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The Fishing Productivity Assessement Upstream and Downstream of Tucuruí Hydroeletric Dam, Tocantins-Araguaia basin, Brazil

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Abstract**—** *The Tocantins-Araguaia basin is the second largest in Brazil and the most extensive in the drainage area totally placed in Brazilian territory. A time series of fishery production of more than 30 years of Tucuruí Hydroeletric dam, between 1981 and 2016, in low Tocantins, in ten landing harbor (five upstream and five downstream) was analyzed to compare productivity and indicate suggestions for better planning and public policies focused on the fishery resources in this basin. After analyzing over 16,000 landing data, CPUE (kg / day) indicated that after an exponential growth upstream in the first 15 years of the dam, there was a decline trend in fish stocks up to 2016, mainly upstream. The biodiversity of the ichthyofauna was higher downstream and Mapará H. marginatus was the main species captured. It is concluded that the maintenance and accessibility by society of a program to monitoring landings in the region, as well as studies of population dynamics in order to better plan the fishing effort, is fundamental. It should also be emphasized that environmental education should focus on the involvement of fishing communities, alerting public managers about the importance of knowledge about productivity and that the decline trend of upstream stocks should be considered in the formulation or incentive of policies aimed at development of artisanal fisheries on Tocantins-Araguaia basin.*

Keywords**— artisanal fisheries, CPUE, fisheries data, inland.**

I. INTRODUCTION

Since the Industrial Revolution, citizens' quality of life and the economic competitiveness of countries have been strongly influenced by the advent of electricity generation. Considering a global market and growing concerns about the environment, this influence stands out more and more as decisive. (Tolmasquim et al., 2007). The hydroelectric potential estimated in the Brazilian territory is about 43 thousand MW (Eletrobras, 2017), and there are still heavy investments in this field, either in UHEs (Hydroelectric Dams) and / or Small Hydroelectric Plants (PCH). The first Brazilian UHE Marmelos-MG) has begun activity in 1889. Since then, they have been multiplying in national territory due to the great hydro potential. In the Tocantins-Araguaia basin, UHE - Tucuruí was the first to be built, inaugurated in 1984.According to the National Water Agency-ANA (2009), the Tocantins-Araguaia basin (2nd largest Brazilian basin) requires a withdrawal flow of 95 m3/s, the main use being irrigation, with 57 m 3/s (60% of the total), followed by animal consumption (16 m3 / s) and, thirdly, human consumption (13%). This basin still has the second largest hydropower potential installed with 11,573 MW (16% of the country), Tucuruí (8,365 MW), the largest generation capacity of a national plan. The UHE-Tucuruí interrupted the natural flow of the Tocantins River, forming upstream an artificial lake of 2,875 km², with a maximum depth of 75 m and an average of 17.8 m, covering seven municipalities in the state of Pará (ELETRONORTE, 1987).The installation and operation of a hydroelectric dam provoke great environmental impacts altering the ecological processes fundamental for the maintenance of biodiversity and of the fishing stocks (Agostinho et al., 2008; Agostinho et al., 2007), producing a significant amount of greenhouse gases by deforestation and flooding of the remaining forests (Kahn et al., 2014). Also, artisanal fishing in the area of influence of the Tucuruí Hydroelectric Power Plant has high social and economic importance for the municipalities upstream and downstream of the dam (Cintra et al., 2007) and about 25 thousand fishermen are affiliated with surrounding colonies et al., 2004). With the formation of the lake, it is estimated that around 200 thousand people depend on the fishing productive chain, being 70%, exclusively in the fishing activity (Aviz, 2006). The characteristics of artisanal fishing in this region are not different from the Brazilian or Latin American scenario, which includes the diversity of species and catch strategies, low capital involved, intense labor, high seasonality in the number of active fishermen, low bargaining power in the commercialization and lack of infrastructure for fisheries (Salas, et al., 2007). In this sense, fishing productivity is a

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socioeconomic and environmental indicator aimed at subsidizing better public policies aimed at this productive chain. It should be remembered that the production of fish immediately after the formation of the UHE Tucuruí lake quintupled in nine years (1984-1992) from 472 T to 2,318 Tons and in the following ten years production doubled from 2,648T (1991) to about 5,000 Tons (Juras, et al., 2004), indicating an initial process of stability. However, it is necessary to consider the fishing effort employed in the region that increased significantly with the formation of the UHE lake.This work aims assess at comparing the productivity and the composition of the catch upstream and downstream of the Tucuruí UHE, also indicating suggestions for a better management of fishing resources and better planning for the sustainable development of the fishing productive chain in the region.

