FISHING PRODUCTION OF *Pinirampus pirinampu* AND *Brachyplatystoma platynemum* CATFISH HAS BEEN AFFECTED BY LARGE DAMS OF THE MADEIRA RIVER (BRAZILIAN AMAZON)

Igor Rechetnicow Alves SANT'ANNA[1]*

Carlos Edwar de Carvalho FREITAS[2]

Raniere Garcez Costa SOUSA[3]

Hélio Daniel BELTRÃO dos Anjos[4]

Carolina Rodrigues da Costa DORIA[5]

[1] Universidade Federal de Rondônia – UNIR, Programa de Pós-Graduação em Desenvolvimento Regional e Meio Ambiente. Campus José Ribeiro Filho, Porto Velho, CEP: 76801-059, RO, Brazil. igorpaizao@outlook.com (*corresponding author)

[2] Universidade Federal de Amazonas – UFAM, Departamento de Ciências Pesqueiras. Bloco da Faculdade de Ciências Agrárias, Av. General Rodrigo Otávio Jordão Ramos, 6200, Coroado I, CEP: 69077-000, Manaus, AM, Brazil.

[3] Universidade Federal de Rondônia – UNIR, Departamento de Engenharia de Pesca, Campus de Presidente Médici. Rua da Paz, 4376, Lino Alves Teixeira, CEP: 76916-000, Caixa Postal 32, Presidente Médici, RO, Brazil.

[4] Universidade Federal de Amazonas – UFAM, Programa de Pós-Graduação em Ciências Pesqueiras nos Trópicos – PPG-CIPET. Av. General Rodrigo Otávio Jordão Ramos, 6200, Coroado I, CEP: 69077-000, Manaus, AM, Brazil.

[5] Fundação Universidade Federal de Rondônia – UNIR, Departamento de Biologia, Laboratório de Ictiologia e Pesca. Rod. BR 364, Km 9,5, CEP: 76801-059, Porto Velho, RO, Brazil.

ABSTRACT

The present study analyzed landing events of commercial fishing of two species of large catfish in 11 fish landing sites along the Madeira River, and temporally and spatially characterized the exploitation of these species before and after the closure of the Jirau and Santo Antônio hydroelectric dams. Our results show that the Madeira River dams have negatively affected the fishing production of *Pinirampus pirinampu* and *Brachyplatystoma platynemum* catfish, drastically reducing these species' harvest as well as the incomes of regional fishers. If the irreversible loss of these species of Amazonian catfish is to be avoided, public policies and measures for the management and sustainable handling of this fishery resource must be implemented urgently.

Keywords: artisanal fishing; fishery resources; Amazonian catfish; environmental impact.

PRODUÇÃO PESQUEIRA DOS BAGRES *Pinirampus pirinampu* E *Brachyplatystoma platynemum* É AFETADA POR GRANDES BARRAGENS NA BACIA DO RIO MADEIRA (AMAZÔNIA BRASILEIRA)

RESUMO

O presente trabalho analisou o desembarque pesqueiro comercial de duas espécies de grandes bagres, em 11 pontos de desembarque ao longo do rio Madeira, caracterizando a exploração temporal e espacial dessas espécies antes e depois do fechamento das hidrelétricas de Jirau e Santo Antônio. Os resultados mostraram que os barramentos do rio Madeira têm impactado de forma negativa a produção pesqueira dos bagres *Pinirampus pirinampu* e *Brachyplatystoma platynemum* diminuindo drasticamente a o desembarque de seu estoque e reduzindo a receita dos pescadores na região. Políticas públicas para a gestão e manejo sustentáveis desse recurso pesqueiro devem ser concretizadas com urgência para evitar a perda irreversível desses bagres amazônicos.

Palavras-chave: pesca artesanal; recursos pesqueiros; bagre amazônico; impacto ambiental.

INTRODUCTION

In the Amazon, artisanal fisheries commercially exploit several medium and large size fish species (Berkers et al., 2006). These fish species can be found in fishing markets throughout the basin's rivers (Barthem and Goulding, 2007; Cardoso and Freitas, 2008; Lopes et al., 2016). As the largest tributary of the Amazon River, the Madeira River is home to 57 categories of species that have been identified as fish tagged for trade in different fishing landing sites (Doria et al., 2012). However, in river ports within the state of Rondônia, most of the recorded catches include only 7 to 12 fish species (Doria et al., 2010; Lima, 2017).

The construction of hydroelectric dams has caused widely recognized impacts on geomorphology, thermal regime, flow regime and other physicochemical and biological characteristics that shape local aquatic ecosystems, and drive fish diversity, composition, distribution and abundance (Agostinho et al., 2008; Kirchherr and Charles, 2016). In the Madeira River, the natural water level variations determine the life cycle of commercially

important fish species, thus affecting artisanal fishing, as such, the anthropic interference of hydroelectric power generators that can threaten fish production and consequently livelihoods (Isaac et al., 2016; Lima et al., 2017; Almeida et al., 2020). Among these species are two migratory catfish, the "barba chata" catfish (*Pinirampus pirinampu*, Spix & Agassiz 1829) and the "babão" catfish (*Brachyplatystoma platynemum*, Boulenger 1898). The *P. pirinampu* is a large catfish in the Pimelodidae family and has medium distance migratory behavior and is distributed throughout the tropical region of South America (Barthem and Goulding, 2007). Its maximum size can vary from 60 (Santos et al., 2006) to 75 cm (Agostinho and Júlio Junior, 1999). It has large barbels (Lauzanne and Loubens, 1985) and an adipose fin that starts after the dorsal and runs almost to the caudal fin (Queiroz et al., 2013). This species is important in the Madeira basin, where it represented 2.1% of total landings between 1990 and 2014 and is considered one of the key species (Lima, 2017; Lima et al., 2020).

The *B. platynemum* is a large fish of up to 1 meter in length, has a depressed head, small eyes and large, flat wattles, with a bluish gray color on the back and yellow on the belly (Santos et al., 2006). It is a carnivorous fish and feeds on fish and invertebrates. This species is also important in the Madeira basin, where it represented between 1.0 and 3.6% of total landings before the construction of two hydroelectric dams in the Brazilian portion of the Madeira basin (Doria et al., 2018). Both the aforementioned fish have been identified as sales leaders, besides commanding the highest market prices in the region (Doria et al., 2016).

