https://doi.org/10.22478/ufpb.1981-1268.2022v16n4.62389

Influence of seasonal fluctuations of the Madeira River level in the southern Brazilian Amazon fisheries

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Received 25 February 2022.
Accepted 14 December 2022.
Published 29 December 2022.

Abstract - The Amazon basin encompasses the most diverse fauna of freshwater fish and the greatest potential for inland fisheries of any river basin in the world. Given this, the present study characterized the fish stocks of the Madeira River and analyzed the influence of seasonal fluctuations in river levels on the local fish fauna. This analysis was based on fishery catch data obtained from the "Dr. Renato Pereira Gonçalves" (Z-31) fishing cooperative in the municipality of Humaitá in the Brazilian state of Amazonas. The data collected for each excursion included the location of the fishing grounds exploited, the period of the fishing trip, the species captured, and the total catch (kg), for the 10-year period between 2001 and 2010. A total of 47 taxa were recorded, representing 16 families and five orders. During the study period, a total of 3,001,468 kg of fish were landed at Humaitá. The Characiformes was the predominant order, contributing 77,7% of the total catch. The most abundant fishes were the pacu, curimatã and jaraqui. The catches landed at Humaitá presented considerable seasonal variation, related primarily to the fluctuations in the level of the river and the migratory behavior of the principal species captured.

Keywords: Amazon region**.** Madeira Basin. Fish fauna. Fisheries management. Conservation.

Influência nas flutuações sazonais do nível do rio Madeira sobre a pesca no sul da Amazonia brasileira

Resumo - A bacia Amazônia possui a maior diversidade de peixes de água doce e o maior potencial de produção pesqueira continental do mundo. Sendo assim, este trabalho tem o objetivo de caracterizar os estoques pesqueiros e analisar a influência da sazonalidade fluviométrica sobre a ictiofauna do rio

Madeira. Para isso foi utilizado dados de desembarques pesqueiros ocorridos na colônia de pescadores Z-31 "Dr. Renato Pereira Gonçalves", localizada no município de Humaitá (AM). Os dados obtidos foram registrados diariamente contendo o local de pesca, data de partida e chegada das expedições, espécies capturadas e o número do total de captura em quilogramas (kg) no período de 2001 a 2010. Foram registradas 47 espécies taxonômica de peixes, divididos em 5 ordens e 16 famílias. Ao longo de todo o período amostral, foram contabilizados 3,001,468 kg de peixes desembarcados. Characiformes foi a ordem mais frequente, com 77,7% de toda produção pesqueira naquele período. Os peixes mais frequentes foram o Pacu, seguido pelo Curimatã e Jaraqui. Os desembarques ocorridos em Humaitá se caracterizaram pela sazonalidade das capturas, devido principalmente às variações nas cotas fluviométricas e ao comportamento migratório das principais espécies capturadas.

Palavras-chave: Região Amazônica**.** Bacia do rio Madeira. Ictiofauna. Gestão Pesqueira. Conservação.

Influencia de las fluctuaciones estacionales del nivel del río Madeira en la pesca en el sur de la Amazonía brasileña

Resumen - La cuenca del Amazonas tiene la mayor diversidad de peces de agua dulce y el mayor potencial para la pesca continental en el mundo. Por lo tanto, este trabajo tiene como objetivo caracterizar las poblaciones de peces y analizar la influencia de la estacionalidad fluviométrica en la ictiofauna del río Madeira. Para ello, se tomaron datos de incidentes de pesca en la colonia pesquera Z-31 "Dr. Renato Pereira Gonçalves", ubicado en el municipio de Humaitá (AM). Los datos capturados se registraron diariamente, conteniendo el lugar de pesca, fecha de salida y llegada de expediciones, especies y el número total de capturas en kilogramos (kg) en el período de 2001 a 2010. Se registraron 47 taxón especies de peces, divididas en 5 órdenes y 16 familias. A lo largo de todo el período de muestreo se registraron 3,001,468 kg de pescado desembarcado. Characiformes fue el orden más frecuente con el 78% de toda la producción pesquera. Los peces más buscados fueron Pacu seguido de Curimatã y Jaraqui. Los desembarques capturados en Humaitá se caracterizan por la estacionalidad, principalmente por variaciones en las cuotas fluviométricas y el comportamiento migratorio de las principales especies.

Palabras clave: Región Amazónica. Cuenca del Río Madeira. Ictiofauna. Gestión Pesquera. Conservación.

Introduction

The Amazon basin is widely considered to be the freshwater ecosystem with the greatest diversity of fish species in the world (Lévêque et al. 2008), with 2320 fish species including 1,488 endemic ones (Winemiller et al. 2016). Currently, only for the Madeira basin is estimated that there are more than 1,300 species of fish, representing almost half of the species known for the entire Amazon basin (Cella-Ribeiro et al. 2016). The diversity of Amazonian fish is derived from the vast area of the basin, and the heterogeneity of the habitats found within this region (Hallwass et al. 2011; Doria et al. 2018). The intensity of local fisheries, and the quantity and quality of their catches are determined primarily by the hydrological cycle and the ecological characteristics of the target species (Santos et al. 2018; Santos et al. 2020).

Indigenous populations fished in the Amazon basin long before European colonization, and fish was an essential component of their diets (Santos and Santos 2005). In the present day, many communities still depend on this natural resource for their subsistence (Cardoso and Freitas 2007), and fish is the principal source of animal protein and financial revenue for countless riverside communities in the Amazon basin (Duponchelle et al. 2021). Approximately 368,000 people and tens of thousands of fishing vessels are responsible for an annual production of 166,000-173,000 tons of fish (Barthem and Goulding 2007; MPA 2010). The Amazon basin fish landings are estimated to have an annual revenue of approximately US$436 million and the Madeira's River basin was about US$14.7 million (Duponchelle et al. 2021).

