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# The potential of citizen science to assess migratory patterns of Amazon fish

## El potencial de la ciencia ciudadana para identificar patrones de migración de peces amazónicos

**SHORT COMMUNICATION/**
NOTA CIENTÍFICA

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## ABSTRACT

This paper discusses the application of citizen science and participatory monitoring initiatives for the identification of migratory patterns of Amazon fish. We interpreted fisheries data collected in the Madeira River basin by fishers using an applicative on smartphones to register catches or landings. The results for two Siluriform and two Characiform genus were contrasted with historical fisheries data. The main strength of the tool is the opportunity to create and share knowledge between traditional scientists and citizen scientists, across the basin.

**Keywords:** Smartphone, hydropower, participatory monitoring, fisheries

## RESUMEN

Este manuscrito analiza el uso de la ciencia ciudadana y las iniciativas de monitoreo participativo para la identificación de los patrones migratorios de los peces amazónicos. Interpretamos los datos de pesca recopilados en la cuenca del río Madeira por los pescadores utilizando una aplicación en los teléfonos inteligentes que les permite registrar capturas o desembarques. Los resultados para cuatro géneros pertenecientes a los ordenes Siluriformes y Characiformes se compararon con datos pesqueros históricos. La principal fortaleza de la herramienta es la oportunidad de crear y compartir conocimientos entre científicos tradicionales y científicos ciudadanos de toda la cuenca.


**Palabras clave:** Celulares, energia hidroeléctrica, monitoreo, pesquerías

## INTRODUCTION

Migratory fish have historical, economic, and cultural importance in Amazonian society. They contribute about 93% (range 77–99%) to the fisheries landings in the basin, amounting to ~US$436 million annually, in addition to their nutritional value and contribution to food security (Duponchelle *et al*. 2021). Despite their importance, they are threatened by anthropogenic activities, mostly related to economic growth, such as overfishing, deforestation, climate change, and hydroelectric dams (Castello & Macedo 2016, Duponchelle *et al*. 2021). Considering the diversity of fish migrations and the scales at which they occur in the Amazon basin, conservation of migratory fish species would ideally require the implementation of a riverscape basin-wide approach (Castello *et al*. 2013, Goulding *et al*. 2018, Duponchelle *et al.* 2021).

However, this is a challenge that requires studies and continuous fisheries monitoring programs to be implemented at basin scale, coordinated between governmental agencies of all Amazonian countries. In regions such as the Amazon, with an extensive hydrographic network, fish landings are not well documented, especially in tributaries distant from the main consumer markets (Lima *et al*. 2012, Inomata & Freitas 2015). The Amazon region tends to be less intensively monitored than other river basins, and adequate statistical and landing data are often lacking because the fisheries are carried out in remote places, in irregular landing sites, in numerous small-scale fisheries (Ruffino 2014, Doria *et al.* 2018a). In addition, part of these catches does not enter a formal market system, being destined directly to informal interchange and household consumption.

The lack of robust fisheries data is one of the greatest challenges for stock management and conservation (Ruffino 2014, Escobar 2015). The situation is worrying in the Brazilian portion of the Amazon, where official fisheries monitoring has not been carried out since 2012 (Batista & Isaac 2012). In the Madeira river basin the few existing data after 2013 are controlled by private companies (e.g. hydroelectric dam construction companies) and are difficult to access by managers or resource users such as fishers, riverside dwellers and indigenous people (Doria *et al*. 2020). A similar situation occurs in the Bolivian Amazon where there do not exist official statistics of fishery landings and only a few punctual and temporary efforts have provided scattered information, not allowing detection of tendencies in population status of the commercial species (Van Damme *et al*. 2011). In the Upper Madre de Dios Basin (Peru) official fisheries statistics have not been collected using a standardized format (Duponchelle, pers. comm.).