Studies of migratory catfish landings are important for the management of their fisheries and help to verify the possible impacts of overfishing and habitat loss resulting from the construction of large hydroelectric plants in the Amazon Basin (Doria et al., 2018). These constructions result in the disruption and modification of the bioecology along large river stretches and making these environments unsuitable for fish species whose migration and reproduction processes rely on the lotic environment and on the presence of rapids (Fearnside, 2013).

Current management strategies of Amazonian fisheries have largely ignored the knowledge of local and indigenous fishers, and this knowledge may be an important component in the assessment and management of fisheries, especially for tropical fisheries that lack data on fish production and other aspects related to riverine communities (Villas-Bôas et al., 2015; Doria et al., 2017). The extent of the impact these dams on the bioecology of migratory fish species is still poorly understood and emphasizes the need for studies that provide information on the exploitation of local fishing stocks in these situations.

With the aim of understanding the status of *P. pirinampu* and *B. platynemum* fisheries before and after the installation of the Jirau and Santo Antônio dams, both located on the Madeira River, this study analyzed the commercial landing of these fish species in eleven fishing landing sites between the municipalities of Humaitá (Amazonas state) and Guajará-Mirim (Rondônia state). It thus tests the hypothesis that there have been no changes in the production values of either catfish species associated to restriction of the river due to the completion of the dams.

MATERIAL AND METHODS

Study area

The Madeira River is the largest tributary of the Amazon River in terms of area, flow and sediment transport. It flows 1.4 million km^2 through Brazil, Bolivia and Peru (Latrubesse et al., 2005). With a transnational extension, its main tributaries are the Beni River in Bolivia and the Mamoré River in Brazil (Goulding et al., 2003).

Since the 1980s, some regions of the Madeira River have been studied and identified for hydroelectric potential (Eletrobras, 1987). Among the river's 18 waterfalls, two stood out, namely the Santo Antônio and Caldeirão do Inferno waterfalls. These two waterfalls are currently flooded after the construction of the Santo Antônio and Jirau hydroelectric power plants on the Madeira River. The energy production of these plants began in September 2011 and November 2012, respectively (Doria et al., 2015).

The data used in this research were collected in the Madeira River region by the Laboratório de Ictiologia e Pesca – LIP/UNIR, during the Fishing Activity Monitoring Program (in Portuguese, *Programa de Monitoramento da Atividade Pesqueira*), and was made possible by an agreement between Santo Antônio Energia – S.A. and UNIR, which began in April 2009 and ending in August 2013. The fishery landing sites selected for this study were cities located on the banks of the Madeira River (Figure 1), as well as riverine communities with fishery landings (Table 1).

In 2009, there were 1,200 registered fishermen across this region. The fishing fleet consisted mostly of small wooden fishing vessels (non-motorized and motorized canoes totalled more than 1,000 units) and a few fishing boats (Doria et al., 2018). Non-motorized and motorized wooden vessels (average length 5.8 m) are used for fishing and for transporting fish. Non-

Table 1. Landing sites cities and geographic coordinates selected for study.

| Landing sites	Geographic coordinates
Cities	
Abunã	09°41'58.1"S - 65°22'08.7"W
Nova Mamoré	10°24'26.7"S - 65°20'06.9"W
Guajará-Mirim	10°47'33.1"S - 65°20'53.8"W
Jaci-Paraná	09°15'37.1"S - 64°23'43.6"W
Porto Velho	08°46'11.62"S - 63°54'32.27"W
Humaitá	07°30'22"S - 63°01'38"W
Riverine communities	
Cachoeira do Teotônio (Vila Amazonas)	8°51'39.65"S - 64°03'43.91"W
São Sebastião (Novo Engenho Velho)	8°46'08.75"S - 63°55'21.03"W
Nazaré (Boa Vitória)	08°14'03.4"S - 63°19'12.1"W
São Carlos	08°25'35.58"S - 63°27'42.12"W
Calama	08°01'46.4"S - 62°52'39.4"W
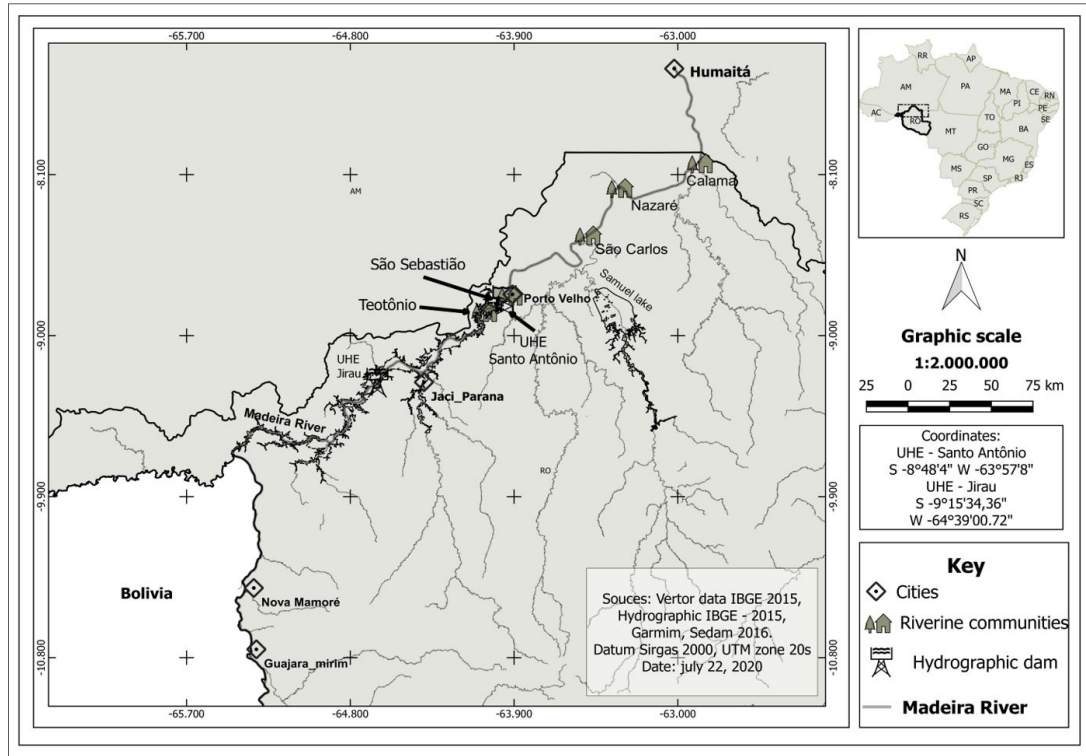
Figure 1. Location of the eleven fishery landing sites analyzed along the Madeira River.

motorized canoes are normally smaller than motorized canoes and have less storage capacity (250 and 600 kg, respectively). Larger fishing boats are motorized (average size 9 m ± 2.3 m), with larger storage capacity (on average 2,500 kg) and mainly use ice for fish conservation (Doria et al., 2015).