Despite the socio-economic importance of fisheries in the Amazon basin, and the enormous quantity of fish landed each year, few detailed data are available on the region's stocks (Barthem and Goulding 2007; Duponchelle et al. 2021). Among other impacts, these stocks are threatened by an increasing number of hydroelectric dams, which are being established throughout the region (Fearnside 2015; Duponchelle et al. 2021). In 2012, two large-scale hydroelectric schemes (the Santo Antônio and Jirau dams) were inaugurated on the Madeira River in the Brazilian state of Rondônia. These dams impounded reservoirs with a total area of 241 km^2, 138 km^2 at Santo Antônio and 110 km^2 at Jirau, which will cause irreparable damage to the local fauna and flora in the near future (Fearnside 2015; Santos et al. 2018). Hydroelectric dams may alter the physical-chemical structure of the environment and modify the composition and trophic structure of local fish communities, as well as interrupting the spawning migrations of many species (Van Damme et al. 2019; Hahn et al. 2020; Lima et al. 2020; Santos et al. 2020).

Given this destruction of habitats and the impacts on the local fish fauna, reliable data on the diversity of this fauna, and the temporal and spatial fluctuations in fish stocks are essential for the development of adequate management strategies and the implementation of effective socio-environmental policies for the region (Santos and Santos 2005; Santos et al. 2020). Studies of this type also provide important insights into the integrity of environments, given that fish are important bioindicators in aquatic ecosystems (Chovanec et al. 2003; Plessl et al. 2017).

As one of the principal tributaries of the Amazon, the Madeira River plays an important role in the commercial fisheries of the whole Amazon region (Duponchelle et al. 2021). Barthem and Goulding (2007) estimated that the Madeira River contributes approximately 4% of the total fishery production of the Amazon basin, and the river plays highly significant socio-economic and cultural roles in the region (e.g., Goulding 1979; Cardoso and Freitas 2007; Goulding et al. 2019; Duponchelle et al. 2021).

In this context, the present study characterized the fishery stocks of the Madeira River and analyzed the influence of fluctuations in the level of the river on the local fish fauna, based on catch data obtained from the "Dr. Renato Pereira Gonçalves" (Z-31) fishing cooperative, located in Humaitá, in the Brazilian state of Amazonas. The objective of this study is to understand the influence of the level of the Madeira River in relation to the volume of the catches landed at Humaitá municipality according to the cooperative practises multi-species commercial fishing. The results of the study will contribute to the understanding of fishery practices in the undisturbed period of an Amazon basin, helping to manage the region's fishery stocks, and the implementation of effective socio-environmental policies.

Material and methods

Study area

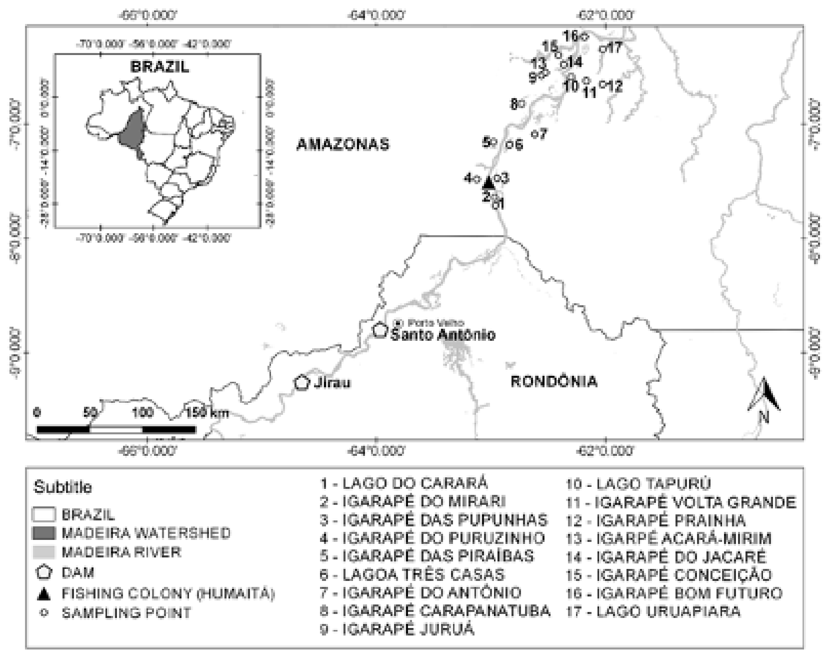
The Madeira River is the principal tributary of the right margin of the Amazon River (Gibbs 1967). The Madeira originates in the Bolivian Andes from the confluence of the Beni and Mamoré rivers (Goulding, Barthem and Ferreira 2003), and has a total length of 3240 km, including 1425 km within the Brazilian states of Rondônia and Amazonas, where it flows into the Amazon River near the town of Itacoatiara. Annual precipitation in the region is between 2250 mm and 2750 mm, with a relatively short dry season (Martins et al. 2006). The local climate is humid tropical, with mean annual temperatures varying from 24°C to 26ºC, and relative humidity of 85–90% (Carvalho 1986).

The present study was based on fishery catch data from the municipality of Humaitá, in southern Amazonas, 675 km southwest of the state capital, Manaus. With a total area of 34,430 km^2, the municipality of Humaitá is located on the left margin of the Madeira River at an altitude of around 90 m above sea level (Carvalho 1986) and has approximately 57,195 inhabitants (IBGE 2022).

Data sampling

The characteristics of the fishery stocks of the Madeira River and the influence of river levels on the fish fauna were evaluated based on fishery production data for 2001–2010, provided by "Dr. Renato Pereira Gonçalves" fishing cooperative (Z-31). The catches landed at Humaitá were obtained by 1655 fishers registered at the cooperative, who operate at 17 different fishing grounds found along the Madeira River and adjacent waterways (Figure 1). All the fish landed at the cooperative (Z-31) were daily caught in the Madeira basin. The data were registered in the cooperative Z-31 by recording the location of the catch, the period of the fishing trip, the species captured, the catch weight in kilograms (kg) and subsequently sold in the municipal market.

