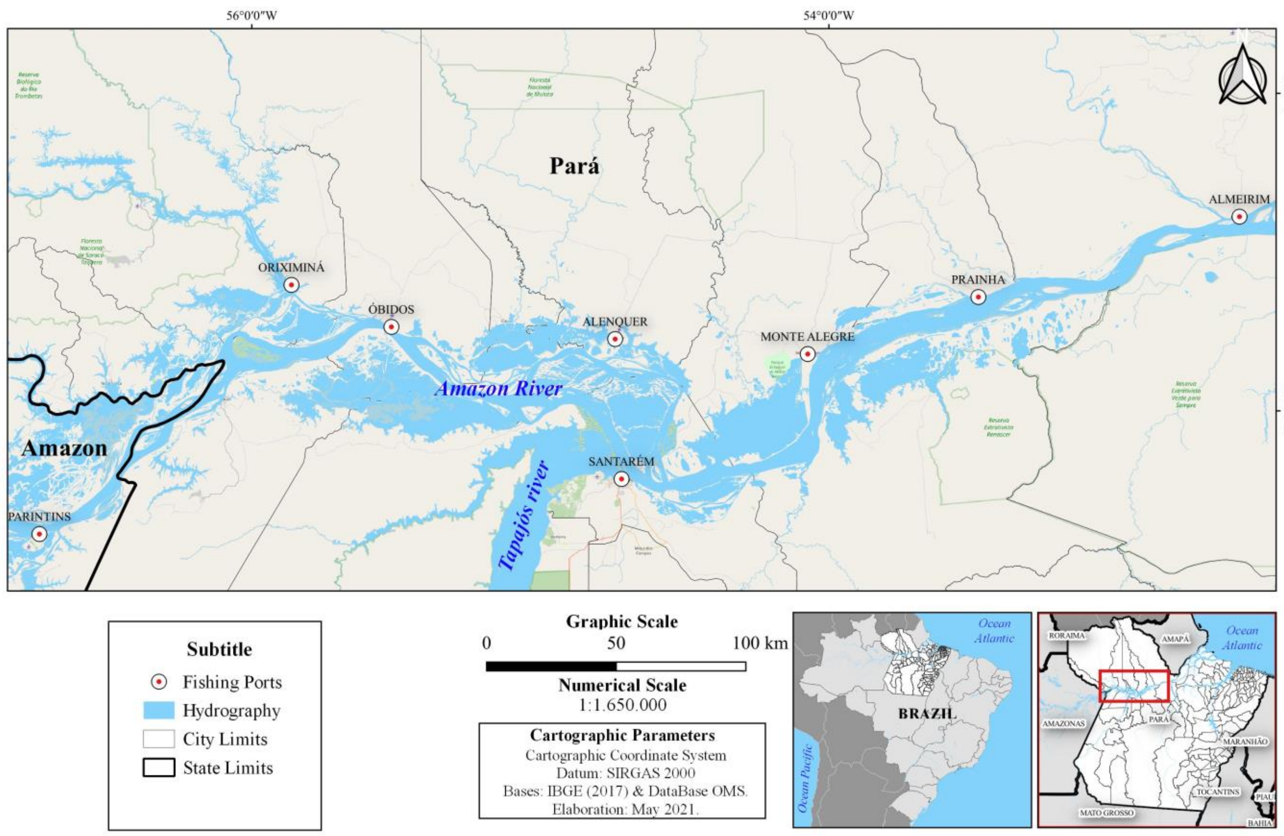

Figure 1. Location of the eight fishing ports on the lower Amazon River, at which the fishery data analyzed in the present study were collected.

2.2. Data Collection

The fishery data were collected from ports in eight municipalities (Figure 1), with the data being collected between January 1993 and June 2011, except for an interval between July 2005 and February 2008, when a lack of financial resources led to the suspension of research activities. The data were compiled in a database used for the analyses presented here.

The monitoring consisted of daily interviews with the fishers or owners of the vessels that docked at the ports, for the collection of the following information: (i) the type of vessel, (ii) the environment (lake or river) fished, (iii) the number of fishers, (iv) the duration of the trip, (v) the effective fishing days, (vi) the fishing techniques used (gillnets or lines), and (vii) the weight of the fish caught, which were classified according to the common name used for the species by the fishers. Each interview form referred to a single fishing trip. The Total Catch (TC) was defined as the sum of the weights of the 42 ethnospecies (Supplementary Table S1).