Data collection

Data consisted of daily records of fish landings, obtained by structured questionnaires that included the following variables: total production of *P. pirinampu* and *B. platynemum* in kilograms (kg); fishing gear employed; fishing grounds and operating costs. The lists of equipment identified in the landings of two species were as follows: cast net (*tarrafa*), longline (*grozeira*), longline (*espinhel*), fishing rod (*caniço*) handline (*linha-de-mão*), *covi* (a conical, submersible fishing device made of metal-mesh), combined equipment and fiber and cotton gillnets (*caçoeira*). These items are also described in Sant'Anna et al. (2015). The results correspond to two study periods: pre-damming (from April 2009 to September 2011), and the second, post-damming (from October 2011 to August 2013). The water level data from the Madeira River at the Porto Velho station were obtained using the hydrological information system of the National Water Agency (www.hidroweb.ana.gov.br).

Data analysis

The Kruskal Wallis non-parametric test on the monthly average values in fishing landings between the hydrological cycle of the different seasons, during the pre-damming and post-damming periods was assessed. The choice of this test was made based on the result of the analysis of normality and homoscedasticity of the data, carried out using the Shapiro Wilk and Levene tests, respectively. This statistical test was performed with the aid of the Statistica 7.1 software and the significance level adopted was $p < 0.05$. A serial correlation test was performed with standardized errors between the variables for fishing production (y) and the hydrological level of the Madeira River (x) for the pre-damming and post-damming periods.

Fishery output were assessed by a non-parametric test of catch history. The Mann–Kendall test for monotonic trend detection was also applied to determine fish production trends pre- and post-dam construction. This statistical analysis was performed using *R* 2.14.1 software (R Core Team, 2018).

A correspondence analysis (CA) was also used to study the production of both catfish species and the fishing gear employed, according to river water level seasonality of the Madeira River and the pre- and post-damming periods.

The variation in gross revenue and purchasing power of fishermen was calculated using the values of landed fish production and their respective sales prices that prevailed during the pre- and post-damming periods of the Madeira River. The Mann–Whitney non-parametric test for the comparison of averages in independent samples was performed to compare the prices of the *P. pirinampu* and *B. platynemum* for pre- and post-damming periods.

RESULTS

Fish production versus seasonal water level

Landings of *P. pirinampu* and *B. platynemum* were recorded in the eleven fish landing sites. A 133.5 tonnes production of *P. pirinampu* catfish (8.8% of the total production) was recorded in the period prior to damming of the Madeira River (herein after referred to as pre-damming). This species was among the top five productions. In the post-dam period (herein after referred to as post-damming), production reached 1.98 tonnes (0.5%). On the other hand, *B. platynemum* production reached 24.5 tonnes pre-damming (1.6%), and 1.2 tonnes (0.3%) post-damming.

The catch distribution for *P. pirinampu* peaked during the drought and rising water level (pre-damming). Therefore, for the *B. platynemum,* the highest productive output occurred during the flood water seasons in the pre-damming. During post-damming, species production output was lower for both fish species and presented a fishery production close to zero during the drought phase (Figure 2).

In the pre-damming period, significant average fish production for *P. pirinampu* occurred between the four seasons of the hydrological cycle (Kruskal-Wallis: H = 15.233; df = 29; p<0.05), which also occurred for *B. platynemum* (Kruskal-Wallis: H = 15.515; df = 29; p<0.05). In the post-damming period, *P. pirinampu* (Kruskal-Wallis: H = 8.753; df = 22; p<0.05) and *B. platynemum* (Kruskal-Wallis: H = 8.990; df = 22; p<0.05) showed significant difference in production between the seasons of hydrological cycle. On the other hand, when observing the linear regression, despite presenting a negative slope, which indicates that the higher the river level, the lower the fish production, no correlation was observed, $R^2 = 0.09$; $p = 0.089$, between the variables for fishery production (y) and the hydrological level of the Madeira River (x) in the pre-damming period (Figure 3A). There was a positive correlation, $R^2 = 0.43$; $p<0.05$, between these variables in the post-damming period, when fishery production came close to one ton (Figure 3B). The Mann-Kendall test did not reveal a significant trend (p>0.05) in relation to the values of fishery production for *P. pirinampu* (Pre: τ = - 0.14 and Post: τ = 0.20) and for *B. platynemum* (Pre: τ = 0.11 and Post: τ = - 0.24).

Catfish production according to locality and fishery equipment

During the pre-damming period, the location with the largest landings of *P. pirinampu* was Cachoeira do Teotônio (Teotônio Waterfall), with a production of approximately 122 tonnes (91.7%), followed by Humaitá, with 5 tonnes (3.9%). The total landed in the other fishing ports accounted for 4%. Cachoeira do Teotônio was also the place with the highest production of *B. platynemum*, and reached 13 tonnes (32%), followed by Humaitá, with approximately 4 tonnes (18%). The other localities produced a total of 5.5 tonnes (23.6%).

During the post-damming period, production of each species showed a different trend. Humaitá became the greatest producer of *P. pirinampu*, with 0.7 tonnes (33.3%), followed by Jaci Paraná with 0.5 tonnes (25.7%). The other fish landing sites

totaled 0.8 tonnes (41%). The catches of *B. platynemum* were also greater in Humaitá and Guajará-Mirim; both fish landing sites attained production of 0.3 tonnes (23%), with the other landing sites totaling 0.7 tonnes (55%).

