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Monitoring a critical population of the Bolivian river dolphin, *Inia boliviensis,* before and after closing the floodgates of a hydroelectric dam in the Amazon Basin, Brazil: A quantitative analysis

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ABSTRACT

Dam constructions threaten aquatic fauna, degrading their habitats and causing population fragmentation. Environmental impact studies were carried out from March 2010 to July 2015 as part of the licensing process concerning the Jirau Hydroelectric Dam construction, located on the Madeira River, Rondônia, Brazil, aiming to assess its impacts on the local fauna. The dam closed its gates in December 2012 and the water level rose from 2013 to 2015, creating a 468 km^2 reservoir. Dams may be a source of negative effects to several species, including the Bolivian river dolphin, *Inia boliviensis*, which have a restricted distribution in northern Bolivian rivers and part of the Madeira River Basin. This study evaluated the presence of *I. boliviensis* in different sections of the Madeira River before reservoir filling (BRF) and after reservoir filling (ARF) through a quantitative analysis. Dolphins were actively searched along linear transects in four sections of the river: Abunã, Mutum, Caiçara and Canteiro, over 125 km (250 km round trip). A total effort of 986 h was carried out along 210 days during the hydrological seasons (falling, low, rising and high-water level). Twenty-nine (29) groups were recorded BRF in the direct dam influence area (N = 62), while thirty-eight (38) groups were documented ARF (N = 111). The highest number of sightings was recorded in Abunã during both periods: 24 in BRF (N = 50) and 33 in ARF (N = 101). The greatest number of dolphins was detected during the falling and low hydrological seasons: 19 in BRF (N = 48) and 30 in ARF (N = 92). This is expected, since decreasing water levels lead to a higher concentration of prey and, consequently, higher numbers of dolphins can be observed. Standardized methodology and experienced staff are essential to ensure adequate dolphin population estimates, especially in these critical habitats, where the main impacts caused by the dam are population fragmentation, isolation and extirpation, and reproductive segregation.

1. Introduction

Dams are currently considered the solution for water and electricity demands. However, the production of this “clean energy” has impacted river systems worldwide. Reservoirs inundate vast land areas that are usually densely forested and rich in biotic and mineral resources (Reeves & Leatherwood, 1994). These constructions transform riverine habitats, disrupt water flows, increase sediment loads upstream, alter thermal conditions and nutrient balance, and increase the impact of sewage and industrial waste (Pavanato et al., 2016). The main threats of waterway obstructions include habitat loss, population fragmentation and prey availability reduction, and are a particular concern for large mammals, such as riverine dolphins (Araújo & Wang, 2014; Paschoalini et al., 2020; Pivari et al., 2017; Reeves & Leatherwood, 1994).

Unfortunately, dam constructions in Brazil continue to increase. According to ECOA et al. (2017), a total of 13 dams currently operate in river dolphin distribution areas, and about 150 more are planned to be built by 2030. The Madeira River is the fifth largest river in the world in terms of water discharge (Latrubesse, 2008), and the largest and most heavily sedimented whitewater Amazon River tributary (Castello et al.,

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2013; Guyot, 1993; Macedo & Castello, 2015). The Madeira river sub-basin represents 20.1% of the total Amazon basin area, occupying 1.4 million km^2 (Goulding et al., 2003). It originates in the Andean Piedmonts and the Brazilian Shield, formed by the confluence of four major rivers, i.e., the Guaporé, Mamoré, Beni, and Madre de Dios rivers (Bourrel et al., 2009; Goulding et al., 2003). Two hydroelectric power plants are currently operational in the area, Santo Antônio and Jirau. The last one closed its gates in December 2012 and the reservoir was filled from 2013 to 2015, totaling a submerged area of 468 km^2 (Cochrane et al., 2017).