Tools for independent fisheries monitoring have been gaining strength among communities in different contexts, including the monitoring of impacts suffered by infrastructure projects and the monitoring of environmental and ecosystem transformations (Chaves & Pinto 2021). The challenge is to obtain data at a large temporal and spatial scale which helpd to understand natural and human-induced change. Different participatory or citizen science approaches aiming at expanding the involvement of local actors in data collection, planning, analyzing and decision-making have shown that citizen participation can help to improve environmental management (Reed 2008, Van Damme *et al*. 2015, Doria *et al*. 2019, Silvano & Hallwass 2020).

The ecosystem equilibrium and environmental services in the Amazon basin are threatened by numerous human activities. The main threat is hydroelectric dam construction, driven by the development plans of local and regional governments. The Brazilian government's Accelerated Growth Plan (MME/EPE 2017) enabled the construction of two large hydroelectric dams in the Madeira River basin (Santo Antônio - operation started in 2011 and Jirau - operation started in 2012). However, 160 new hydroelectric dams are planned for the entire basin, compromising river connectivity and endemic and migratory species (Anderson *et al*. 2018).

In this scenario, this study analyzes the potential use of a citizen science tool, a smartphone application, to answer the following question: What is the potential of the information generated by the tool and how can this information be used to assess changes in the migratory patterns of fish species caused by hydroelectric projects in large river basins? This question is answered using the Madeira basin affected by hydroelectric projects as a case study.

## MATERIAL AND METHODS

### Study area

The Madeira River is the largest tributary of the Amazon River, with approximately 1 370 000 km² of total drainage area, which represents more than 20% of the entire

Amazon basin, crossing three countries: 50% of its area overlaps with Brazil, 42% with Bolivia and 7% with Peru (Barthem & Goulding 2007).

Considering the ecological and geomorphological characteristics of the sub-basins that form the Madeira basin, the stretches were divided into Upper, Middle and Lower (Table 1 and Figure 1; for more details see Doria *et al*. 2018a). The Upper Madeira basin comprises white water rivers that drain the Andes Mountains, heavily loaded with Andean suspended sediments and transporting huge amounts of organic matter (Barthem & Goulding 2007), and clear water rivers that drain the Brazilian Precambrian shield, with eroded soils and, therefore, low in minerals and suspended materials. The Middle Madeira basin extends from Guajará-Mirim to the flooded area of Cachoeira de Teotônio. In this stretch, the Madeira River changes abruptly, with the formation of 19 rapids. Some of these have been flooded by the reservoirs of the Jirau and Santo Antônio Hydroelectric Power Plants (HPP) after 2012 (Doria *et al*. 2018b). The Lower Madeira basin is in the transition between the Brazilian Shield and the Amazon Lowlands, receiving sediments from the Central Amazon floodplain (Table 1).

**TABLE 1.** Study area and subbasins of the Madeira River (based on Doria *et al*. 2017) indicating the locations where fisheries landings were recorded using ICTIO.

| Study area | Subbasins | Main landing sites surveyed |
|---|---|---|
| Upper Madeira | Upper Madre de Dios (Peru) | Manu River, Puerto Maldonado |
| | Beni, Mamoré, Lower Madre de Dios (Bolivia) | TCO Tacana, Riberalta, Puerto Villarroel |
| | Iténez or Guaporé (Bolívia and Brasil) | Pimenteiras |
| Middle Madeira | Mamoré (Brazil) and Madeira (between Guajará-Mirim and Vila Nova do Teotônio), Abunã. | Guajará-Mirim, Nova Mamoré, Lata, Abunã, Jaci-Paraná, Vila Nova do Teotônio |
| Lower Madeira | Madeira (between Porto Velho and Nova Olinda) | Porto Velho, São Sebastião, Distrito São Carlos, Humaitá |

Fish is an important commercial product in urban markets and is also the main source of protein in most riverine communities in the Madeira basin (Doria *et al*. 2012, Doria & Lima 2017). Approximately sixty species are recorded in commercial catches in the Madeira River basin, mainly consisting of medium and large migratory species of Characiformes and Siluriformes (Carvajal-Vallejos *et al*. 2011, Doria *et al*. 2012, Doria & Lima 2015). Fishing activity in this basin is characterized as small-scale, multi-specific and multi-gear. Both commercial and subsistence fishing are practiced. In addition to being socio-economically important for riverside communities. Around 5 000 fishers spread over the entire basin are involved (Doria *et al*. 2018a).