Figure 1. Fishing grounds exploited by the Dr. Renato Pereira Gonçalves (Z-31) fishing cooperative at Humaitá, Amazonas, Brazil.



Data analysis

The data were inserted in an electronic spreadsheet for the production of the descriptive statistics, including the absolute and relative catches of each fish 47 taxon (family and order). To evaluate monthly productivity in the context of the seasonal variation in river levels, monthly fluviometric data were obtained for the Madeira River (station 15630000) from the hydrological data information system of the Brazilian National Waters Agency (ANA 2017), installed 200m downstream of the Fishing Colony Z-31 (Figure 1). The daily data were grouped in monthly catches for the production of box plots, and compared with mean monthly river levels. The Z-31 cooperative, during the period from January to April 2008, did not record the fish catch because it was under maintenance of the pier (See the Supplementary material). A Spearman correlation was used to evaluate the relationship between fishery productivity and the level of water of the Madeira River. Seasonal variation in fishery productivity was evaluated using the Kruskal-Wallis nonparametric analysis of variance (Vieira 2004). The normality of the data was assessed using the Shapiro-Wilk test (Shapiro, Wilk and Chen 1968).

The influence of seasonal fluctuations in river levels: flood season (February-April), flooding (November-January), drying (May-July) and dry season (August-September) on the productivity of the principal target species was evaluated using a Principal Components Analysis (PCA). Finally, a cluster analysis using the main and commercialized species was applied, based on Euclidean distances. The statistical analyses and graphs were performed using the R software (R Core Team, 2020).

Results

A total of 40 ethnospecies were recorded in the Humaitá fisher community between 2001 and 2010, divided into 47 taxonomic species (Table 1). The species belonged to 16 families distributed in five orders. The Characiformes was the predominant order, accounting for 77,7% of the total catch, followed by the Siluriformes, with 15,6% of the production (Table 1). The remaining orders – Perciformes (3,9%), Osteoglossiformes (1,9%) and Clupeiformes (0,01%) – provided minor contributions to the total catch.

Table 1. Fish species landed in the municipality of Humaitá (Amazonas, Brazil), between 2001 and 2010. Species not identified by fishermen and not taxonomically classified represent 1,0%.

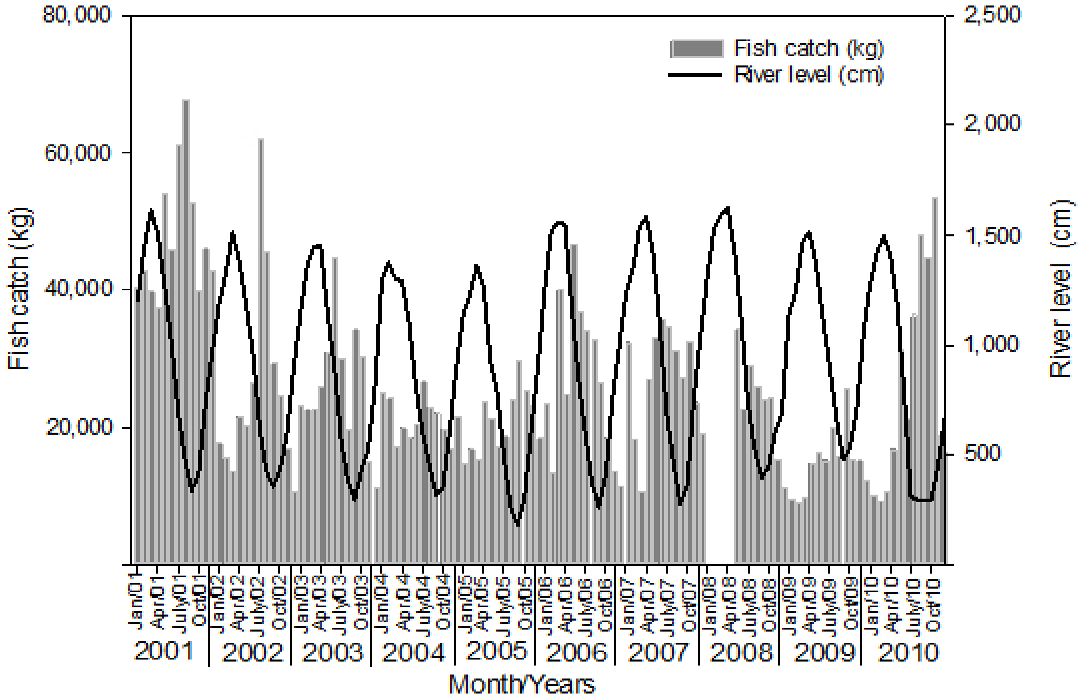
Order/family	Common name	Taxon
Characiformes (77,7%)		
Anastomidae	Piau	*Schizodon fasciatus, Leporinus* spp.
Bryconidae	Jatuarana	*Brycon amazonicus*
	Matrinxã	*Brycon melanopterus*
Serrasalmidae	Pacu	*Mylossoma* spp., *Myleus* sp.
	Piranha	*Serrasalmus* sp., *Pygocentrus nattereri*
	Pirapitinga	*Piaractus brachypomus*
	Tambaqui	*Colossoma macropomum*
Triportheidae	Sardinha	*Triportheus auritus, Triportheus angulatus*