This area is inhabited by the South American river dolphins of the genus *Inia,* listed as Endangered by The International Union for Conservation of Nature and Natural Resources (IUCN) (da Silva et al., 2018). On the upper Madeira River, the Bolivian river dolphin (*Inia boliviensis*), also known as boto or bufeo, faces several threats, as overfishing, deforestation, habitat degradation and hydroelectric construction, that can result in the current population decline (Aliaga-Rossel & Escobar-WW, 2020; Guizada & Aliaga-Rossel, 2016). The species occurs in the Mamoré River and in most of its tributaries in Bolivia (Rapulo, Maniqui, Curiraba, Isiboro and Ichilo), in rivers that represent international limits between Brazil and Bolivia (Iténez-Guaporé, Abunã and Madeira), and along most of the Madeira River in Brazil, including the rapids area (Gravena et al., 2014b; Tavera et al., 2010). The Bolivian river dolphin differs from other *Inia* populations in some cranial morphological characteristics such as rostral length and a significantly different number of teeth (da Silva, 1994). The *boliviensis* form was geographically isolated from *Inia* populations in the Amazon main stem by a series of rapids and waterfalls between Guayaramerin, Bolivia and Porto Velho, Brazil (ca. 400 km). This isolation occurred during the late Pliocene (5–6 million years ago), which would be the cause of the allopatric separation from other Amazon basin *Inia* populations (Banguera-Hinestroza et al., 2002; Hamilton et al., 2001). Previous studies on comparative mitochondrial and nuclear DNA (Banguera-Hinestroza et al., 2002; Gravena et al., 2014b; Hrbek et al., 2014) have suggested the existence of two different lineages, corresponding to *I. geoffrensis* and *I. boliviensis.* The Society of Marine Mammalogy have already recognized *Inia boliviensis* as a species in the past. However, Gravena et al. (2015) suggested the existence of an extensive hybrid zone in the Madeira River, downstream the main waterfall (Teotônio waterfall), that appears to be ancient and is characteristic of an introgressive hybridization.

Regarding the construction of hydroelectric dams, Brazilian legislation only grants the necessary licenses to build (which are three: prior, installation and operation licenses) if environmental impact assessments are carried out, and if mitigation and compensatory measures are taken (Alho, 2011). Dam construction present loss of connectivity, changes in their hydrological cycles and water temperature, acidification and variation on nutrient balance, and alteration in water velocity and flow (Fearnside, 2019; Junk et al., 1989; Paschoalini et al., 2016). All these factors lead to an increased load of sediment upstream, flooding of land tracts, increased impact of sewage and industrial effluents, and reduced fish diversity and abundance (Dudgeon, 1992; Kondolf, 1997; Luz-Agostinho et al., 2008; Rosenberg et al., 1997; Sabir et al., 2013).

Inia species inhabiting these highly impacted rivers deal with population fragmentation, isolation and extirpation, and reproductive segregation (Fearnside, 2019; Junk et al., 1989; Paschoalini et al., 2016). This process leads to the isolation of subpopulations, lowering their genetic variability (da Silva & Martin, 2010; Gravena et al., 2014b), which may cause local extinction. The Tucuruí dam located in the lower-medium Tocantins River in Pará State (north Brazil) is an example of a dam that fragmented two river dolphin populations: *I. geoffrensis* and the recently described *I. araguaiaensis* (Hrbek et al., 2014; Paschoalini et al., 2020). In 1984, the world's fifth largest hydropower dam in terms of energy generation capacity was constructed, isolating the boto populations of the Araguaia-Tocantins river basin (*I. araguaiaensis*) from their conspecifics in the Amazon River basin (*I. geoffrensis*) (Araújo & Wang, 2012; da Silva & Martin, 2010). This fragmentation affected *Inia* species at a population level by the formation of subpopulations and/or reduction in their distribution range (Braulik et al., 2015; Reeves & Leatherwood, 1994; Smith & Reeves, 2012). To date, several river dolphin populations have been affected by dam constructions. In the Ganges river system in Nepal and India, dams and barrages fragmented the South Asian river dolphin (*Platanista gangetica*) population into smaller groups that have been drastically reduced or even disappeared (Reeves et al., 2000). In the same line, the Yangtze river dolphin (*Lipotes vexillifer*), was declared "functionally extinct" in China, due to population fragmentation caused by dam constructions among other threats (Turvey et al., 2007).