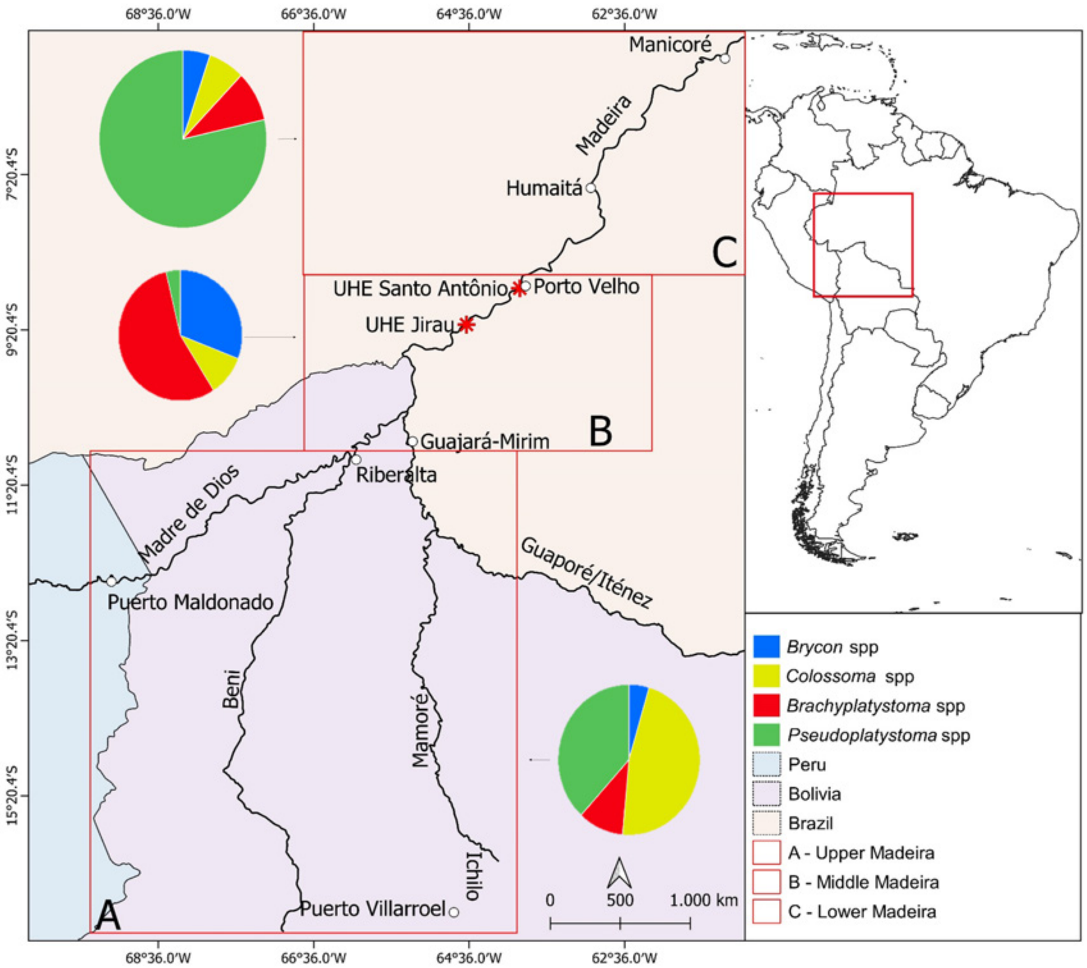


**FIGURE 1.** Madeira River Basin and study areas. Relative percentage of selected migratory species groups uploaded to the ICTIO application after dam construction in the Upper Madeira (2020) and in the Middle and Lower Madeira (2020-2021 average) .