Order/family	Common name	Taxon
Curimatidae	Branquinha	*Potamorhina latior, Psectrogaster amazonica, Potamorhina altamazonica*
Cynodontidae	Peixe-cachorro	*Rhaphiodon vulpinus Cynodon gibbus, Hydrolycus scomberoides, Hydrolycus scomberoides*
Erythrinidae	Jeju	*Hoplerythrinus unitaeniatus*
	Traíra	*Hoplias malabaricus*
Prochilodontidae	Curimatã	*Prochilodus nigricans*
	Jaraqui	*Semaprochilodus insignis, S. taeniurus*
Clupeiformes (0,01%)		
Pristigasteridae	Apapá	*Pellona castelnaeana, Pellona flavipinnis*
Osteoglossiformes (1,9%)		
Osteoglossidae	Aruanã	*Osteoglossum bicirrhosum*
Perciformes (3,9%)		
Cichlidae	Acará-Açu	*Astronotus crassipinnis*
	Tucunaré	*Cichia* spp.
Sciaenidae	Pescada	*Plagioscion squamosissimus*
Siluriformes (15,6%)		
Callichthyidae	Tamoatá	*Hoplosternum littorale*
Doradidae	Bacú	*Lithodoras* sp.
	Cuiú-Cuiú	*Oxydoras niger*
Loricariidae	Bodó	*Hypophthalmus* sp.
Pimelodidae	Babão	*Brachyplatystoma platynemum*
	Barba-chata/Barbado	*Pinirampus pirinampu*
	Dourada/Dourado	*Brachyplatystoma rousseauxii*
	Filhote/Piraiba	*Brachyplatystoma filamentosum*
	Jundiá	*Leiarius marmoratus*
	Jaú	*Zungaro zungaro*
	Mandi	*Pimelodus* sp.
	Mapará	*Hypophthalmus* spp.
	Peixe-lenha	*Sorubimichthys planiceps*
	Pintado/ Surubim	*Pseudoplatystoma* spp.
	Piramutaba	*Brachyplatystoma vaillantii*
	Pirarara	*Phractocephalus hemioliopterus*
	Surubim	*Pseudoplatystoma punctifer*

A total of 3,001,468 kg of fish were landed over the course of the study period (2001–2010), with a mean annual catch of 300,147 kg. The highest annual catch was recorded in 2001, at 569,925 kg (Figure 2), with a peak in productivity in August, during the drying period of the Madeira River.

The principal fish landed in 2001 were the curimatã and the jaraqui (Figure 3). Peaks in productivity were also observed in July 2002 (drying period) and at flooding, in April 2006 (Figure 2). A clear peak in the production of jatuarana was also observed in 2006 (Figure 3).

Figure 2. Monthly fish catches landed in the municipality of Humaitá (Amazonas, Brazil), and the monthly variation in the level of the Madeira River between 2001 and 2010.



In 2004, 2005 and 2007, peaks in the catches were recorded in both floods to flooding periods and the drying to dry periods. The smallest catch – 177,541 kg – was recorded in 2009, followed by 2008, when no catches were recorded between January and April (Figure 2).

Analyzing the data by species, it is evident that the jaraqui and curimatã provided almost the whole of the total catch recorded in 2001 (Figure 3, Table 2).

The contribution of these species declined during subsequent years, due to both a reduction in their catches (2002–2006), and an increase in the catches of other species, such as the branquinha, between 2003 and 2007, the pacu between 2002 and 2010, and the jatuarana in 2006. The pacu increased considerably in importance during the last four years of the study period (2007–2010), when it became the most abundant species caught (Figure 3, Table 2).

Figure 3. Annual catch (kg) of the principal target species landed and commercialized in the municipality of Humaitá between 2001 and 2010.

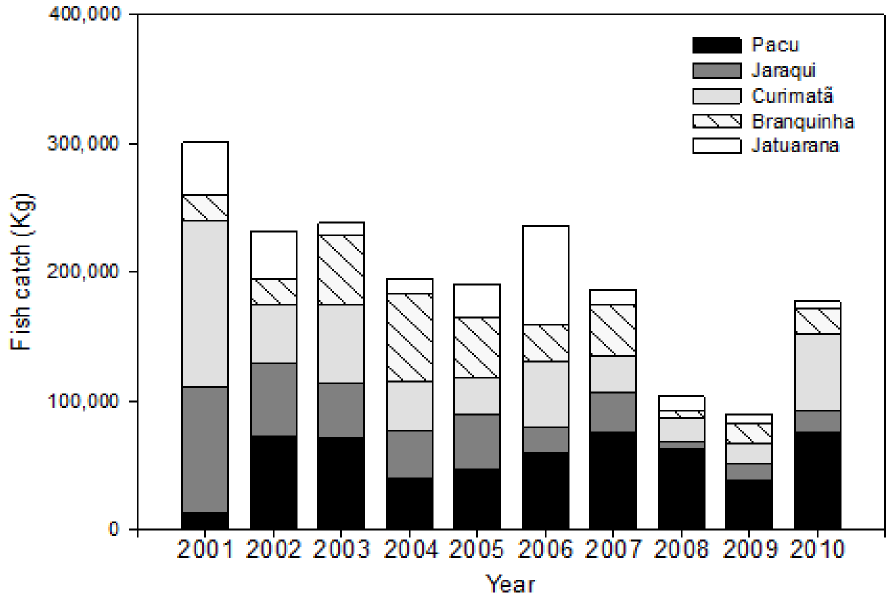
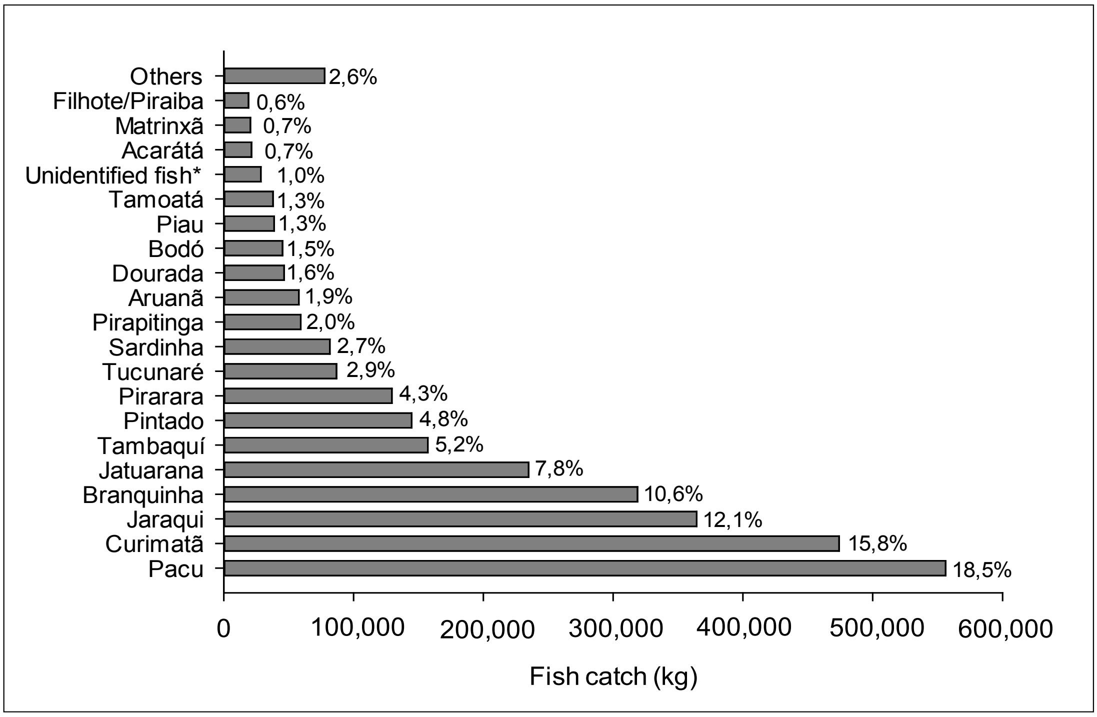