The data were filtered to include only the catches landed by motorized fishing vessels operating on floodplain lakes, other environments subject to flooding (such as blackwater swamp [igapó] and marsh) or rivers, including all associated watercourses, such as bifurcations, channels, and major streams. The analyses focused on motorized vessels because they account for the majority of the total catch (approximately 87%). The dataset was also restricted to trips during which either gillnets (GN) or lines (L) were deployed (Table 1), given that these two types of gear were together responsible for around 85% of the total catch.

Table 1. Characteristics of the different types of fishing gear used by the artisanal fisheries of the Lower Amazon basin (adapted from Isaac et al., 2004 [28]). The local names of the different types of fishing gear are shown within parentheses in the third column.

Type	Category	Gear	Description	Usage
NETS	Gillnets	Driftnet ("bubuia")	Long, tall gillnet, which is left to drift in the river channel.	Used to catch catfish.
		Gillnet ("malhadeira")	Rectangular nets of multifilament nylon, with different mesh sizes.	Widely used near the surface or near the bottom, in the still waters of rivers or in floodplains. This net catches all different types of fish, depending on the mesh used and the site targeted. These nets may also be deployed actively, being trawled manually or by vessels.
		Small gillnet ("miqueira")	Rectangular nets of monofilament nylon, with different mesh sizes.	Used in environments with strong currents, principally to catch mapará.
	Cast nets	Cast net ("redinha")	Rectangular net used actively to encircle fish.	Used in deep water free of obstacles for the capture of fish in shoals, in particular the jaraqui.
	Others	Handnet ("puçá", "rapiché")	Funnel-shaped nets with a fine mesh and pole.	Used in the dry season (low water), primarily at the margins of islands and in areas with gravelly bottoms.
LINES	Lines	Handlines and rods ("caniço", "rapazinho")	Long nylon line with a baited hook at the end, either held in the hand, tied to the bank, or attached to a rod.	Used in lentic environments, near fruiting trees or in sheltered locations. Used to catch pacu, aracu, and other fish in flooded areas.
		Paternoster ("espinhel")	Longline gear, to which a series of short lines with hooks are attached.	Used to target catfish in the river channel.

The weight (in tons, t) of each day's catches was summed for each study month or year. For analysis, the months with no data (July 2005 to February 2008) were assigned the mean value for the respective month calculated for the rest of the study period. These monthly means were also used to fill in for missing data on the number of fishers, effective fishing days, and fishing effort. This resulted in a dataset with a total of 222 monthly and 19 annual catch and effort data points. The mean catch and effort data recorded for each month were used for the analysis of monthly patterns. The combined fishing effort (E) was obtained using Equation (2) from Petrere Jr. et al. (2010) [29]: $E = \sum NF \times \sum FD$, where NF = the number fishers and FD = the number of effective fishing days.

The total catch (in tons, t) and combined fishing effort values were transformed by the natural logarithm to standardize the linearization and homoscedasticity of the data. Even so, the relationship between catches and effort did not align with the origin, which impeded the calculation of the CPUE (Catch per Unit Effort), as recommended by Petrere Jr. et al. (2010) [29]. Given this, only the catches were used as the response variable [11] in the Analysis of Covariance (ANCOVA).

The River Level (RL) values recorded in the study area for the period between 1993 and 2011 were obtained from the Hydrological Information System (HidroWEB) of the Brazilian National Waters Agency (ANA) [30]. These data were compiled from ANA's network of pluviometers and fluvial gages at Santarém. The analyses were based on the mean monthly (cm) level recorded for each year. To better characterize the hydrological cycle for the analysis of the catch dynamics associated with river levels, the data were arranged in four phases according to the level of the Amazon/Solimões river system [14]: (i) flooding (January–March), (ii) high water (April–June), (iii) ebb (July–September), and (iv) low water (October–December).

2.3. Statistical Analysis

Exploratory and descriptive analyses were applied to the monthly and annual total catches (t) and the combined fishing effort data. The Mann–Kendall test, with $\alpha = 0.05$ was run in PAST® 4.02 [31] to determine possible temporal trends in the monthly data on total catches, fishing effort, and the catches obtained with gillnets or lines in rivers or lakes. This test calculates an S statistic, of which negative S values indicate a decreasing trend and positive values an increasing trend, while $S = 0$ reflects a lack of any significant trend [32]. As the Mann–Kendall test is nonparametric, it does not require normally distributed data [33,34]. The dynamic relationships among the different environments and types of fishing gear were illustrated using graphic plots.