Among the fishing gear used to catch *P. pirinampu* and *B. platynemum* during the pre-damming period, three were responsible for 88% and 64% of production, respectively. The most
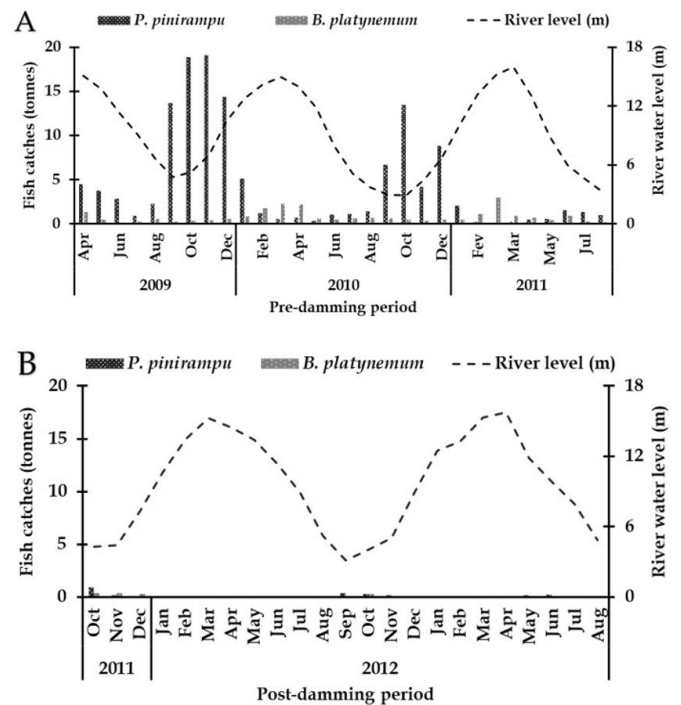

Figure 2. Monthly production of *Pinirampus pirinampu* and *Brachyplatystoma platynemum* for the "pre-damming" (A) and "post-damming" (B) periods, in tonnes (t), according to seasonal water levels of the Madeira River.
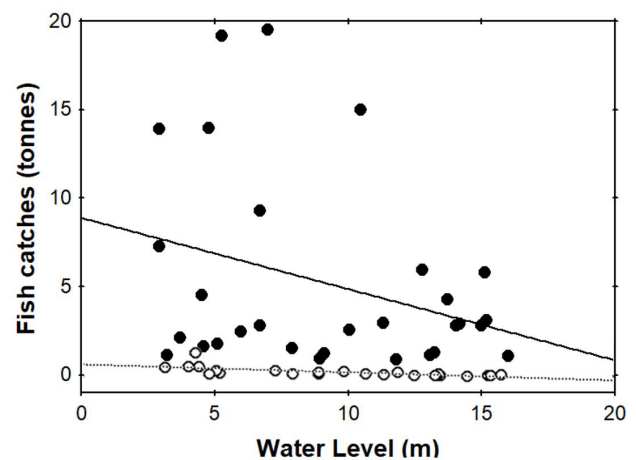

Figure 3. Fishery production of *Pinirampus pirinampu* and *Brachyplatystoma platynemum* in relation to Madeira River water levels, pre-damming (●) and post-damming (○) with the Jirau and Santo Antônio dams.

common gear used for catching *P. pirinampu* were cast nets (*tarrafas*), longlines (*grozeira*) and handlines (*linha-de-mão*) (Table 2). For catching *B. platynemum*, the most often employed were cast nets, *covi* (a conical, submersible fishing device made of a metal mesh) and gillnets made from fiber (*malhadeira de fibra*) (Table 3).

Fishing gear such as cast nets, longlines and handlines were the most used in Cachoeira do Teotônio, and resulted in the greatest production of *P. pirinampu*. In the same region, the cast net and the *covi* were associated with the greatest production of *B. platynemum*. In addition, the fiber gillnet was responsible for the largest captures of this species in the Humaitá region.

In the post-damming period, the fiber gillnet was the most used device, accounting for 70% of *P. pirinampu* production. The fiber gillnet also had a large participation in Humaitá's fisheries, followed by Jaci-Paraná, whose production using this device was the second greatest. The device was also the most used by the fisheries in the Santo Antônio hydroelectric reservoir area. The fiber gillnet also became the most used device in the production of *B. platynemum*, responsible for 62.7% of catches in Guajará-Mirim and nearby communities (Table 3).

Correspondence analysis explained 87.65% of the variance in fishery data, distributed among dimensions 1 and 2 of the projection graph (Figure 4). In dimension 1 (64.77% inertia), *P. pirinampu* was grouped on the left part of the graph, linked to the hydrological cycle of flood and drought and to cast net, handline and longline (*grozeira*). The *B. platynemum* was placed on the right side of the plot. However, regards to this species, there was a clear productive separation in respect to equipment preference and hydrological seasons, distributed mainly among dimension 2 (22.88% inertia). Production during the flood season appears in upper-right part of the graph, linked to the *covi*, while the bottom-right part concentrates the catches made during the drought phase using various types of equipment such as the cotton gillnet, the fiber gillnet, and the gillnet (*caçoeira*).

In the pre-damming period, dimension 2 represents a grouping of *B. platynemum* catches during the flood phase, concentrated on the top of the chart, with catches during the drought phase appearing on the bottom part. In the post-damming period, the same dimension groups the catches of the same species during both the flood phase and the drought phase and appear on the bottom part of the graph. The species *P. pirinampu* was separated into opposite poles of the plot, depending on the seasonality of fishery water levels. Production was greatest during the drought, as seen in the upper left of the projection – with cast nets (Casn), handlines (HdL) and (*grozeira*) longlines (Lon) appearing separated – while lowest during the flood, as seen in the bottom right of the projection – with cotton and fiber gillnets appearing separated (Figure 4).