II. MATERIALS AND METODS

2.1 Study area and data source.

We compiled fishing landing data from Tocantins-Araguaia Basin, more specifically in the area of influence of the Tucuruí UHE. This basin is the second largest in Brazil and the most extensive in a drainage area totally inserted in Brazilian territory (Figure 1). This basin is the scene of a dynamic process of socioeconomic development that is expected to intensify in the coming decades due to the national and international demands for commodities (BRASIL, 2009 ANA).In total, ten landing ports had sampled production data, grouped by region of landing, five upstream (Marabá, Itupiranga, Santa Rosa, Porto novo and Km Onze) and five downstream (Tucuruí, Baião, Mocajuba, Limoeiro Ajuru and Cametá) of the dam (Figure 1), all located in the state of Pará. The fishing landing regions upstream of the UHE are within the limits of the Mosaic of Units of Conservation of the Lake of Tucuruí, created in 2002.The fishery production, by species or group of fish, was recorded monthly between 2005 and 2016. The data are part of the Fishing and Ichthyofauna Program of ELETRONORTE. Other past data, from different sources, were used in order to give more breadth and understanding to historical and productivity trends. However, only annual total volume data were available (Table 1). The data were from 1981, through the closure of the dam 1984 until 2005 (CINTRA et al., 2007, CET, 1989, INPA, 1986, Colart, 1986; Ribeiro et al., 1995, considering five municipalities upstream (Maraba, Jacundá, Itupiranga, Goianésia do Pará and Tucuruí) and five downstream (Tucuruí market, Baião, Mocajuba, Limoeiro do Ajuru and Cametá) (Juras, et al., 2004; Cintra et al. al., 2007). The main index of abundance used for productivity was Capture per Unit of Effort - CPUE (in kg/day), this being an important indicator and widely used for evaluations of fish stocks and for estimating trends and abundance of fisheries (Nicholas, et al., 2018). The productivity data between 1984 and 2001 were considered at upstream sites, since the cited literature reported only the increase the production after dam closure in 1984 (Juras, et al., 2004). Due to the fishing dynamics in the Tocantins Araguaia basin, whose fishing expeditions are limited to the autonomy and the carrying capacity of the vessels (Silva and Farias, 2017), an average fishing effort of 20 days per month was considered. For the analysis of the catch composition, only the period between 2005 and 2016 was considered, whose robustness of data per species is greater.

III. RESULTS AND DISCUSSION

We analyzed 16,107 CPUE data and catch composition between 2006 and 2015, while between 1981 and 2005 we analyzed only the total annual volume whose CPUE was estimated by dividing the total by 12 months and then by 20 days. Considering the grouping of landing regions, the exponential increase of CPUE upstream was evident in the first 15 years after the dam closure, with peaks in 1991 (11,000 kg/day) and 2003 (32,212 kg/day) (Figure 2). This increase was mainly due to the expansion of the fishing area and increase of primary productivity, with a direct effect on the food supply along the trophic fish chain (Juras et al., 2004). From 2004, CPUE showed a decreasing trend until 2015, from 24,500 to 16,700 kg/day, indicating a decline in productivity. According to Cintra et al. (2011), the perception of the artisanal fishermen of the Tucuruí lake is that the stocks of fish of economic interest are in decline due to a series of factors like the disrespect to the closed season, lack of inspection and use of illegal gill nets. However, CPUE downstream, which was higher before the dam closure, at 4,950 kg/day (1981), declined until 1986 (770 kg/day). Between 1999 and 2004 there was a slow growth from 1,829 to 5,325 kg/day, when it fell again, stabilizing from 2006 onwards in the range of 4,000 kg/day (Figure 2). Although there is stability of the CPUE downstream, we should consider that this fact can be a trap caused by the increase in the number of fishermen, which also increases the effort on fishing (Camargo & Petrere Jr 2004).