The ANCOVA [16] permits the inclusion of quantitative variables related to the dependent variable of the variance model, which is why ANCOVA was appropriate for the evaluation of whether the effects of the catches taken using nets or lines were independent. The Box-Cox transformation was used to adjust the data to the models [35]. For this, the net catch data were first considered as the response variable, with the line catch data being considered to be the covariable and the months as the independent variable or treatments. This approach aimed to determine whether the net catches varied monthly and whether this variation was correlated with the line data (dependent variable). This procedure was then repeated, with the line data as the response variable in the model. Duncan's test [36] was then used to compare the pairs of means because it is one of the least conservative but most powerful tools available for this type of analysis [37]. All the analyses were run in the R for Windows platform, version 3.6.2 [38], using the car, agricolae, and olsrr packages.

3. Results

The mean monthly total catch of the Lower Amazon fishery, for the whole study period, was 182.4 t (±111.3 t), corresponding to a combined mean monthly effort of 21.6 (±6.3) fisher days. The local artisanal fishing fleet undertook trips with a mean duration of four (±3.0) effective fishing days, with a mean of five (±4.2) crew members per trip. Almost 65% of the total catch (26,316 t) was taken in lacustrine environments. Gillnet fishing provided the greatest production overall, with almost 99% (39,949 t) of the total catch.

Catches and fishing effort presented similar patterns of variation over time (Figure 2). The total catch was highest in 2001, followed by 1995 and 2002, while fishing effort peaked in 1994 and 2001 (note that data were only collected in the first half of 2011).

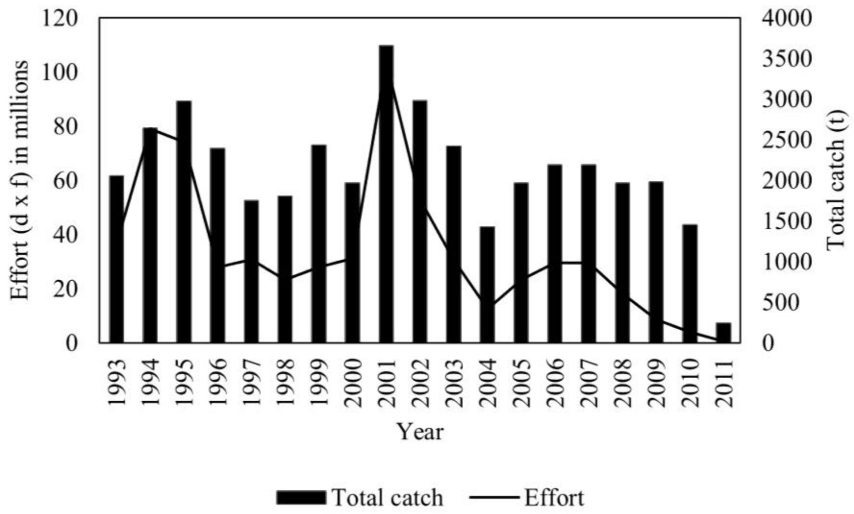

Figure 2. Annual total catch (t) and fishing effort (days × fishers) recorded at the ports on the lower Amazon between 1993 and 2011.

The Mann–Kendall test (Table 2) revealed significant ($p < 0.05$) decreasing trends over time in the total catch, fishing effort, and the gillnet catches in both environments. The total line catches from the lakes followed the opposite trend (increasing over time), whereas the line catches from rivers did not vary significantly ($p > 0.05$).

Table 2. Results of the Mann–Kendall test (*S* values and probabilities) for the evaluation of trends in fishery variables on the lower Amazon between January 1993 and June 2011 (* $p < 0.05$).

Variable	*S*	*p*
Total catch	–3837	0.0005 *
Fishing effort	–8691	0.0000 *
Gillnets in lakes	–2927	0.0082 *
Gillnets in rivers	–3622	0.0011 *
Lines in lakes	2301	0.0376 *
Lines in rivers	–1088	0.3258

The catch varied seasonally and was associated with the hydrological cycle (Figure 3A). The largest catches were recorded in August and September, which corresponds to the ebb period, when the river level was falling. The fishing effort, number of fishers, and the number of fishing days all decreased as the level of the river increased between January and July (Figure 3B–D).