In Brazil there is a constant demand to increase energy capacity. The Ministry of Mines and Energy, the federal agency responsible for ensuring the implementation of public policies for the sustainable management of the country's energy and mineral resources, together with the Federal Government, launched the National Energy Plan 2050 (PNE 2050) (Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2020). The government proposed a transition in energy generation towards a low carbon economy and a smaller environmental footprint, decreasing the use of fossil fuels and carbon emitters and increasing the use of renewable sources. It is estimated that the country's electrical matrix will predominantly be hydraulic energy until 2050. The PNE 2050 Hydroelectric Power Plants (HPPs) projects have already been inventoried and are spread across all hydrographic basins. However, the vast majority of these projects are located in the Amazon and Araguaia-Tocantins river basins (Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2020), which are inhabited by river dolphins (Araújo & Wang, 2014). Within this plan, there is also the possibility of energy integration with other countries of Latin America, both in the sense of carrying out the modernization of existing HPPs, as well as in new construction projects (Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2020). Among the hydroelectric power plants proposed with the objective of supplying energy to Brazil and Bolivia, two HPPs were already built in the Madeira River, Santo Antônio and Jirau Dam, in Santo Antônio and Caldeirão rapids, respectively. Santo Antônio Dam closed its floodgates in August 2011, and Jirau Dam, in December 2012. The two HPPs now keep the waters of the Madeira River dammed, forming reservoirs of approximately 350 km^2 and 303 km^2 (Energia Sustentável do Brasil, 2010; Santo Antônio Energia, 2011). These reservoirs, which have already reached their maximum levels, have already submerged nine of the 18 rapids of this region, completely transforming the environment (Gravena et al., 2014a), and affecting the local fauna and flora, including human populations. The rapids were considered barriers to the movement of boto species, restricting the distribution of *I. boliviensis* upstream, and *I. geoffrensis* downstream. Interestingly, *Inia* individuals were found in the 290 km section between the rapids, but it was unclear which species they were from (Pilleri & Gihr, 1977; Tavera et al., 2010). Nowadays, it is known that the rapids did not act as barriers to the dispersion of *I. boliviensis*, which was able to overpass the barriers in the downstream directions, probably during river overflows. The Teotônio waterfall, initially considered a barrier to *I. geoffrensis* (Gravena et al., 2014b), was also surpassed by the botos, leading to the formation of hybrids (Gravena et al., 2015). The population of *I. boliviensis* restricted to the region between rapids was identified as genetically different, originating a different management unit (Gravena et al., 2015).

In order to monitor the boto population in the construction's influence area of the Jirau Hydroelectric Dam, we conducted active search of *I. boliviensis* in different sectors of the upper Madeira River. This study was part of an environmental impact study carried out from March 2010 to July 2015 as part of the Jirau Hydroelectric Dam construction licensing process. We aimed to compare the distribution of botos along the different sectors of the Jirau Dam before and after filling in the dańs influence area through quantitative analyses, once the dams increase sediment loads upstream. That change in the habitat might affect the diversity and prey biomass, consequently affecting the number of individuals in the different areas. Also, aspects of methodological patterns and data acquisition are discussed regarding the licensing process and undertaking of monitoring programs in accordance with Brazilian legislation.

2. Material and methods

2.1. Study area

The study area is located in the Jirau Hydroelectric Dam influence area, state of Rondônia, northewestern Brazil, comprising a 125 (Braulik & Smith, 2019; Gomez-Salazar et al., 2011; Guizada & Aliaga-Rossel, 2016; Peixun & Yuanyu, 1989) km stretch of the Madeira River, between the Jirau Dam (20M 8975671S/318597W) and the confluence between the Madeira and Abunã rivers (20M 8929802/232062S) (Fig. 1).