Table 2. Annual catch (kg and %) of the principal target species landed and commercialized in the municipality of Humaitá between 2001 and 2010.

Year	**Fish catch**									
	Pacu		Curimatã		Jaraqui		Branquinha		Jatuarana	
	kg	(%)	kg	(%)	kg	(%)	kg	(%)	kg	(%)
2001	13,585	2	128,800	27	97,474	27	20,314	6	40,180	17
2002	73,201	13	45,396	10	56,650	16	19,870	6	36,688	16
2003	71,451	13	59,982	13	42,800	12	54,835	17	8,780	4
2004	39,973	7	38,675	8	36,818	10	67,746	21	11,346	5
2005	46,930	8	28,415	6	43,057	12	46,789	15	25,504	11
2006	59,952	11	50,422	11	20,171	6	29,073	9	76,593	33
2007	75,238	14	28,920	6	31,207	9	39,474	12	11,500	5
2008	62,258	11	18,809	4	5,724	2	5,793	2	10,538	4
2009	38,128	7	15,451	3	13,617	4	14,745	5	8,341	4
2010	75,492	14	59,194	12	16,909	5	20,158	6	5,424	2
Total	556,208	18,50	474,064	15,8	364,427	12,1	318,797	10,6	234,894	7,8

The pacu was the fish caught most frequently, with a total of 556,208 kg, corresponding to 18.5% of the total catch recorded in the present study (Figure 4). The second most frequent fish was the curimatã, with 474,064 kg (15.8%) of the total, followed by the jaraqui, with 364,427 kg (12.1%) of the total (Figure 4). The category "others" includes 47% of the total number of species, but contributed only 2.6% of the total catch. Overall, 1,0% of the total catch was made up of unidentified fish, for which the taxon could not be determined (Figure 4).

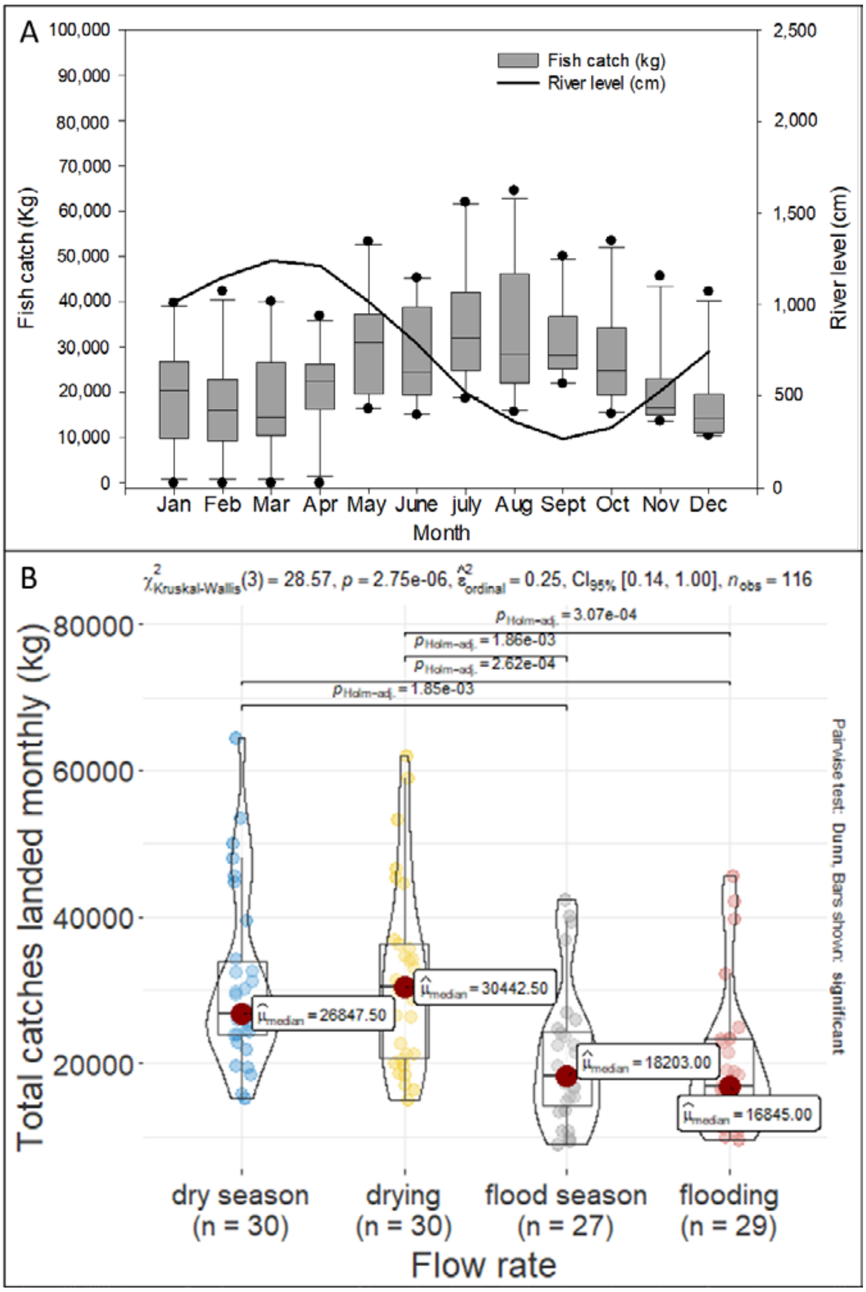
Figure 4. Total catch (in kg and %) of each fish species landed in the municipality of Humaitá (Amazonas, Brazil) between 2001 and 2010. Species that contributed less than 0.5% of the total catch are included in the "others" category. *Species not identified by the fishers, and not classified taxonomically.