## Data collection

The ICTIO tool is an application for smartphones developed by the Laboratory of Ornithology of Cornell University in cooperation with the Citizen Science for the Amazon network and the Wildlife Conservation Society (WCS). Fisheries data can also be uploaded independently using a web-based platform (https://www.ictio.org/) (Citizen Science for the Amazon 2022). The use of ICTIO in the Madeira Basin region is a strategy to generate information on migratory fish at the Amazon basin scale and aims to contribute to the sustainable management of fisheries. The fisheries data recorded through the app and the web platform are the species caught (30 species), number of individuals, total weight per species, sale price, location, and date.

The records by ICTIO users (from the app and/or platform) in the Madeira basin study area in the period between 2018 and 2021 were grouped by area and subbasin, the Upper Madeira, the Middle Madeira and the Lower Madeira, respectively (Table 1). The data used in the analysis were: (a) number of users per area; (b) number of observations per area; (c) total fish catch recorded in each area; (d) total capture of the main migratory species recorded in each area in the years 2020 and 2021 (considered here as a post-dam period). Data from the genera *Brycon*, *Colossoma*, *Brachyplatystoma* and *Pseudoplatystoma* were selected and grouped, representing commercially important medium-distance (100-1000 km) and long-distance (> 1000 km) migratory species (Doria *et al.* 2018b) (Table 2). For the Upper Madeira, only the annual catch of 2020 was used and, for Middle and Lower Madeira, the average annual catch was analyzed considering the records from 2020 and 2021 only. These differences are related to differences in the project start in different basins. The relative percentages of selected migratory species were contrasted with the historical data from fisheries monitoring in the same areas of the Madeira River basin recorded before dam construction (between 2009 and 2011) (Doria *et al*. 2018b).

**TABLE 2.** Migratory species selected for the study and type of migration (based on Doria *et al*. 2018a). Common names used in the Upper Madeira basin are indicated with *.

| Order / Genus | Species | Common name | Migration type |
|---|---|---|---|
| **Characiformes** | | | |
| *Brycon* | *Brycon amazonicus* | Jaturana, yatorana* | Medium |
| | *Brycon melanopterus* | Matrinchã | Medium |
| | *Brycon* sp. | Jatuarana/matrinchã | Medium |
| *Colossoma* | *Colossoma macropomum* | Tambaqui, pacú* | Medium |
| **Siluriformes** | | | |
| *Brachyplatystoma* | *Brachyplatystoma filamentosum* | Filhote, piraíba* | Long |
| | *Brachyplatystoma platynemum* | Babão, barbachata* | Medium |
| | *Brachyplatystoma rousseauxii* | Dourada, dorado* | Long |
| | *Brachyplatystoma vaillantii* | Piramutaba | Long |
| *Pseudoplatystoma* | *Pseudoplatystoma fasciatum* | Surubim, pintado, surubi* | Medium |
| | *Pseudoplatystoma* sp. | surubim/pintado | Medium |
| | *Pseudoplatystoma tigrinum* | Caparari, chuncuina* | Medium |

## RESULTS

Throughout the entire Madeira river basin, during the four years of implementation of the ICTIO application 11 755 observations of various fish species were recorded by 182 users, totaling 1 049 tons of fish (Table 3). The highest number of users was registered in the Upper Madeira basin (128), whereas the highest total capture (887 t) was recorded in the Lower Madeira. The mean capture per user over the total study period was 5 763 kg, whereas the mean capture per observation was 124 kg.

The records obtained for the four genera in the Upper Madeira in 2021 (428 observations, total weight: 15 t) and in the Middle and Lower Madeira in 2020 and 2021 (respectively, 68 and 1 044 annual observations, total weight: 2 t and 75 t). show a predominance of *Pseudoplatystoma* in the Lower Madeira (78% of total weight), a dominance of *Brachyplatystoma* in the Middle Madeira (56% of total weight) and a dominance of Colossoma in the Upper Madeira (47% of total weight). Figure 2 shows the relative abundance and distribution of the four groups in the microbasins of the Madeira River.