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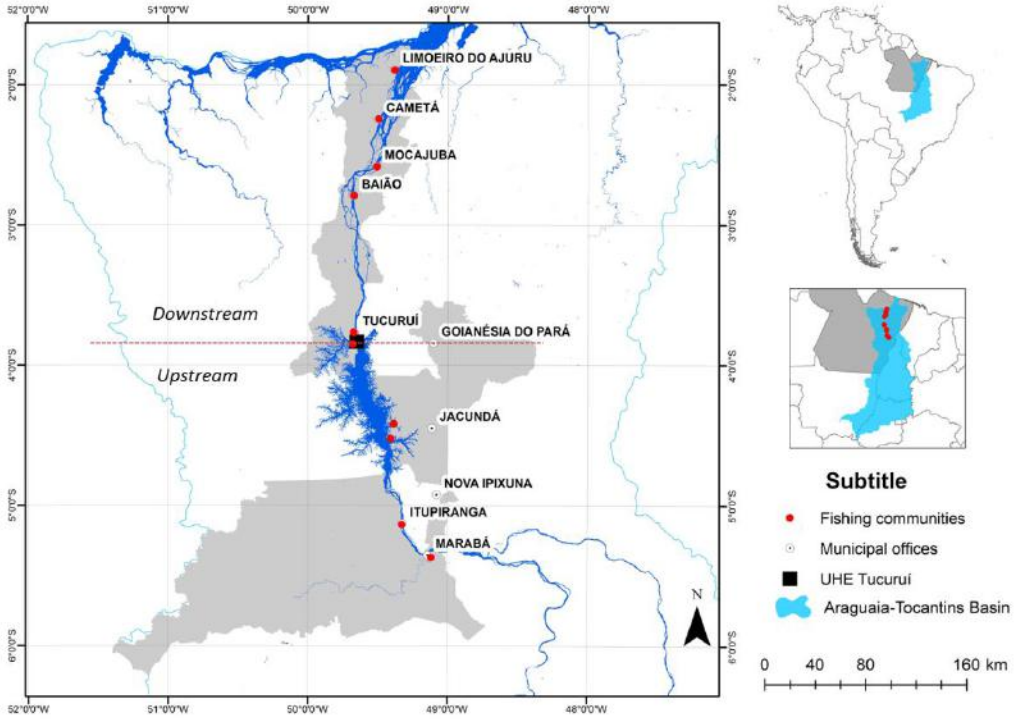

Fig.1: Location of landing ports and their respective municipalities downstream and upstream of Tucuruí UHE, Pará, Brazil.

Table.1: References used for annual data of fishery production in the surroundings of UHE-Tucuruí, Pará, Brazil.

UHE position	Year	Data basis	Reference
Downstream and Upstream	2006 a 2015	Total Cacth byr specie/month/harbour	*Eletronorte (This study)*
Downstream and Upstream	2001 a 2005	Annual Total Cacth	*Cintra et al, 2007*
Upstream	1989 a 1992	Annual Total Cacth	*Juras et al., 2004*
Upstream	1981, 1986, 1987 e 1988	Annual Total Cacth	*CET, 1989; Ribeiro et al.,1995*
Downstream	1981	Annual Total Cacth	*Collart, 1986.*

Between 2006 and 2015, which is a more continuous period and it was possible to distinguish productivity in more detail, CPUEs both upstream and downstream are accompanied respectively by their total productions (Figure 3). However, the downward trend indicates a warning that the fishing effort is beyond what fish stocks support, in other words, overfishing. Camargo & Petrere Jr. (2004) already warned about the depletion of fishing in the region of Lake Tucuruí and indicated that fishery production would decline in 2001 and overfishing in 2005. This can be explained by a combination of factors such as (i) an increase in the number of fishermen and an easy access to fishing resources;(ii) the increase or permanence of the fishing effort employed in previous years whose production was exponential due to the formation of the reservoir; (iii) the non-implementation of the fishery management plan in the reservoir in the initial years and (iv) the gradual reduction of the length of the species captured during this period, which compromises the reproduction and recruitment of young fish. In the downstream region, CPUE and total production are on average 5 times lower than upstream (Figure 3), but with no indication of decline. It is important to emphasize that the downstream region is directly influenced by the alteration of the hydrological cycle by the river dam and the operational procedures of the UHE Tucuruí, which causes mortality of eggs, larvae and fingerlings, thus compromising the recruitment and replenishment of fish stocks (Juras et al., 2014). Another important issue regarding the sustainability of fishing in the region is the social role and representativeness of fishermen in the context of the productive chain in the UHE Tucuruí. Only in the upstream region is estimated in 2000 year, more than 2,600 fishermen registered in fishing Colonies and