The catches landed at Humaitá were influenced significantly (Kruskal-Wallis: $X^2 = 28,6$; $p < 0.001$) by seasonal fluctuations in the river level (Figure 5). The Spearman correlation analysis indicated a negative relationship between catches and the level of the Madeira River ($r = -0.32$; $p < 0.001$).

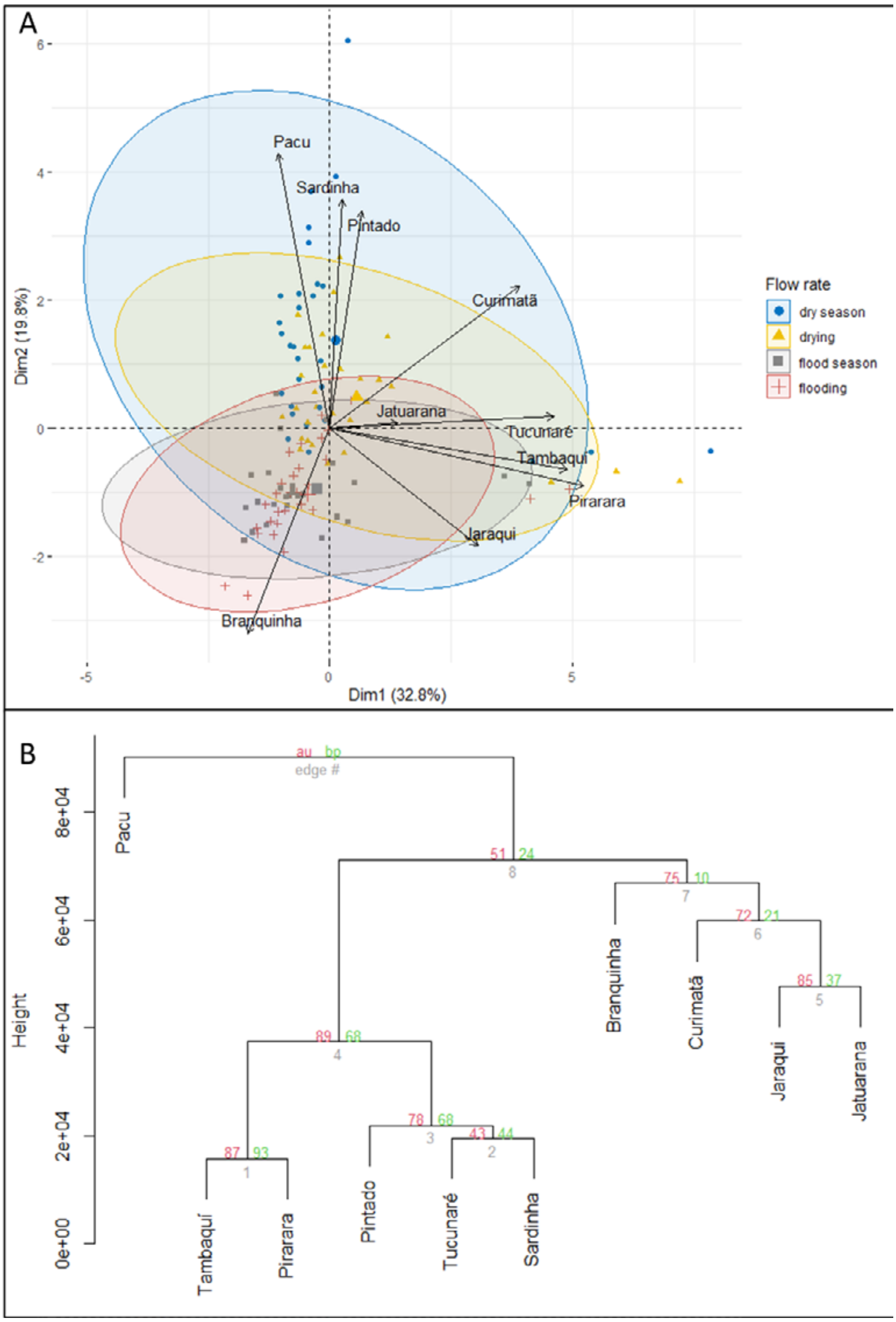
The box plot of monthly productivity (Figure 5) indicated that catches were largest between May and October, when the river reaches its lowest levels. This six-month period corresponds to 62% of the total catch. July and August were the most productive months, contributing 23% of the total catch. Catches decline from November onwards, following the increase in the level of the river in October and November, with reduced catches being recorded between November and March (Figure 5).