2.2. Study design and data collection

The 125 km stretch of the Madeira River assessed herein was divided into four sections, i.e., Abunã, Mutum, Caiçara and Canteiro (Fig. 1), beginning from upstream to downstream, where the dam was built. Field data collection was performed during 210 nonconsecutive days (21 fields campaigns) between March 2010 and July 2015, during four hydrological seasons namely: falling (waters going down: May, June and July), low (dry season: August, September and October), rising (waters going up: November, December and January) and high-water (full season: February, March and April) (Pivari et al., 2017). Four different research teams collected data over five years of boto monitoring. The different periods were compared to evaluate the abundance and distribution of this boto population during different time periods of the reservoir filling along the four sampled study areas. The data collected between March 2010 and August 2012 were considered the "before reservoir filling" (BRF) and between March 2013 and July 2015, "after reservoir filling" (ARF). Data were collected by active searches, applying the visual census technique (Fuller & Mosher, 1981; Fundación Omacha et al., 2008) using simple counts from an 5 m aluminum boat with a 15 or 30 HP engine driven at speeds between 5 and 10 km/h. Linear transects running parallel to both river margins (main shores) were pre-established (modified from Gomez-Salazar, Trujillo, Portocarrero-Aya, & Whitehead, 2012a). One river section along one of the margins was traversed each day, returning by the other side. Low water depths prevent access to several areas during the low hydrological season; consequently, surveys were conducted in the river's central channel. Two observers searched for boto groups at the bow of the boat, using binoculars. Each covered a 90° field of view ranging about 200 m each. The boat halted when boto groups were sighted and data concerning date, time, position (*Garmin Etrex Legend*, UTM, SAD 69), group size, group composition (e.g., adults, juveniles and calves) and behavioral activities (e.g., feeding, socialization, resting and travelling) were recorded. A group of river dolphins was defined, in this study, as a set of animals that are seen together within 250 m from the boat, likely engaged in the same activities, and does not necessarily correspond to a social group (see McGuire & Winemiller, 1998). Also, for the analysis we considered solitary individuals as group. The data registered were inserted in a database and converted into a map with the location of each boto group. Statistical analyses were conducted using the *Bioestat 5.0* software. Quantitative boto group data were analyzed by descriptive statistics (total number [N], range, median and standard deviation [SD]).

3. Results

Field effort corresponded to 968 h, during 210 non-consecutive days along the 250 km upstream stretch (travelled distance), comprising 43.072 km. The gathered data before reservoir filling consisted in 106 groups of botos (216 individuals), while the data after reservoir filling comprised 42 groups of botos (120 individuals). However, only part of the data was eligible for the analysis due to non-conformities related to data acquisition and failure to comply with the delimitations of the dams influence area that previously established by other researches. Despite these complications in data compilation, a total a total of 67 records were still considered for the analysis (Table 1).

It is important to highlight that is possible that some of the individuals were counted more than once. Yet, since our analysis focus on

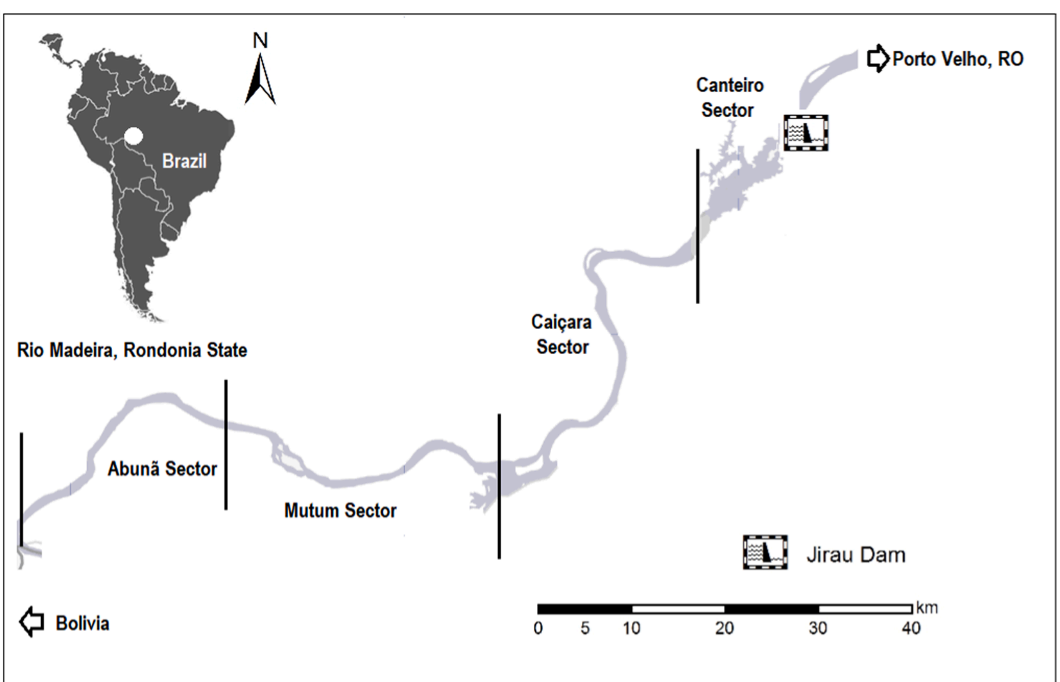

Fig. 1. Map indicating the Madeira River study area, located in Rondônia, Brazil, and the 125 km river stretch divided into four sections: Abunã, Mutum, Caiçara and Canteiro (where the dam is located).