**TABLE 3.** Number of users, number of observations and total catch (tons) of fish recorded from 2018 to 2021, by study area and subbasin

| Madeira basin | Sub-basin | Number of observations | Total capture (t) | Number of users |
|---|---|---|---|---|
| **Upper** | Madre de Dios | 1 517 | 23 | 57 |
| | Beni | 567 | 33 | 45 |
| | Mamoré | 325 | 19 | 25 |
| **Middle** | | 874 | 86 | 15 |
| **Lower** | | 8 454 | 887 | 39 |
| **Total** | | **11 755** | **1 049** | **177** |

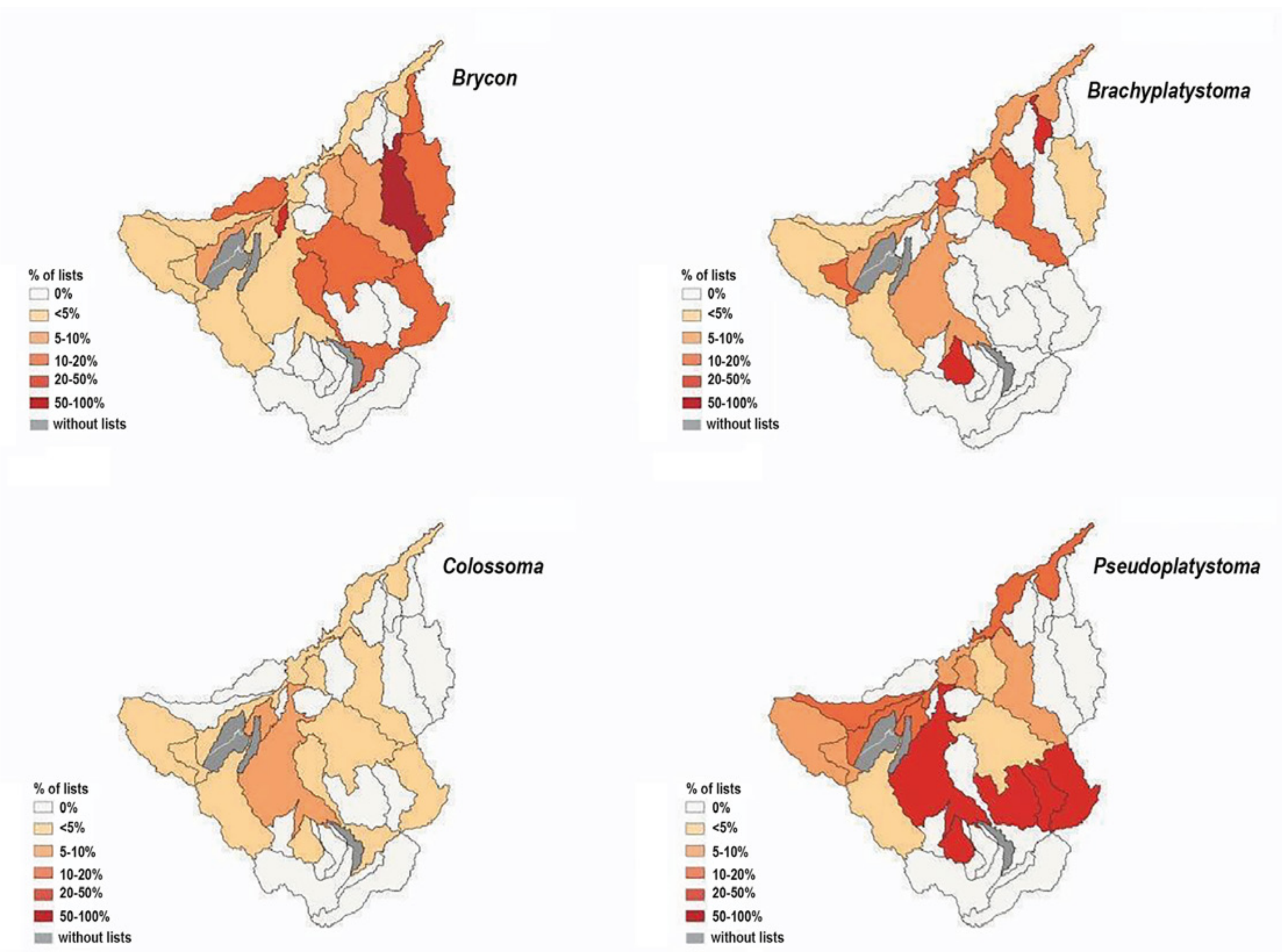


**FIGURE 2.** Relative abundance (%) and distribution of four genera (*Brycon, Brachyplatystoma, Colossoma, Pseudoplatystoma*) of migratory species registered by ICTIO in sub-basins of the Madeira River basin.

## DISCUSSION

The number of users, number of observations and, consequently, the recorded total capture in each study area depends on many factors. In the upper part of the basin, the number of users as well as the number of observations were high, due to intensive promotion of the application. In the Madre de Dios sub-basin, 24% of users were indigenous people within a protected natural area, the Manu National Park, uploading records corresponding to subsistence fishing. In this region, fishing is exclusively for family consumption and, whereas a high number of observations was made, the catches are low compared to other records in the same sub-basin. The high number of users in other Upper Madeira sub-basins could be explained by the outreach activities in the framework of ICTIO implementation strategies. In the Middle Madeira, the number of users and observations was lower than in other areas, and reflects not only the low number of active commercial fishers after the construction of the Santo Antônio HPP reservoir, but also the decrease in catch per fishery. Arantes *et al*. (2021) showed that after the construction of the barriers, the capture per unit of effort decreased, on average, 37%. This decline reflects the low efficiency of the dam transposition system implemented (Hahn *et al*. 2020) and the consequent decrease in the abundance of some species. In the lower part of the basin, the high number of observations (8 454) is related to the fact that one of the users uploads daily records at the Porto Velho fishing market. This heterogeneity in users makes difficult to undertake comparisons between regions. Future inter-region comparisons may be feasible when users with similar profile in different regions would be involved.