Figure 5. Box plot of the mean monthly (A) and by season (B) catches landed in the municipality of Humaitá (Amazonas, Brazil) between 2001 and 2010, and the mean monthly level of the Madeira River over the same period.



In the Principal Components Analysis (PCA), the first and second axes explained 52.5% of the variation in the data, with the first axis explaining 32.8% and the second, 19.8% (Figure 6A). The majority of the variation in the data was explained by the first principal component, reflecting the influence of dry and drying season on the fish catches. The second principal component is influenced primarily by the flood season and flooding periods (Table 2 and Figure 6A). The total amount of fish species also varied by season, as observed in pacu, curimatã, pintado and sardinha which were more caught during the dry or drying season, on the other hand species as jaraqui and branquinha were more caught in flood or flooding season. Some species seems not being deeply affected by the river seasonality, as tucunaré, jatuarana, pirarara and tambaquí.

Figure 6. A) Principal Components Analysis of fish catches in relation to the phase of the hydrological cycle (flood season, flooding, drying and dry season) between 2001 and 2010 in Humaitá (Amazonas, Brazil). B) Dendrogram of the cluster analysis (with p values) of the principal most commercialized fish species landed in the municipality of Humaitá (Amazonas, Brazil) between 2001 and 2010.



Tucunaré, jatuarana, pirarara and tambaqui were close related with axis 1, reflecting the relation among the catches of these species during the dry period. The production of the pacu, pintado and sardinha were highlighted on axis 2, which were more related with flood season (Figure 6A and Table 2).

Table 2. Principal Components Analysis of the fish species landed and most commercialized at Humaitá (Amazonas, Brazil).

Common name	Axis 1 (58.35%)	Axis 2 (30.94%)
Pacu	-0.104	0.542*
Curimatã	0.383	0.281
Jaraqui	0.299	-0.232
Branquinha	-0.165	-0.406
Jatuarana	0.138	0.010
Tambaquí	0.481*	-0.083
Pintado	0.064	0.428*
Pirarara	0.514*	-0.115
Tucunaré	0.454*	0.023
Sardinha	0.024	0.452*

* Values that had the greatest influence on the principal component.

The cluster analysis of the principal target species, based on Euclidean distance (Figure 6B) identified two distinct groups in the catches landed at Humaitá. The first group is formed by the species whose catches were influenced primarily by low river levels, such as tambaqui, tucunaré, sardinha, pintado, and pacu in a separated cluster. The second group was formed by branquinha, jatuarana and jaraqui which were influenced most by flooding periods. Some species presented a not well-defined pattern of catchment during the river season, such as pirarara.

Discussion

Fisheries play a number of prominent socio-economic and cultural roles in the Amazon region, providing an important source of revenue and employment, as well as being one of the principal sources of animal protein for local communities (Barthem and Goulding 2007). These roles are supported by the enormous diversity of the region's fish fauna, and the volume of annual catches (Costa et al. 2013; Santos et al. 2018).

Large catches of an ample diversity of fish species were recorded in the present study. This reflects a multi-species commercial fishery that targets a broad variety of fish types, and supplies local markets (Doria et al. 2018; Santos et al. 2020).

Multi-species fisheries are typical of tropical environments, which are characterized by high species richness and accentuated environmental heterogeneity (Hallwass et al. 2011; Begossi et al. 2019), but most of the catch was derived from the capture of a small number of Characiforms (Winemiller et al. 2016; Santos et al. 2018). Alcântara et al. (2015) obtained similar results in the municipality of Juruá, also in the Brazilian state of Amazonas, where a total of 50 fish species and 12 families were recorded. In other study on the Madeira River, Doria et al. (2012) recorded an even greater diversity, with 57 species and 18 families, although six fishing ports were monitored, representing a considerable increase in sampling effort.

This is consistent with the findings of fishery studies in the central Amazon basin, where the bulk of the production is provided by migratory Characiforms (e.g., Merona and Bittencourt 1988; Batista and Petrere 2003; Gonçalves and Batista 2008; Doria et al. 2012; Begossi et al. 2019). Cardoso and Freitas (2007) obtained similar results in the municipality of Manicoré, also in Amazonas, with emphasis on the production of jaraqui, followed by the pacu and curimatã, all characiforms. In the municipality of Juruá (Amazonas), Alcântara et al. (2015) recorded a predominance of the pacu (15.8% of the total catch), as well as in this present study.

The contribution of migratory fish to the catches landed at Humaitá accounts for the pronounced seasonality of the landing data. Amazonian fisheries are based primarily on migratory species (Barthem and Goulding, 2007; Doria et al. 2018; Santos et al. 2020), whose migrations are influenced by river levels or other effects also like climate, deforestation, overexploitation and dams (Duponchelle et al. 2021). In this context, it is important to note that the principal peaks in productivity were observed in August 2001 and July 2002, corresponding to the drying and the dry season in the study region. Santos, Ferreira and Val (2010) noted that, at low river levels, many migratory species form large shoals to migrate from the flooded forest to adjacent lakes and rivers (Santos et al. 2020). This concentration of shoals facilitates fishing (Barthem and Goulding 2007). Previous studies in the Amazon region (e.g., Alcântara et al. 2015; Batista and Pretere 2003; Doria et al. 2012) have produced similar results.