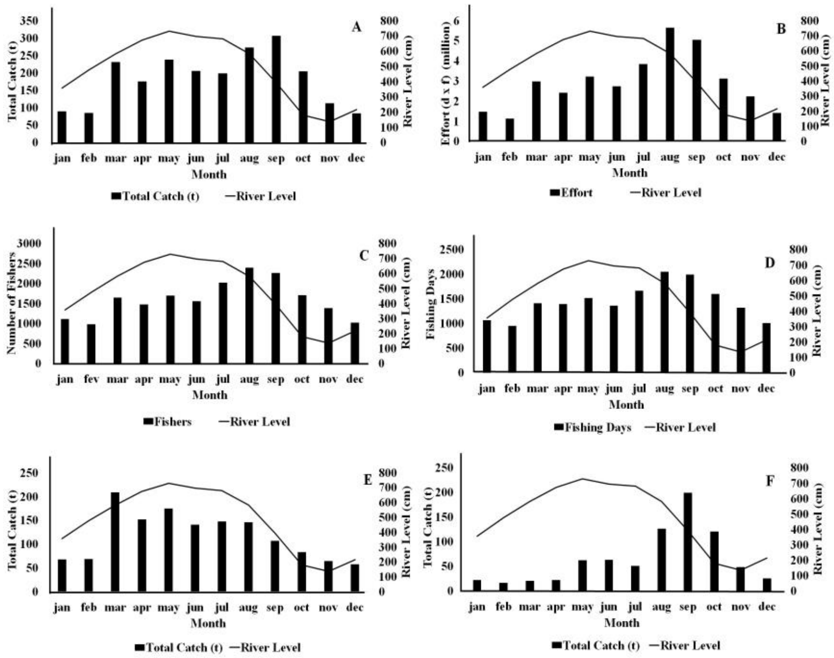

Figure 3. (**A**) Mean total monthly catches (t), (**B**) mean monthly fishing effort (fisher-days), (**C**) mean number of fishers per month, (**D**) mean number of effective fishing days, per month (**E**) mean monthly total catches (t) from lake environments, and (**F**) mean monthly total catches (t) from river environments. The mean values were obtained from the data recorded on the artisanal fishing fleet that operates on the lower Amazon, between January 1993 and June 2011, and mean monthly level of the Amazon River during the study period.

Fishery production from the rivers varied most in seasonal terms, for both lines and gillnets, with peaks during the ebb water period—that is, in August and September (Figures 4C and 5C). Considering the type of gear and environment specifically, the gillnet catches in the lakes were the most homogeneous over the course of the year, but peaked during the high-water months, i.e., March through May (Figure 5B), whereas line fishing in the lakes was most productive in December and January, that is, during the flooding phase (Figure 4B).

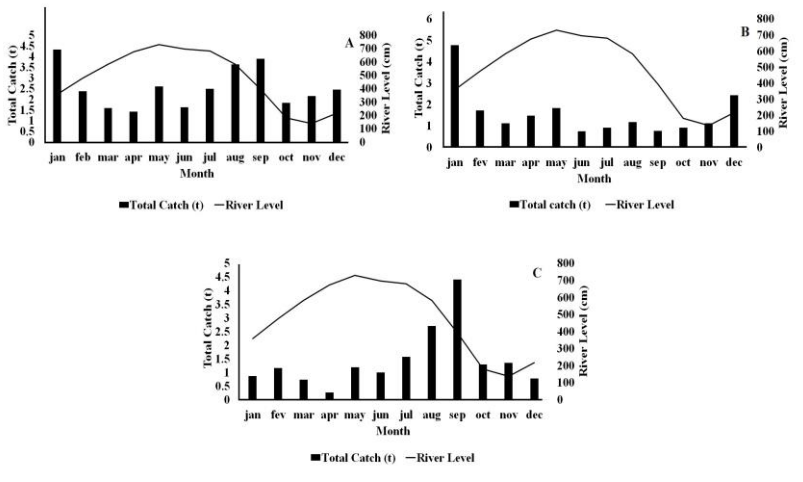

Figure 4. Mean monthly line fishing catches (t) recorded (**A**) during the study period as a whole, (**B**) in the lake environments, and (**C**) in the river environments. The mean values were obtained from the data recorded on the artisanal fishing fleet that operates on the lower Amazon, between January 1993 and June 2011, and mean monthly level of the Amazon River during the study period.