The results suggest that a great effort has been made to involve users throughout the basin. However, it is important to note that these data do not represent the total values of what was caught in the region in the four years of the study, acknowledging the relatively low recruitment of citizen scientists for fisheries monitoring. Also, the logistical difficulties of implementing ICTIO in some parts of the basin should be considered, with low internet coverage and limited access to digital technology. As well, we should consider the users' difficulty in adapting and taking ownership of the application's daily use. In addition, we highlight the effect of the COVID-19 pandemic, when isolation measures led to the discontinuity in monitoring.

Despite the difficulties encountered in data recording, the results show that the ICTIO application made it possible to collect, on the same data platform, fisheries information registered by users from three countries (Brazil, Bolivia and Peru). These users uploaded information from fishing markets, subsistence or commercial fisheries. Many of these users fish to sustain their livelihoods, and participate in fisheries that are little or never officially monitored by government agencies. This type of monitoring might become extremely relevant in large-scale basin-wide studies, and has the potential to improve the understanding of biological and ecological characteristics of shared fish stocks. In particular, this would make it possible to understand the migration patterns of species, detect changes in these patterns and evaluate the human impact on fish resources.

Migratory species are dominant in the Madeira basin fisheries (Doria *et al*. 2018a). In the upper portion of the basin, medium-distance migratory catfish species dominate commercial captures (Van Damme *et al*. 2011, Miranda-Chumacero *et al*. 2011). In the Middle and Lower Madeira, Characiformes represent 50 to 65% of landings, totaling an average of 567 (± 193. 6) t year$^{-1}$ (Doria et al. 2018b). Siluriformes, medium to long distance migratory species, represent about 14 to 22% of production/year, but have higher economic importance (Doria *et al*. 2018b). However, after the construction of the dams, a sharp drop in catch (>40%) was observed in the middle and lower portions of the basin (for Porto Velho see Lima *et al*. 2020 and for Humaitá see Santos *et al*. 2018). This decline is a result of a marked decrease in the capture of long- and medium-distance migratory Characiformes and Siluriformes. Lima *et al*. (2020) point out that from 2009 onwards, the average landings of the genus *Brachyplatystoma*, comprising species of large Amazonian catfish, showed a drop of 63.8%, while the production of the *Pseudoplatystoma* species increased by 61% (Sant'Anna *et al*. 2020). In the same period, Sant'Anna *et al*. (2020) observed a population reduction of *Brycon* spp. and C. macropomum.