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another countless non-associated contingent (Juras et al., 2004). In 2018, the Institute of Forestry and Biodiversity of the State of Pará (Ideflor-Bio), registered 4,769 fishermen, fish buyers and intermediaries using the fishery resources of Tucuruí lake. However, although artisanal fishing depends on collective social capital to promote the sustainability of fishery resources, it is well known that artisanal fisheries representations generally have a low degree of governance, especially in developing countries (Kosamu, 2015). Governance here is understood as shared decision-making between government, whether national and/or local, and other institutions interested in maintaining fishery and fisheries resources, which may include users of fishery resources, local communities, environmental organizations, non-governmental organizations (NGOs) and scientists (BOWN et al., 2012). The top-down policies of fisheries management, commonly observed in Brazil, need to be gradually redirected towards participatory management, focusing on the rights and responsibilities of fishermen and their communities (Grafton, 2005). Upstream of the Tucuruí UHE, there are no fisheries agreement initiatives, which have been evaluated as an important tool for local governance for the maintenance of fishery resources (Castello 2007). However, downstream of the UHE, initiatives of fisheries agreements were initiated from 2001 (PDA, 2006), as well as initiatives of co-management of the fishing (Silvano et al., 2014). The measures taken downstream have contributed to a better representation of the fishermen in the decision-making processes with the public authority (Vilhena 2017), as well as an increase in the abundance of fish in managed lakes (Silvano et al., 2014). A total of 95 species were cataloged in this study, which corresponds to approximately one-third of the 300 species cataloged in the Tocantins -Araguaia Basin (Santos et al., 1984). For the composition of the catch, 85% of the catches (12,908 landings) were considered whose species were identified by scientific name. The remaining 15% were not identified because they were declared at the landing as "mix", "miscellaneous" or "others". It has been noted that downstream species diversity is on average 30% higher than upstream between 2006 and 2015, but in the last year of monitoring (2015) the number almost equals (Figure 4). This fact may have the following explanations: (i) the greater effort and volume captured upstream increases the chances of catchability and depletion of the species existing therein as already indicated in figure 3; (ii) there is no UHE downstream to the mouth of the Tocantins River, consequently during the flood season, a greater diversity of fish climbs the river to spawn, as the mouth of the Tocantins flows into the Guajará bay complex, river Pará, Guamá and the fluvial group of the Amazon river (Almeida, 2010) and (iii) downstream of the UHE there are initiatives for sustainable fisheries management through co-management and fisheries agreements, which has resulted in improved quality and quantity of fish at downstream (Silvano et al., 2014; Vilhena, 2017).

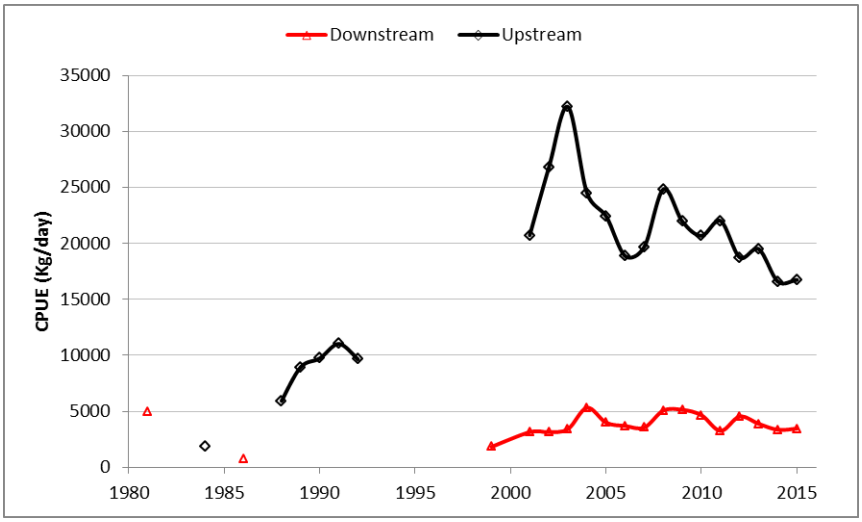

Fig.2: CPUE Variation between 1981 and 2015, upstream and downstream of Tucuruí UHE, Pará, Brazil.