Table 1
Sampling data (N = number of boto groups) obtained before and after reservoir filling in the Madeira River, Rondônia, Brazil. The data was obtained between the years of 2010 and 2015, in four different expeditions per year, totaling around 490 h of observations along a distance (km) in the Jirau Hydroelectric dam influence area.

Before Reservoir Filling (BRF)					After Reservoir Filling (ARF)				
Year	Effort (h)	Days	Distance(km)	Groups (N)	Year	Effort (h)	Days	Distance(km)	Groups (N)
2010	186:15:00	40	2688	13	2013	203:21:00	40	2817	12
2011	167:32:00	40	4275	07	2014	210:21:00	30	3179	18
2012	145:06:00	40	3052	09	2015	73:42:00	20	1706	08
Total	498:53:00	120	10,015	29	Total	487:24:00	90	7702	38

boto groups instead of individuals this bias did not affect the results. In total, 29 records of groups were sighted before and 38 after reservoir filling (Table 2).

The highest number of groups was recorded at the Abunã sector (N = 24), followed by Mutum (N = 5), Caiçara (N = 3) and Canteiro (N = 2) (Table 3; Fig. 2).

Comparing both periods (BRF and ARF) the highest number of groups was also registered at the Abunã sector (Table 3).

Regarding hydrological season, 30 records of boto groups were sighted during the low period, 19 during the falling water period, 10 during the rising period, and 8 groups during the high period (Table 4). Before the reservoir filling, 16 records were reported during the low season, followed by 6 during the rising, 4 during the high and 3 during the falling season. After reservoir filling, 16 records were performed during falling, 14 in low, 8 in high and 4 in rising seasons (Table 4). Fig. 3 presents the number of boto groups reported by sector and hydrological season before (BRF) and after reservoir filling (ARF).

4. Discussion

Historically, upstream dam reservoirs can have lower nutrient availability, smaller prey biomass and minor density overall (Perrin & Brownell, 1989). Nutrient enrichment and increased sedimentation rates can, in fact, become significant issues in these areas (Reeves & Leatherwood, 1994). The formation of a reservoir typically changes river dynamics from lotic to lentic environments, with specific physical, chemical and biological characteristics that distinguish this artificial ecosystem from natural rivers and lakes (Baxter, 1977). Even through, the largest number of sightings was recorded ARF in the upstream stretch of the Madeira River. This value might be misinterpreted since surveys carried out after the dam construction were performed only during reservoir filling periods (2013, 2014 and 2015), and there is an inconsistency of data prior to filling. It is possible that the number of botos occurring in the area BRF was greater since part of the monitoring effort occurred beyond the dam's influence area delimited for the monitoring plan. Groups of botos were recorded outside, but nearby the delimited study area, so it is possible that they used the study area, but records were not computed. It is essential that the boto population in the upstream stretch of the Madeira River is continuously monitored to verify possible alterations during dam operations.

About 80% of the boto groups were reported in the Abunã sector during our monitoring of the 125 km stretch between the Abunã sector and the Jirau dam. In the upper Abunã area, the Abunã River flows directly into the Madeira River, which until recently experienced intense ferryboat traffic to transport cars, motorbikes and trucks on the federal highway BR364, which connects the states of Rondônia and Acre. Despite intense ferryboat traffic in the upper Abunã area, this is the most preserved area of all the studied area and still exhibits margins with forests and floodplains. Abunã is also the most distant sector of the dam and is the area with lower direct impact from the dam construction.

Table 2
Quantitative analysis of boto groups observed before and after reservoir filling in the Madeira River, Rondônia, Brazil. Range = variation in individuals' number within group; SD = Standard Deviation.