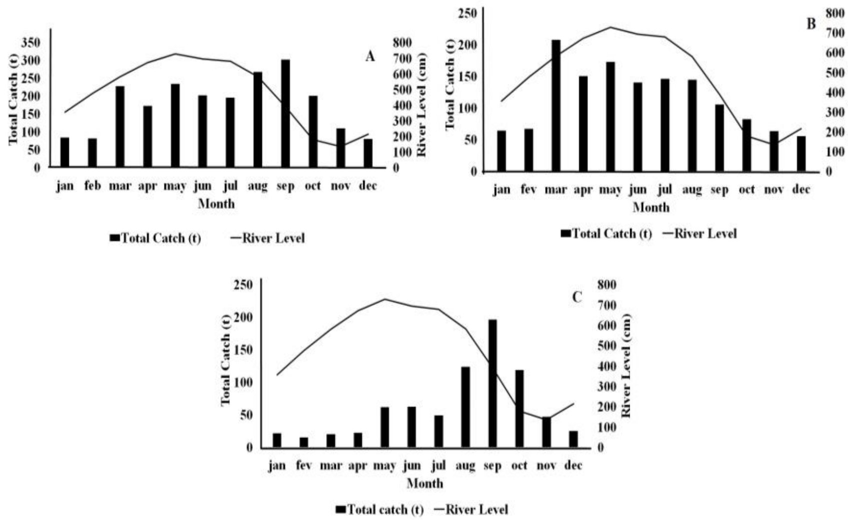

Figure 5. Mean monthly gillnet catches (t) recorded (**A**) during the study period as a whole, (**B**) in the lake environments, and (**C**) in the river environments. The mean values were obtained from the data recorded on the artisanal fishing fleet that operates on the lower Amazon, between January 1993 and June 2011, and mean monthly level of the Amazon River during the study period.

The selection of the fishing technique and environment also varied seasonally, according to the hydrological cycle (Figures 4B,C and 5B,C), with the drier months producing better yields. On the rivers, the largest catches were produced in August and September, which is the ebb phase (Figure 3F). Line fishing (Figure 4A) was most productive in January (flood), and August and September (ebb), whereas the gillnets (Figure 5A) produced the largest catches in August and September. Overall, productivity decreased as the level of the water increased. There was also a clear alternation over time (Figures 3–5), with fishing activities being concentrated in the river environments during the low-water period, and in the lacustrine environments at high-water (Figure 3E,F).

The inclusion of line or net fishing as a covariable in the respective models did not affect fishery production—that is, they were independent variables. Fishery production did vary significantly among months in both models, however (Table 3).

Table 3. Results of the Analysis of Covariance (ANCOVA) for the monthly catches obtained using gillnets and lines in the study area on the lower Amazon River (* $p < 0.05$). F = F statistic and Pr = probability).

Gillnets				
	Sum of the Squares	**Degrees of Freedom**	***F***	**Pr (>F)**
(intercept)	571,322	1	75.6725	9.994×10^{-16} *
Line (covariate)	4891	1	0.6478	0.4218
Month (independent variable)	1,156,612	11	13.9268	2.2×10^{-16} *
Residual	1,577,936	209	-	-
Lines				
	Sum of the Squares	**Degrees of Freedom**	***F***	**Pr (>F)**
(intercept)	31.67	1	6.1932	0.01362 *
Gill nets (covariate)	0.54	1	0.1065	0.74455
Month (independent variable)	117.14	11	2.0825	0.02295 *
Residual	1053.44	206	-	-

The normality of the residuals (p = 0.2088) and the homogeneity of their variances (p = 0.7037) confirmed that the model used for the gillnet fishing data was adequate. The adequacy of the line fishing model was also confirmed (normality: p = 0.4030; homogeneity of variances: p = 0.7836) following the Box-Cox transformation. In the case of the monthly gillnet catches, the results of Duncan's test indicated the formation of three distinct groups (Figure 6): group 1 (red), the most productive months (August and September); group 2 (green), the least productive months, from low water to the onset of the flood (November–February); and group 3 (yellow), which corresponds to the principal flood months (March–July) plus October.