Gross revenue and price according to landing location

In the pre-damming period, *P. pirinampu* fisheries presented a total gross revenue of R$ 350,367.36 (US$ 197.947,66). However, in the post-damming period, the fisheries' gross revenue was R$ 173,210.57 (US$ 85.325,40). *Brachyplatystoma platynemum* landings

Table 2. Production *Pinirampus pirinampu* by type of fishing equipment, in the pre-damming and post-damming periods of the Madeira River. (-) = No records available.

| Equipments | *P. pirinampu* – production (kg) | | | |
	Pre-damming	(%)	Post-damming	(%)
Cast net	52,512.2	39.7	467	15.2
Longline (*grozeira*)	50,198.5	37.9	46.4	1.5
Handline	12,665.5	9.6	185.2	6.0
Fiber gillnet	5,198.7	3.9	2,159.5	70.1
Longline (*espinhel*)	3,153.7	2.4	71.0	2.3
Cotton gillnet	2,105.7	1.6	-	-
Combined equipment	510	0.4	-	-
Gillnets (*caçoeira*)	316	0.2	58.0	1.9
Other equipment	5,700.5	4.3	92.0	3.0

Table 3. Production *Brachyplatystoma* platynemum according to fishing equipment, in the pre-damming and post-damming periods in Madeira River. (-): No records available

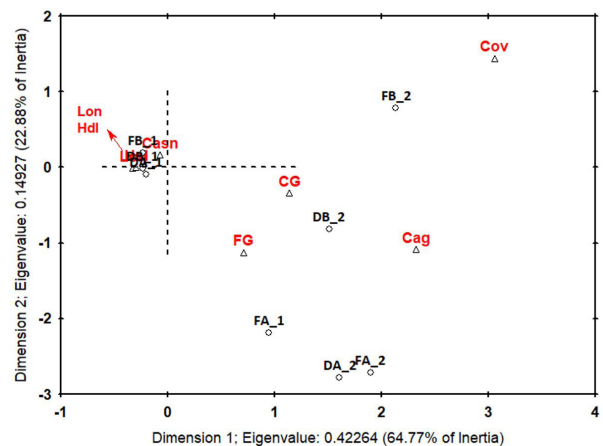| Equipments | *B. platynemum* – production (kg) | | | |
	Pre-damming	(%)	Post-damming	(%)
Cast net	6,553.5	27.9	-	-
Covi	4,649	19.8	-	-
Fiber gillnet	2,478	10.5	1,372.6	62.7
Gillnets (*caçoeira*)	2,400	10.2	572.2	26.1
Cotton gillnet	2,217.4	9.4	22.0	1.0
Trident	477	2.0		
Longline (*grozeira*)	400.3	1.7	118.1	5.4
Handline	286.2	1.2	36.8	1.7
Other equipment	4048.2	17.2	69.0	3.1

Figure 4. Correspondence analysis of each device's influence on the studied catfish throughout the phases of the hydrological cycle, for the pre-damming (B) and post-damming (A) periods. 1 = *Pinirampus pirinampu*, 2 = *Brachyplatystoma platynemum*. "F" = Flood season, "D" = Drought season. Red letters indicate the fishery equipment used. Cast net – Casn; Handline – LdM; longline (*grozeira*) – Lon; *covi* – Cov; cotton gillnet – CG; the fiber gillnet – FG; gillnet (*caçoeira*) – CaG.

produced a gross revenue of R$ 82,068.93 (US$ 46.366,63) in the pre-damming period. This number decreased to R$ 24,371.00 (US$ 12.005,42) in the post-damming period. The average price during the pre-damming for *P. pirinampu* was R$ 3.26 (US$ 1.80) and for *B. platynemum* was R$ 4.60 (US$ 2.23), but in the post-damming period, prices were R$ 4.27 (US $ 2.07) and R$ 6.43 (US $ 3.12), respectively.

DISCUSSION

The construction of dams in the region of the middle Madeira River caused drastic changes in the production and fishing of *P. pirinampu* and *B. platynemum*, and production after construction corresponds to around 10% of what it was before. The fish production was greater in the drought season and also shows peaks in landings in the hydrological levels of the rising and flood periods. The diversity of equipment was much greater previously, as well as the level of income achieved by fishers.

Fisheries in the Madeira River region are classified as small-scale artisanal fishing and present traits common to fishing activities conducted in other areas of the Amazon basin, such as being multi-species, multi-equipment and seasonal (Doria et al., 2012). Hydrological seasonality interferes with the total production and catch composition of fish species, since fish stocks are synchronized with river water level variations due to their migratory reproduction and dispersal processes (Garcez et al., 2017; Lima et al., 2017). Meanwhile, fishers demonstrate knowledge of the fishing environment and adapt to these variations to succeed in their livelihood (Isaac et al., 2015; Garcez et al., 2017).

The influence of water seasonality on fishery activity in the Amazon basin directly interferes with catches from local fishery stocks. An example of this complexity of interactions in fishery activity is the lower fishery production during months when river levels are highest and fish assemblages are highly dispersed throughout flooded environments (Garcez et al., 2017). The opposite occurs during the receding and drought phase, leading to greater production (Garcez et al., 2017). For the fishing of large catfish in the Madeira River, however, this seasonal phenomenon presents variations: fish production also goes through spikes during the rising and flood periods, when catfish migrate upstream to reproduce (Cella-Ribeiro et al., 2016).

Higher yields of big catfish on the Madeira River generally occurred in areas restricted by natural barriers, such as Cachoeira do Teotônio, seen as a distinct fishing area. Thus, more than 90% of landings of *P. pirinampu* and 60% of landings of *B. platynemum* came from this locality. However, catfish fishing required the use of various types of equipment at different stages of the hydrological cycle, a phenomenon seen both at Cachoeira do Teotônio (Sant'Anna et al., 2015) and other fishery landing sites within this study's area (Doria et al., 2015).

Prior to dam construction, three types of fishing operations accounted for most of the production of large catfish stocks in the study area. After the dam construction, due to the considerable loss of fishing areas and changes in the Madeira River's water level dynamics, only the gillnet stood out in the production of captured fish, being responsible for the catches of more than 80% of the total produced fish.

Fishers specializing in catching large catfish in the Madeira River operated especially in Cachoeira do Teotônio and in the Madeira river's main channel, near Humaitá, where they also used other equipment, albeit in lesser quantity and frequency. These included the (*caçoeira*) gillnet, the longline (*espinhel*), the cotton gillnet, the fiber gillnet, the trident, the fishing rod (*caniço*) and the handline (Doria et al., 2015).

In the Cachoeira do Teotônio region, fishermen used cast nets in pond channels formed by the slower current in the central part of the Madeira River channel. This activity usually took place on specific fishing grounds, such as granite slabs (rock islands) or on rock banks with rapids. Prior to dam construction, fishing with cast nets in Cachoeira do Teotônio was productive, especially during the receding, drought and flood of the hydrological cycle (in the first month of rising water, when fish migrated upstream). However, the (*grozeira*) longline was also used predominantly during drought, especially in areas with less severe currents, as it allowed the fisherman to selectively capture larger fish, since individuals were confined in smaller puddles, thus making them easier to catch.