By contrast, the lower productivity recorded during the flood–flooding season months reflects the reduction in the concentration of shoals, as the fish disperse to the flooded forests, limiting fishery operations and reducing catches (Santos et al. 2020). It is important to note that the reduction in productivity recorded in Humaitá during the flood-flooding season period is also related to the closed season on the Madeira River. During this period, fishing is prohibited by federal law 11,959 of November 29th 2009 (Brasil 2009), in order to protect species during the spawning phase, which can be defined for a given species or a specific region. In the Brazilian state of Amazonas, the closed season is defined by the Amazonas State Environment Council (CEMAAM), and is generally applied between the months of November and March.

Despite the inverse relationship between river levels and productivity, peaks in catches were observed in some flood–flooding season periods. The increase in catches recorded during these periods are probably related to the reproductive migrations of some Characiforms, which spawn during the flood or flooding season period (Goulding 1979; Vazzoler and Menezes 1992; Lowe-mcconnell 1987).

In the present study, the PCA indicated that the peaks in productivity recorded during these periods may be related primarily to the catches of jaraqui, branquinha and jatuarana. Lowe McConnell (1987) established that Prochilodontidae, like the jaraqui, are part of a group of tropical species characterized by a short spawning season that occurs during the flood or at flooding period. Given this, the jaraqui is an important target species for the fisheries of the Madeira River during the flooding season period.

The mean annual catch recorded at Humaitá was greater than those recorded in other municipalities in the same region, such as Manicoré, in 2004 (Cardoso and Freitas 2007), and in Guajá-Mirim between 2001 and 2004 (Doria et al. 2012). However, productivity was relatively low in comparison with the historical series (1980–2004) from the Tenente Santana (Z1) fishing cooperative in Porto Velho, in the Brazilian state of Rondônia, analyzed by Doria et al. (2012). Differences in productivity among sites may be related to specific characteristics of the fishing cooperatives, such as the type of equipment used and the fishing grounds exploited. Differences in productivity may also be related to fishery effort and environmental variables (Santos et al. 2020; Duponchelle et al. 2021)

The seasonal variation in productivity was also confirmed by the cluster analysis, which identified one group (jaraqui, branquinha and jatuarana) influenced by high river levels, and a second group (sardinhas, tucunaré, pintado, pirarara and tambaqui), which was affected by low levels. Despite this, a third group, formed by the highest productive species, did not appear to be affected systematically by river levels (pacu). In this case, the data on the reproductive biology and population ecology of these species should be considered to ensure that the management models applied to the more productive, seasonal species, are not applied arbitrarily to the less productive species, which are also less seasonal.

In the present study, it was possible to identify a reduction in the productivity of some species and an increase in the relative importance of others, in dependency of the seasonality. Reductions in fish stocks and modifications of community structure have been recorded in the Amazon region in response to overfishing, deforestation, ranching, mining, and in particular, the constructions of hydroelectric dams (Santos et al. 2020). On the Madeira River in Rondônia (upstream from Humaitá), the recent construction of a major hydroelectric scheme has created considerable threats to the local fish fauna and fishing cooperatives (Santos et al. 2018). The Santo Antônio (construction initiated in 2008) and Jirau (initiated in 2010) dams were inaugurated in 2012 (Escada et al. 2013). Agostinho et al., (1999) found that dams alter the composition and abundance of the fish fauna profoundly, increasing the abundance of some species, while reducing that of others, or even driving them to extinction. The situation of migratory species is especially preoccupying, given their importance to the commercial fisheries of the Amazon basin, and the fact that they are the most threatened by dams, in particular the large-bodied catfish, which migrate the longest distances (Fearnside, 2015; Lima et al. 2020; Duponchelle et al. 2021). Commercially important species, such as the jatuarana, curimatã and jaraqui, which migrates longitudinally over long distances each year, may also be impacted intensively by the construction of dams (Van Damme et al. 2019; Hahn et al. 2020; Lima et al. 2020; Santos et al. 2020).

Given the dependence of fish on the seasonal fluctuations in river levels, climate change may represent an additional threat to Amazonian diversity, with knock-on effects for the economies of local communities (Doria et al. 2012). In the Amazon basin, cyclical climatic phenomena may accentuate fluctuations in water levels, with El Niño affecting the drying rates and low water levels, while La Niña events tend to provoke intense flooding (Bittencourt and Amadio 2007). Smolders et al. (2000) attributed the collapse of the curimatã fisheries on the Pilcomayo River in Bolivia to the El Niño events that occurred between 1990 and 1995.

This study provides an improved understanding of the influence of seasonality on a production of fish from the Madeira River basin, as well as accurately characterize the main species caught and landed in this region. The present study confirmed the hypothesis that the catches landed at Humaitá are affected by the level of the Madeira River. It was also possible to confirm that the fishers of the local cooperative practises multi-species commercial fishing. Finally, studies of fishing landings during historical series of capture data are fundamental and extremely important for understanding the fishing dynamics and the state of conservation of the ichthyofauna, in addition to contributing to the development of effective public policies for the management of fish and fish stocks, for the sustainability of this resource, in view of its great ecological, economic and cultural importance for the traditional communities of the Amazon.

Acknowledgments

We thank for tree anonymous reviewers. The Ecohydrology laboratory of the Centro de Formação em Ciências Ambientais-CFCAm/UFSB. The President of fishermen colony Z-31, Aulinei Malta de Carvalho and the Secretary, José Maria for their help in data collection and the effort to make available together the fishermen of Humaitá with the necessary information, turning this work possible.

Authors' contribution: FBZ - database, writing and revision; RS - data analysis, writing and revision; FMN - statistical analysis and writing; RF - database and writing.

Research authorization: does not apply.

Data availability statement: Supplementary dataset available.

Funding: No Funding.

Conflict of interest: The authors have no conflicts of interest to declare.

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