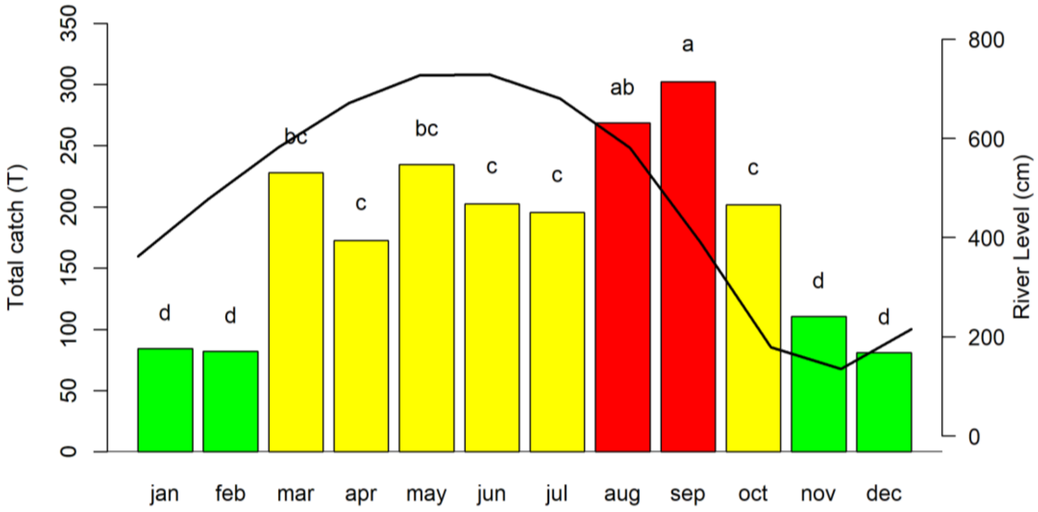

Figure 6. Mean monthly gillnet catches (t) recorded from the catches landed at the artisanal fishing ports on the lower Amazon, between January 1993 and June 2011, showing the probability of the pairwise differences between pairs of means (α = 0.05). Distinct colors indicate groups of months that differ from each other.

The same analysis of the line-fishing catches (Figure 7) revealed two groups—group 1 (September) and group 2, with all the other months.

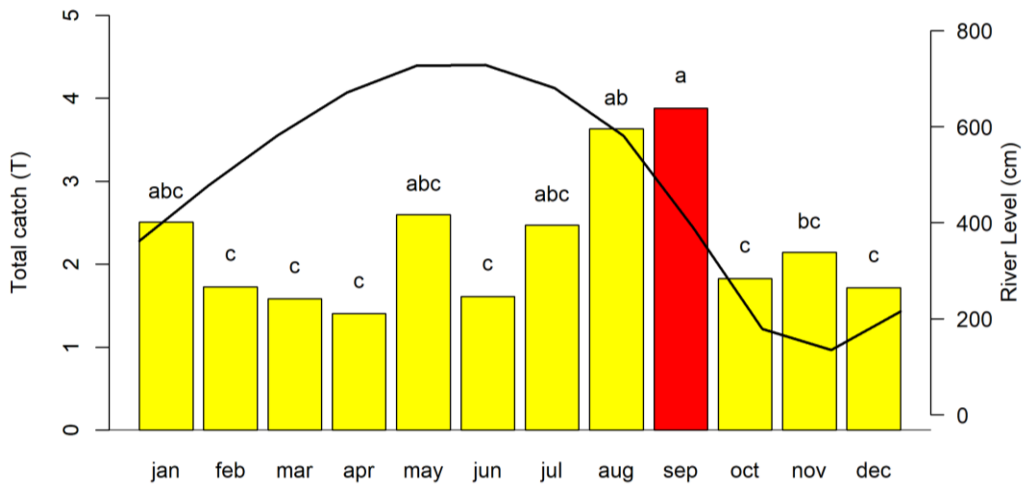

Figure 7. Mean monthly line-fishing catches (t) recorded from the catches landed at the artisanal fishing ports on the lower Amazon, between January 1993 and June 2011, showing the probability of the pairwise differences between pairs of means (α = 0.05). Distinct colors indicate groups of months that differ from each other.

4. Discussion

The fisheries of the Lower Amazon are typically small-scale, based on a fleet of relatively small, wooden boats [39]. This sector is nevertheless vital to the subsistence of the local riverside communities, providing a relatively reliable source of income that requires little investment [40].