Currently, one of the main problems for the sustainability of large migratory catfish fisheries in the Amazon basin is the construction and operation of hydroelectric dams along the main channels of its largest tributaries, restricting the reproductive and trophic migrations of fish species that live in or utilize the flood basin's aquatic environments as a migratory route (Gubiani et al., 2011; Winemiller et al., 2016). Recent records indicate a decrease in the amount of fish able to cross these barrages (Hauser et al., 2019), which is reflected in the decrease seen in records of fish production reported in the fishery landing sites, especially in upstream regions of these enterprises (Damme et al., 2019). This has been a direct source of harm to small-scale fisheries, which are traditionally responsible for maintaining the supply of animal protein in the riverine communities of the study area (Fearnside, 2013; Lima et al., 2017; Santos et al., 2018).

The impacts of dams on the ichthyofauna and on the decline of important commercial species have also been observed in other aquatic ecosystems around the world (Agostinho et al., 2008; Dugan et al., 2010; Assis et al., 2017). For example, a study of the effects of the Tallowa Dam on the Shoalhaven River (Southeast Australia) found a reduction in the abundance of four migratory fish species and the possible extinction of another ten fish species (Gehrke et al., 2002).

Torrente-Vilara et al. (2011) stresses the relevance of waterfalls in river rapids, especially Jirau and Teotônio, which function as important environmental filters for the local fish fauna, currently blocked by the construction of the Madeira River hydroelectric generators. Some species can surpass waterfalls, others are limited by them; generally speaking, however, fish species compositions differ above and below waterfalls. Moreover, when constructed differently from the proposed model (which imitates the environmental filter), transposition systems lack ecological efficiency in the migration of species that should cross the dams, facilitating upstream invasion of undesirable species

that historically live downstream. Thus, this results in a change in the composition and abundance of commercial fishing target species, especially migratory species, as has been observed in the Brazilian portion of the Amazon basin (Doria et al., 2018).

Furthermore, the change in the aquatic environment caused by the Madeira River dams – linked to decreased production of *P. pirinampu* and *B. platynemum* – is already reflected in the sale prices of these fish species. The values observed during the study were already around 50% higher in 2014 (Lima et al., 2020), as ascertained in markets within the study area. This is explained by the impacts of the barrages on the ecological process of large catfish migrations, which are highly dependent on the Amazon's hydrographic ecosystem. Both dams abruptly changed landing quantities and the supply of fish to the market, immediately leading to an increase in price per kilo of the species under study (Lima et al., 2020).

The largest catfish production recorded in the landings presented here occurred in communities to which fishers were relocated, due to the implementation of the Santo Antônio hydroelectric power plant, which significantly changed the fishing scenario in the region. Moreover, production levels tend to decrease even further, due to the drastic reduction of catfish stocks, among other species, in the short term. This has already been confirmed in a study by Lima et al. (2020), with the authors identifying a multi-species catfish biomass reduction starting in 2011. Given the importance of these catfish as fishery resources throughout the Amazon basin, any reduction in their fishing populations will cause social and ecological impacts far beyond the boundaries of the Madeira River basin (Barthem et al., 2017). Unsurprisingly, in the Madeira River region in the municipality of Porto Velho, more than 5,000 families affected by the construction of the two dams have submitted legal complaints. These riverine communities were not included in the government's mitigation and compensation process, and as a result suffered great economic losses and irreparable social damage (Fearnside, 2016). According to the "Ten-Year Energy Plan" (Brasil, 2020) that contemplates 10 years of expansion of the energy sector in Brazil, three hydroelectric plants are already in the process of implantation in the Brazilian Amazon, in the states of Rondonia, Roraima and Mato Grosso. Together, the three hydropower plants will generate a total of 240 megawatts.

In a study on the visibility of fisheries in the process of hydropower development in the Amazon, Doria et al. (2017) showed the absence of public awareness-raising and impact-mitigating activities (social, economic, and environmental) among riverine populations. This has made it difficult to make more assertive decisions, especially to tackle the problems of fishery activities in the Madeira river basin in an environment marked by the deterioration of some fish stocks.

CONCLUSIONS

The magnitude and scope of the dams' impacts on small-scale fisheries, notably those related to changes in production and landings of *P. pirinampu* and *B. platynemum* species in the post-dam construction period, affect the migration of these two fish species, especially due to their difficulty in surpassing the dams to reach upstream areas. In this context, public policies for the management of *P. pirinampu* and *B. platynemum* should be urgently carried out and give priority to the sustainability of this fishery resource, considering its great cultural, economic and ecological importance to riverine communities.

REFERENCES

Agostinho, A.A.; Júlio Junior, H.F. 1999. Peixes da bacia do alto rio Paraná. In: Lowe-McConnell, R.H. (Ed.). Estudos ecológicos de comunidades de peixes tropicais. São Paulo: EDUSP. p. 374-400.

Agostinho, A.A.; Pelicice, F.M.; Gomes, L.C. 2008. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. Brazilian Journal of Biology = Revista Brasileira de Biologia, 68(4): 1119-1132. **http://dx.doi.org/10.1590/S1519-69842008000500019**.

Almeida, R.M.; Hamilton, S.K.; Rosi, E.J.; Barros, N.; Doria, C.R.C.; Flecker, A.S.; Fleischmann, A.S.; Reisinger, A.J.; Roland, F. 2020. Hydropeaking operations of two run-of-river mega-dams alter downstream hydrology of the largest Amazon tributary. Frontiers in Environmental Science, 8: 120. **http://dx.doi.org/10.3389/fenvs.2020.00120**.

Assis, D.A.S.; Dias-Filho, V.A.; Magalhães, A.L.B.; Brito, M.F.G. 2017. Establishment of the non-native fish *Metynnis lippincottianus* (Cope 1870) (Characiformes: Serrasalmidae) in lower São Francisco River, northeastern Brazil. Studies on Neotropical Fauna and Environment, 52(3): 228-238. **http://dx.doi.org/10.1080/01650521.2017.1348057**.

Barthem, R.B.; Goulding, M. 2007. Um ecossistema inesperado: a Amazônia revelada pela pesca. Belém: Amazon Conservation Association (ACA), Sociedade Civil Mamirauá. 241p.