It is worth noting that even with greater diversity downstream, the rapid lowering of water in the headwaters and marginal lagoons (caused by the dam) causes intense mortality of eggs, larvae and fingerlings (Juras et al., 2004). In addition, the dam interrupted the flow of migratory fish, which reproduced exclusively upstream of the flooded area, such as Curimatá (*Prochilodus nigricans*), which has a low production recorded after the dam closure (Mérona et al., 2010).

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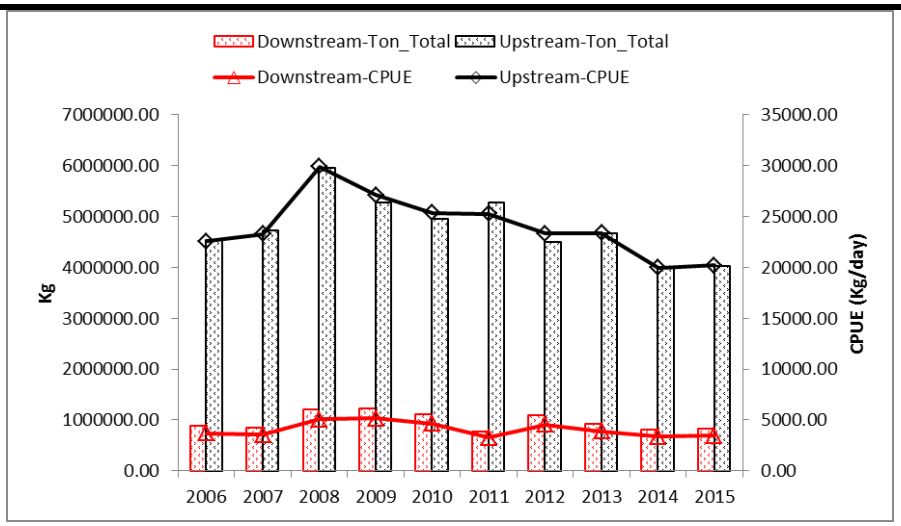

Fig.3: CPUE oscillation and total production (kg) between 2006 and 2015, upstream and downstream of UHE Tucuruí, Pará, Brazil.

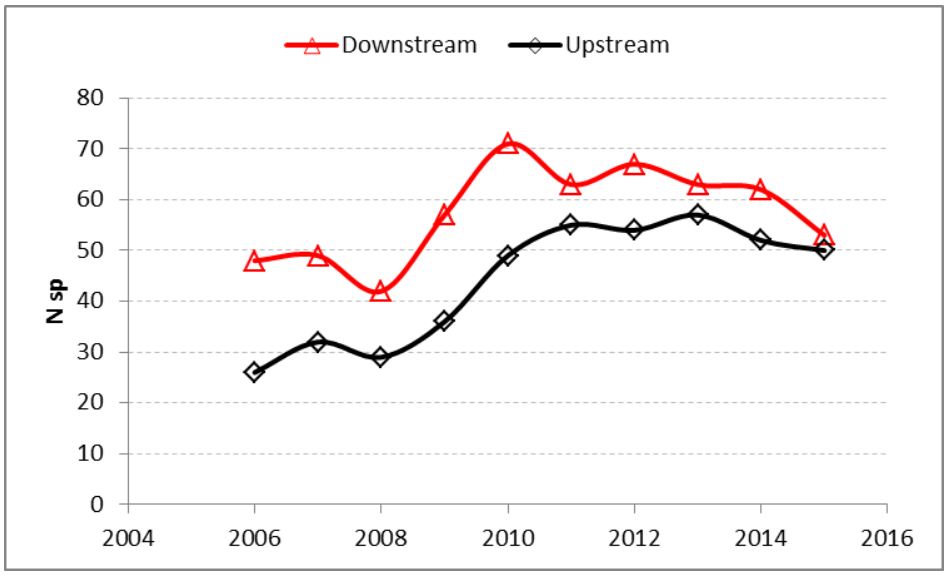

Fig.4: Variation of the diversity of the ichthyofauna exploited by the fishing and downstream of the Tucuruí UHE, Pará, Brazil.