The majority of the total catch was obtained from flooded lacustrine environments using gillnets, which are the gear most used by fisheries nowadays in the region. Fishing on calm, floodplain waters may be the most viable option for inexperienced or young fishers [23]. As some lakes are flooded throughout the year, these environments can be fished continuously. During the rainy season, most of the fish species found in the lakes are in search of refuge and food. Some sedentary species remain in flooded and shallow lacustrine areas, even during the dry season, when fishing can be more productive.

In the past, traditional and indigenous communities used lines and cotton nets for fishing [41]. With the introduction of nylon nets in the 1960s [42], nylon gillnets have become widespread for commercial fishing. Gillnets are relatively more efficient and durable [43,44], easier to handle, capture a greater diversity of fish, and provide more predictable catches than more traditional gear [45]. While gillnets are often a source of conflict [46], they support the commercial success of artisanal fisheries, and provide important economic benefits [4,5,45].

The present study identified a decreasing trend in gillnet catches over time, whereas line fishing on the lakes tended to increase over time (Table 2). This may reflect local fishery agreements [47], which are established by the local communities that share fishing grounds in order to regulate the exploitation of fishery resources and avoid the exhaustion of stocks [48]. These agreements may nevertheless influence the behavior of the fishers, and in most cases they do not permit the use of nets, which are low-selective fishing gears that have a negative impact on fish stocks [49]. The adoption of participative models of management has grown considerably in Brazilian Amazonia since the 1990s, with fishery agreements proliferating in the region of the lower Amazon—in particular, in lake environments [48].

The results of the present study also highlight a general tendency for a decrease in both catches and fishing effort. The lack of government incentives for fisheries and the absence of policies directed at the improvement of the quality of life of fisher populations appear to be among the principal factors motivating the offspring of fisher families to abandon their communities and traditional ways of life [50]. The region's fishers face harsh conditions in general, and artisanal fishing is considered to be an especially risky occupation, not only in terms of personal health, but also the lack of any guarantee of returns [51–53]. While the occupation is still passed down from father to son [40], many individuals of the younger generation prefer alternative professions, justifying their decisions by the inherent uncertainties of artisanal fishing [50]. The operational costs and potential financial risks of these fisheries [40,50] may also have contributed to the decrease in fishing effort and, in turn, production.

Amazonian fisheries are complex and highly dynamic, and depend on the availability of specific environments, which is in constant flux due to the seasonal oscillations in river levels [24,54]. The fishers' knowledge of the patterns of fluctuation in both the environment and the fish fauna [55] is also fundamental to the optimization of fishing strategies. This dynamic was confirmed in the present study, which demonstrated a clear association between catch sizes and the hydrological cycle (Figure 3). The months of the low water phase are known as the harvest season—that is, the most productive period when fisheries increase in efficiency as the dimensions of the aquatic environment shrink [10,21,56].

Fishing techniques are determined by the target species and/or the operational environment [28]. In particular, mono- and multifilament gillnets (*miqueiras* and *malhadeiras*) are used commonly in lacustrine environments, where they are used to target the fish that inhabit these environments during the high-water period [57,58]. These fish include the mapará catfish (*Hypophthalmus edentatus* and *Hypophthalmus fimbriatus*) and some characids, such as the tambaqui (*Colossoma macropomum*) and pacus, *Mylossoma*, *Myleus*, *Metynnis*, and *Myloplus* [59]. The drift gillnets (*bubuias*) are deployed more frequently in the rivers to catch dourada (*Brachyplatystoma rousseauxii*) and other large, migratory catfish that are found in the principal channel [10].

The river level peaks in the high-water phase when catches decline due to the greater dispersal of the fish in the water, where they are able to find an increasing variety of refuges from both natural predators and fishing nets [10,14]. During the ebb phase, the aquatic environment begins to shrink and the fish start to shoal as they return to the fluvial channels, where the adults of many species will then migrate upriver to breed. This is when fishing intensifies (Figure 3). Catches and fishing effort both increase during the months of low water, when the aquatic environments shrink, exposing the fish to predators and, eventually, conditions that intensify both their natural mortality and their vulnerability to fisheries [10,60].