N_{Groups}	$N_{ind.}$	Range	Mean	SD
Total (N = 67)	173	1–8	2.58	1.47
BRF (N = 29)	62	1–4	2.14	1.16
ARF (N = 38)	111	1–8	2.92	1.60

The Abunã River is a blackwater river, while the Madeira is a whitewater river that carries a lot of suspended sediments. The confluence between these two areas might result in abundant and available food resources (Leatherwood et al., 2000; Magnusson et al., 1980; Meade & Koehnken, 1991). A similar assumption was noted by previous assessments carried out by Araújo and da Silva (2014), Pivari et al. (2017), who reported the highest density of *I. araguaiaensis* in the confluence areas of the Araguaia River. Other studies of the genus in the Amazon and Orinoco basins also report high boto concentrations in river confluences areas (Aliaga-Rossel & Duran, 2020; Gomez-Salazar, Trujillo, Portocarrero-Aya, & Whitehead, 2012a; Martin, da Silva, & Salmon, 2004; Vidal et al., 1997). River confluences are described as a preferred habitat for botos mainly because it is considered a non-high energy-consuming habitat, but also because of the greater availability of fish prey (Martin & da Silva, 2004).

After Jirau dam closing in December 2012, high densities of botos were still recorded in the Abunã sector, which had an increase flooded area while maintaining its forested margins. The Abunã and Madeira confluence area is the upper extreme point of the construction's influence area, and probably the construction and filling of the reservoir did not change the biological characteristics of the area. The Abunã and Madeira rivers' confluence still results in available food resources, which aggregate a greater number of botos feeding in the area, which has already been described for other regions (Aliaga-Rossel & Duran, 2020).

The majority of boto groups were recorded during low and falling hydrological seasons, in both assessed periods (BRF and ARF). Aquatic productivity in the Amazon basin is directly affected by extreme seasonal changes (Gomez-Salazar, Trujillo, Portocarrero-Aya, & Whitehead, 2012b). The main channel areas are inundated during the rising and high water seasons, forming floodplains (Hamilton & Lewis, 1990) that increase aquatic productivity (Barthem & Goulding, 1997). During the rising and high hydrological seasons, botos explore the local flooded forests (Martin & da Silva, 2004), as fish migrate from rivers into the newly created floodplains to feed and reproduce (Barthem & Goulding, 1997; Fernandes, 1997; Henderson, 1990). The opposite is noted during the falling and low hydrological seasons, where greater boto concentrations are recorded in main river channels (Martin & da Silva, 2004), especially in meanders or curves along the main river course and confluences (Aliaga-Rossel & Duran, 2020). During these seasons, the water from the floodplains drains into rivers and riverine resources are, therefore, concentrated and easily accessed by predators (Gomez-Salazar et al., 2011), which may facilitate foraging and reduce competition between group members (Best & da Silva, 1989; Hamilton & Lewis, 1990; Junk et al., 2007). Larger *I. boliviensis* groups in the Bolivian rivers have been observed during the falling and low hydrological seasons while smaller groups are noted during the high-water periods (Aliaga-Rossel, 2002). Therefore, our results regarding the variation of group sizes are expected in riverine dolphins due the variation of resources during low and high-water cycles, even after the construction and filling

Table 3
Quantitative analysis of boto groups observed in each season of reservoir filling (before/ after) in four sectors of the Madeira River, Rondônia, Brazil.

Before Reservoir Filling						After Reservoir Filling				
Sector	N_{Groups}	N_{ind}	Range	Mean	SD	N_{Groups}	N_{ind}	Range	Mean	SD
Abunã	24	50	1 – 4	2.08	1.10	33	101	1 – 8	3.06	1.66
Mutum	2	3	1 – 2	1.50	0.71	3	7	2 – 3	2.33	0.58
Caiçara	2	7	2 – 5	3.50	2.12	1	1	–	–	–
Canteiro	1	2	–	–	–	1	2	–	–	–