As for the species, the 10 most caught in volume (kg), both downstream and upstream, together, accounted for more than 95% of the total. *Hypophthalmus marginatus*, regional called "mapará", was the most captured both upstream and downstream, representing 50 and 36% of the catches, respectively (Figure 5). The mapará has great economic importance for fishing in the Amazon basin and Tocantins-Araguaia, its fast growth and high natural mortality (Cutrim and Batista, 2005). The second most caught fish was *Plagioscion squamosissimus* (Pescada-branca), with 15% (downstream) and 30% (upstream) of the catches. The tucunarés (Cichla sp) appear as the third species most captured mainly upstream and is also captured with lines and hooks in specific places (Alves and Barthem, 2008), being also an important resource for sport fishing (Santos and Santos, 2005). The landings analyzed between 1992 and 1998 in Tucuruí and Marabá, the same tendency of our study was presented, being the mapará, pescada-branca and the tucunarés the most captured species (Camargo & Petrere Jr 2004). In the low Tocantins, the most abundant species recorded in landings of a temporal series were pescada-branca and mapará (Hallwass 2015). These data show that these species have still been subject to selective fish pressure, which is largely to serve the export market (Camargo & Petrere Jr, 2004). However, in the absence of proper management, the trend is for fishing to collapse.

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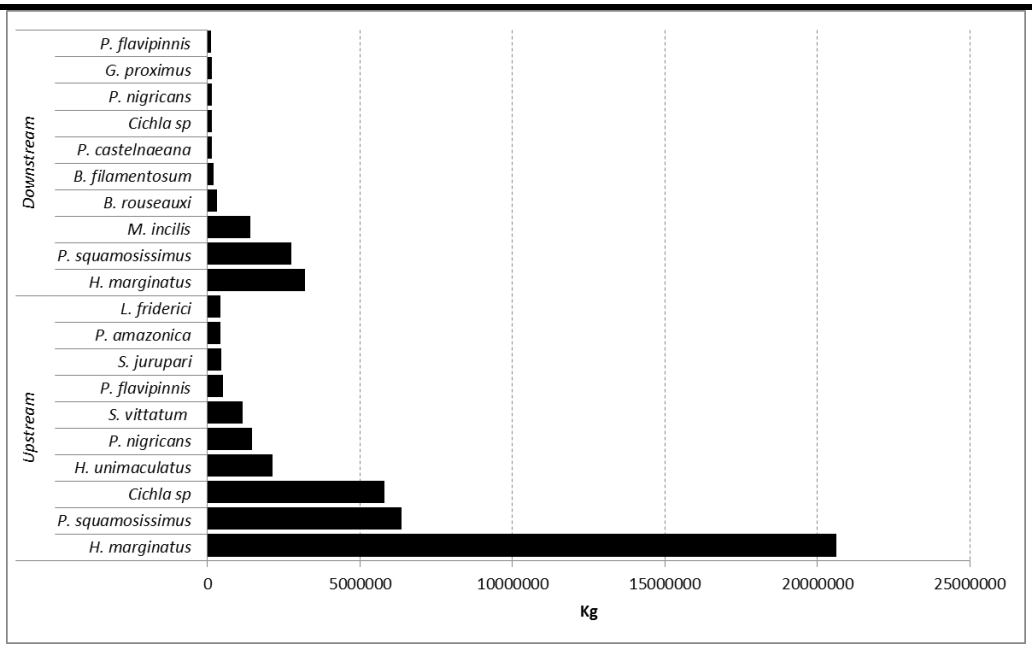

Fig.5: Main species captured downstream and upstream of Tucuruí UHE, Pará, Brazil.

IV. CONCLUSIONS

After a historical analysis of some tendencies and the catch composition of artisanal fishing downstream and amount of Tucuruí UHE, we can consider:

✓ Maintaining a land monitoring program is essential, highlighting the effort and fish stocks, especially in the face of a declining trend between 2006 and 2015, and making this information available to society at all times;

✓ Studies on population dynamics are also important to identify if the average size of the main species caught is being compatible with the fish effort employed, minimizing the effects of overfishing or stock collapse;

✓ Fishery management actions should not only consider total catch volumes but the effort employed in fisheries as well as number of users;

✓ Environmental education as a focus on community involvement, alerting public managers about the importance of knowledge about fishing productivity in the Tocantins-Araguaia basin and promoting a broad and inclusive debate with society about the future of fisheries resources and;

✓ Finally, the upward trend of upstream stocks should be considered in the formulation or incentive of policies aimed at the sustainable development of artisanal fisheries.

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