The covariance analysis (Table 3) indicated that the different months affect the catches of both gillnet and line fisheries, but that their productivity varies independently. While the monthly gillnet catches formed three distinct groups, the lines fishing formed only two groups. In most cases, monthly catches were related systematically to the level of the river, with larger mean catches being landed during the months of the ebb phase—that is, August and September (Figures 4 and 5). In addition to the seasonal pattern determined by the hydrological cycle, the catches from the lake and river environments alternated over time, with the rivers being fished more during the low-water period, and the lacustrine environments being fished more intensively during the rainy season months, when the river level rises (Figure 3E,F).

The fishermen's empirical knowledge of the population dynamics of their target species reflects the characteristics of the traditional fishery systems, which are passed down from generation to generation. The variation in productivity is thus also familiar to the fishers, who attribute fluctuations to the vagaries of the ecosystem and the ecology of the target species [61,62]. This alternation reflects the adaptations of the fishers to the ecological dynamics of the fish, with different types of bait being used for line fishing, according to the feeding preferences of the target species, and the shifting opportunities presented by the different environments [10]. In other words, the productivity of gillnet and line fishing varies independently, especially considering that the two techniques are more effective for different groups of species—in particular, lines for catfish and nets for most other species. This means that species such as the goliath catfish (*Brachyplatystoma vaillantii)* and surubim (*Pseudoplatystoma* spp.) are the primary targets in the rivers, while curimatã (*Prochilodus nigricans*), jaraquis (*Semaprochilodus* spp.), and long-whiskered catfish (*Hypophthalmu* spp.) are the principal resources exploited in the lakes [21,63].

During the flood phase, the fleet (both gillnet and line fishing operations) shifts its attention from the river channels to the lakes (Figure 3E). This period coincides with the migrations of many Amazonian fish species, which move downstream in search of recently flooded areas of *várzea* swamp, which provide important feeding grounds and nursery areas for the juvenile fish. These species include the gilded catfish (*B. rousseauxii*), the long-whiskered catfish (*Hypophthalmus* spp.), and the curimatã (*Prochilodus nigricans*), which occupy the lakes during the flood period and then leave as they dry out [64,65].

Overall, the results of the present study indicate that any shift or alteration in the hydrological cycle may have a major impact on this complex dynamic, which might affect the local fisheries, with potentially profound consequences for the local communities that depend on these fisheries for their subsistence. Regional changes in climate predicted for the near future [66,67] represent one potential threat to this activity, given that a decline in rainfall rates or longer dry seasons would likely have cascade effects throughout the trophic web.

The present study shows that the empirical knowledge of the artisanal fishers in the Lower Amazon region supports their ability to adjust fishing techniques and locations to the phases of the hydrological cycle. The formulation of a comprehensive dataset on Amazonian fisheries will permit the further improvement of the models applied here and will allow for the most effective monitoring of any alterations in this dynamic. Continuous data on landings will permit the rapid development of effective fishery management measures. The reinforcement of a national program for the systematic collection of fishery data, with responsibilities shared between the artisanal fishers themselves and fishery and environmental agencies, would be an extremely valuable asset in this scenario.

The monitoring of landings is considered to be the most efficient methods for the sampling of natural fish stocks and is also the best way to evaluate fishery performance [68–70], providing fundamental data for fishery research and conservation management. Given this, the Brazilian authorities should be encouraged to make all possible efforts to re-initiate the collection of reliable, continuous fishery data in the Amazon region [10], given that these data will be essential to confirm the apparent decline in fisheries as indicated by the findings of the present study. These data will also be fundamental to the assessment of the progressive impacts of climate change and other associated processes on fishery productivity. The long-term data analyzed here revealed a clear decline over time in both the total catch and the fishing effort, which should be investigated in more detail.

5. Conclusions

The fishery catches monitored during the present study showed a clear seasonal pattern that was associated systematically with the hydrological cycle of the Amazon River. Most of the catches were obtained from flooded areas using gillnets. The study also found an influence of fishery agreements on fishing patterns, driving a trend of line fishing in the lakes and the decreased catch with gillnets. The months of low water coincided with a peak in fishing productivity. During the ebb phase, the fisheries use both lines and gillnets. The evidence of decreasing catches and fishing effort should be investigated in more detail. A reliable set of long-term data will be essential for the development of adequate public policy and more effective fishery management strategies in the study area.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes8070371/s1, Table S1: Contribution (%) of the principal fish species or ethno-species landed at the fishing ports monitored on the lower Amazon between 1993 and 2011.

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