Barthem, R.B.; Goulding, M.; Leite, R.G.; Cañas, C.; Forsberg, B.; Venticinque, E.; Petry, P.; Ribeiro, M.L.D.B.; Chuctaya, J. 2017. Goliath catfish spawning in the far western Amazon confirmed by the distribution of mature adults, drifting larvae and migrating juveniles. Scientific Reports, 7: 1-13. **http://dx.doi.org/10.1038/srep41784**.

Berkers, F.; Mahon, R.; McConney, P.; Pollnac, R.; Pomery, R. 2006. Gestão de pesca de pequena escala: diretrizes e métodos alternativos. In: Kaliskoski, D.C. (Ed.). Rio Grande: Ed. UFRG. 359p.

Brasil, 2020. Consolidação dos resultados. In: Brasil, Ministério de Minas e Energia, Empresa de Pesquisa Energética. Plano decenal de expansão de energia 2029. Brasília: MME/EPE. Available from: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-423/topico-490/11%20Consolida%C3%A7%C3%A3o%20dos%20Resultados.pdf> Access on: Jul. 17, 2020.

Cardoso, R.S.; Freitas, C.E.C. 2008. A pesca de pequena escala no rio Madeira pelos desembarques ocorridos em Manicoré (Estado do Amazonas),

Brasil. Acta Amazonica, 38(4): 781-788. **http://dx.doi.org/10.1590/ S0044-59672008000400024**.

Cella-Ribeiro, A.; Lima-Filho, J.A.; Röpke, C.P.; Hauser, M.; Silva, T.M.; Fonseca, M.L.; Torrente-Vilara, G. 2016. Catálogo de informações biológicas de peixes do rio Madeira. In: Cella-Ribeiro, A.; Torrente-Vilara, G.; Lima-Filho, J.A.; Doria, C.R.C. (Eds.). Ecologia e biologia de peixes do rio Madeira. Porto Velho: Edufro. p. 56-78.

Damme, P.A.V.; Córdova-Clavijo, L.; Baigún, C.; Hauser, M.; Doria, C.R.C.; Duponchelle, F. 2019. Upstream dam impacts on gilded catfish *Brachyplatystoma rousseauxii* (Siluriformes: Pimelodidae) in the Bolivian Amazon. Neotropical Ichthyology, 17(4): e190118. **http:// dx.doi.org/10.1590/1982-0224-20190118**.

Doria, C.R.C.; Athayde, S.; Marques, E.E.; Lima, M.A.L.; Dutka-Gianelli, J.; Ruffino, M.L.; Kaplan, D.; Freitas, C.E.C.; Isaac, V.N. 2017. The invisibility of fisheries in the process of hydropower development across the Amazon. Ambio, 47: 453-465. **http://dx.doi.org/10.1007/ s13280-017-0994-7**.

Doria, C.R.C.; Duponchelle, F.; Lima, M.A.L.; García-Vasquez, A.; Carvajal-Vallejos, F.; Mendez, C.C.; Freitas, C.E.C.; Vega, B.; Miranda-Chumacero, G.; Damme, P.A.V. 2018. Review of fisheries resource use and status in the Madeira river basin (Brazil, Bolivia, and Peru) before hydroelectric dam completion. Reviews in Fisheries Science & Aquaculture, 26(4): 594-514. **http://dx.doi.org/10.1080/23308249.2018.1463511**.

Doria, C.R.C.; Lima, M.A.L.; Brasil-de-Souza, S.T.; Neto, L.F.M. 2015. A pesca artesanal comercial e de subsistência na bacia do rio Madeira, porção brasileira. In: Doria, C.R.C.; Lima, M.A.A.L. (Eds.). Rio Madeira: seus peixes e sua pesca. 1ª ed. Porto Velho: EDUFRO. v. 1, p. 33-50.

Doria, C.R.C.; Lima, M.A.L.; Lima, H.M.; Sant'Anna, I.R.A.; Monteiro-Neto, J.M. 2010. Monitoramento da Atividade Pesqueira no rio Madeira. In: Doria, C.R.C.; Leite, R.G.; Röpke, C.P.; Queiroz, L.J. (Eds.). Relatório técnico anual: programa de monitoramento e conservação da ictiofauna do rio Madeira. Porto Velho: Convênio SAE/UNIR/RIOMAR. 215p.

Doria, C.R.C.; Machado-Neto, L.F.; Brasil-de-Souza, S.T.; Lima, M.A.L. 2016. A pesca em comunidades ribeirinhas na região do médio rio Madeira, Rondônia. Novos Cadernos NAEA, 19(3): 163-188. **http:// dx.doi.org/10.5801/ncn.v19i3.2499**.

Doria, C.R.C.; Ruffino, M.L.; Hijazi, N.C.; Cruz, R.L. 2012. A Pesca comercial na bacia do Rio Madeira, estado de Rondônia, Brasil. Acta Amazonica, 42(1): 29-40. **http://dx.doi.org/10.1590/S0044-59672012000100004**.

Dugan, P.J.; Barlow, C.; Agostinho, A.A.; Baran, E.; Cada, G.F.; Chen, D.; Winemiller, K.O. 2010. Fish migration, dams, and loss of ecosystem services in the Mekong. Ambio, 39: 344-348. **http://dx.doi.org/10.1007/ s13280-010-0036-1**.

ELETROBRAS, 1987. Plano 2010: relatório geral Plano Nacional de Energia Elétrica 1987/2010. Brasília. 269p.

Fearnside, P.M. 2013. Decision making on Amazon dams: politics trumps uncertainty in the Madeira river sediments controversy. Water Alternatives, 6(2): 313-325.

Fearnside, P.M. 2016. Tropical dams: to build or not to build? Science, 351(6272): 456-457. **http://dx.doi.org/10.1126/science.351.6272.456-b**.

Garcez, R.C.S.; Souza, L.A.; Frutuoso, M.E.; Freitas, C.E.C. 2017. Seasonal dynamic of amazonian small-scale fisheries is dictated by the hydrologic pulse. Boletim do Instituto de Pesca, 43(2): 207-221. **http://dx.doi. org/10.20950/1678-2305.2017v43n2p207**.

Gehrke, P.C.; Gillgian, D.M.; Barwick, M. 2002. Changes in fish communities of the Shoal haven River 20 years after construction of Tallowa dam, Australia. River Research and Applications, 18(3): 265-286. **http:// dx.doi.org/10.1002/rra.669**.