Are changes in fish catch and landing composition detectable from the data uploaded by ICTIO users? The low number and the high heterogeneity of users makes it difficult to detect these trends. The data reveal similar catch composition as the one reported in the previously mentioned studies, but the interpretation of this information to evaluate dam impacts should be done with caution. However, ICTIO data may be useful to detect drastic changes in the populations, for example, in cases when a species entirely disappears from the records. The combination of citizen science data collected in the entire basin with more local data obtained by conventional fish monitoring and with specific research might make it possible to better explore dam effects.

The catch decline of catfish of the genus *Brachyplatystoma* in the Middle and Upper Madeira basins was demonstrated by several authors. Hauser *et al*. (2018) provided evidence of the negative effects of the Santo Antônio and Jirau HPPs on the migration of the gilded catfish (*B. rousseauxii*). Before the construction of the dams, this species used to migrate from the Madeira to headwater rivers in the Upper Madeira Basin (Duponchelle *et al*. 2016). After the construction the population upstream of the dams became trapped, becoming resident, and the individuals that stayed downstream of the dam cannot mount the Fish Transposition System (STP) (Hahn *et al*. 2018, Hahn *et al*. 2020). Van Damme *et al*. (2019) showed a catch decline of gilded catfish greater than 80%, 1500 km upstream of the dams. Could the ICTIO tool detect these impacts? For example, fishers in Cachuela Esperanza using the tool detected and registered an unusual concentration of young gilded catfish trapped above the Jirau dam (Van Damme, comm. pers.). These forced residents were probably born in the upper Beni River and cannot complete their downstream migration. This example suggests that ICTIO data in combination with scientific research can help to understand the effect of dams on migration success.

Migratory species caught in tropical river fisheries migrate hundreds of kilometers in response to seasonal flood pulses (Duponchelle *et al*. 2021). The ICTIO records partly reflect these patterns (Figure 2). The effects of damming on these species and consequently on fisheries are devastating, as their life cycle intrinsically depends on the interconnectivity of aquatic ecosystems (Winemiller *et a*l. 2016, Lima *et al.* 2020), which affects fisheries productivity in the region. This has a significant impact on rural society, since the fishers and riverine people depend, economically and socially, on fish (Doria & Lima 2015). Furthermore, most of these migratory fish have key ecological roles as apex predators, ecological engineers, or seed-dispersal species. Reducing their population sizes could induce cascading effects with implications for ecosystem stability and associated services (Duponchelle *et al.* 2021). Conserving Amazonian migratory fishes requires a broad portfolio of research, management, and conservation actions that require trans-frontier coordination (Duponchelle *et al*. 2021). Citizen science might become an important tool to overcome this challenge of cross-border coordination and large basin extensions, connecting researchers and users to collect data. Citizen science can help fill information gaps, reduce the cost of collecting information, and expand existing knowledge about the ecology of migratory fish and Amazon aquatic systems (Citizen Science for the Amazon 2022). In addition, producing and recording knowledge strengthens community bonds, the affirmation of identities and the organization of resistance strategies in the face of threats (Chaves & Pinto 2021). This is particularly important in the Madeira basin, given the implementation of hydroelectric plants affecting river connectivity, and the numerous problems caused by fisher's lack of access to fisheries data collected by hydroelectric companies, which inhibit fisher's participation in decision-making.

As a conclusion, the citizen science effort reported here does not compete with or replace official monitoring, but its´ results can complement existing data, as well as suggest guidelines for the monitoring and management of migratory species. Also, citizen science allows for the engagement of fishers in fisheries management, and can provide crucial contributions to the conservation of the migratory fish resource.

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