Goulding, M.; Barthem, R.; Ferreira, E.J. 2003. The Smithsonian Atlas of the Amazon. Washington, DC: Smithsonian Press. 253p.

Gubiani, É.A.; Angelini, R.; Vieira, L.C.G.; Gomes, L.C.; Agostinho, A.A. 2011. Trophic models in Neotropical reservoirs: testing hypotheses on the relationship between aging and maturity. Ecological Modelling, 222(23-24): 3838-3848. **http://dx.doi.org/10.1016/j.ecolmodel.2011.10.007**.

Hauser, M.; Duponchelle, F.; Hermann, T.W.; Limburg, K.E.; Castello, L.; Stewart, D.J.; Torrente-Vilara, G.; García-Vásquez, A.; García-Davila, C.; Pouilly, M.; Pecheyran, C.; Ponzevera, E.; Renno, J.-F.; Moret, A.S.; Doria, C.R.C. 2019. Unmasking continental natal homing in goliath catfish from the upper Amazon. Freshwater Biology, 65(2): 325-336. **http://dx.doi.org/10.1111/fwb.13427**.

Isaac, V.J.; Almeida, M.C.; Giarrizzo, T.; Deus, C.P.; Vale, R.; Klein, G.; Begossi, A. 2015. Food consumption as indicator of the conservation of natural resources in riparian communities of the Brazilian Amazon. Anais da Academia Brasileira de Ciências, 87(4): 2229-2242. **http:// dx.doi.org/10.1590/0001-3765201520140250**.

Isaac, V.J.; Castello, L.; Santos, P.R.B.; Ruffino, M.L. 2016. Seasonal and interannual dynamics of river□floodplain multispecies fisheries in relation to flood pulses in the lower Amazon. Fisheries Research, 183: 352-359. **http://dx.doi.org/10.1016/j.fishres.2016.06.017**.

Kirchherr, J.; Charles, K. 2016. The social impacts of dams: a new framework for scholarly analysis. Environmental Impact Assessment Review, 60: 99-114. **http://dx.doi.org/10.1016/j.eiar.2016.02.005**.

Latrubesse, E.M.; Stevaux, J.C.; Sinha, R. 2005. Tropical rivers. Geomorphology, 70(3-4): 187-206. **http://dx.doi.org/10.1016/j.geomorph.2005.02.005**.

Lauzanne, L.; Loubens, G. 1985. Peces del rio Mamore. Paris: ORSTOM – CORDEBENI/UTB. 116p. (Coleção Travaux et Documents, n. 192).

Lima, M.A.L. 2017. História do ecossistema e dos recursos pesqueiros frente a implementação de hidrelétricas na bacia do rio Madeira. Porto Velho. 138p. (Tese de Doutorado. Programa de Desenvolvimento Regional e Meio Ambiente, Fundação Universidade Federal de Rondônia). Available from: <https://www.ri.unir.br/jspui/bitstream/123456789/2199/1/6709_ maria_alice_lima_tese_2013_2017.pdf> Access on: Apr. 31, 2017.

Lima, M.A.L.; Carvalho, A.R.; Nunes, M.A.; Angelini, R.; Doria, C.R.C. 2020. Declining fisheries and increasing prices: the economic cost of tropical rivers impoundment. Fisheries Research, 221: 105399. **http:// dx.doi.org/10.1016/j.fishres.2019.105399**.

Lima, M.A.L.; Kaplan, D.A.; Doria, C.R.C. 2017. Hydrological controls of fisheries production in a major Amazonian tributary. Ecohydrology, 10(8): e1899. **http://dx.doi.org/10.1002/eco.1899**.

Lopes, G.C.S.; Catarino, M.F.; Lima, A.C.; Freitas, C.E.C. 2016. Small-scale fisheries in the Amazon Basin: general patterns and diversity of fish landings in five sub-basins. Boletim do Instituto de Pesca, 42(4): 889-900. **http://dx.doi.org/10.20950/1678-2305.2016v42n4p889**.

Queiroz, L.J.; Torrente-Vilara, G.; Ohara, W.M.; Pires, T.H.S.; Zuanon, J.; Doria, C.R.C. 2013. Peixes do rio Madeira. 1ª ed. Porto Velho: Dialeto Latin American Documentary. 413p.

R Core Team. 2018. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available from: <https://www.R-project.org/> Access on: Jul. 17. 2020.

Sant'Anna, I.R.A.; Simão, M.O.A.R.; Silva, L.M.L.; Santos, A.R.; Doria, C.R.C. 2015. As pescarias tradicionais da Cachoeira do Teotônio, rio Madeira, Porto Velho, RO. In: Doria, C.R.C.; Lima, M.A.A.L. (Eds.). Rio Madeira: seus peixes e sua pesca. 1ª ed. Porto Velho: EDUFRO. v. 1, p. 33-50.

Santos, G.M.; Ferreira, E.J.G.; Zuanon, J.A.S. 2006. Peixes comerciais de Manaus. Manaus: IBAMA/AM, Provárzea. 144p.

Santos, R.E.; Pinto-Coelho, R.M.; Fonseca, R.; Simões, N.R.; Zanchi, F.B. 2018. The decline of fisheries on the Madeira River, Brazil: the high cost of the Hydroelectric Dams in the Amazon Basin. Fisheries Management and Ecology, 25(5): 380-391. **http://dx.doi.org/10.1111/fme.12305**.

Torrente-Vilara, G.; Zuanon, J.; Leprieur, F.; Oberdorff, T.; Tedesco, P.A. 2011. Effects of natural rapids and waterfalls on fish assemblage structure in the Madeira River (Amazon Basin). Ecology Freshwater Fish, 20(4): 588-597. **http://dx.doi.org/10.1111/j.1600-0633.2011.00508.x**.

Villas-Bôas, A.; Garzón, B.R.; Reis, C.; Amorim, L.; Leite, L. 2015. Belo Monte: não há condições para a licença de operação. Boletim de Notícias do Instituto Socioambiental, 21(59): 1-24. Available from: <https://www.socioambiental.org/sites/blog.socioambiental.org/files/boletim/arquivos/boletim59_0.pdf> Access on: Mar. 12, 2020.

Winemiller, K.O.; Mcintyre, P.B.; Castello, L. 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Science, 351(6269): 128-129. **http://dx.doi.org/10.1126/science.aac7082**.