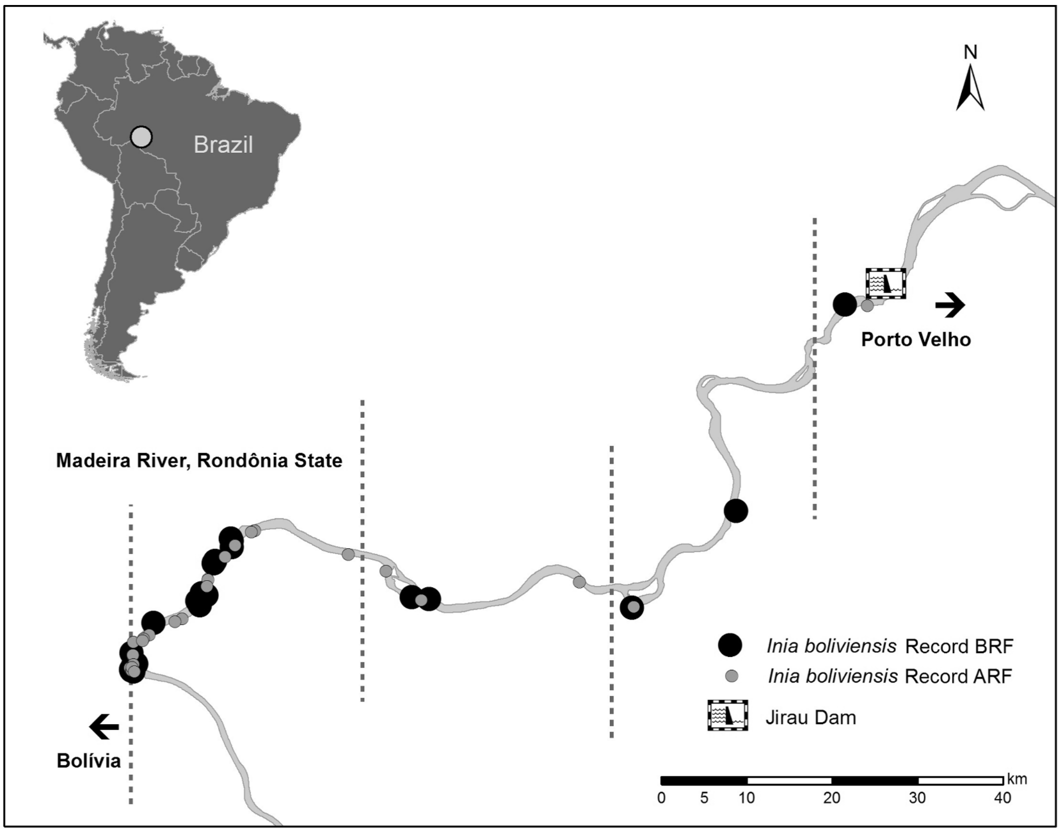

Fig. 2. Spatial distribution of *Inia boliviensis* groups observed in each stretch of the 250 km of Madeira River stretch, Rondônia, Brazil, Before (BRF) and After Reservoir Filling (ARF).

Table 4
Quantitative analysis of boto groups obtained in each season of reservoir filling (before/ after) in the four hydrological seasons of the Madeira River, Rondônia, Brazil.

Before Reservoir Filling						After Reservoir Filling				
Season	Groups	N_{ind}	Range	Mean	SD	Groups	N_{ind}	Range	Mean	SD
Low	16	38	1–4	2.38	0.96	14	41	2–4	2.93	0.83
Falling	3	10	2–5	3.33	1.53	16	51	1–8	3.19	2.17
Rising	6	7	1–2	1.17	0.41	4	11	1–5	2.75	1.71
High	4	7	1–4	1.75	1.50	8	15	1–4	1.88	1.13

of the reservoir of the Jirau hydroelectric dam.

Brazilian legislation for large man-made structures requires specific steps for implementation and operation. First, an Environmental Impact Assessment study must be presented to the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), the Brazilian Ministry of the Environment's administrative branch. This assessment must comprise a species characterization throughout the construction's influence area during different seasons, as well as the impacts the construction might cause, and mitigating measures to minimize these impacts. IBAMA then evaluates the proposals and in the case of granting the license, it is divided into three phases: the prior license, the implantation license, and the operating license. During and after the construction, the company must carry out monitoring studies reported in the form of an Environmental Impact Report (EIR) (Alho, 2011). Despite the financial investments and effort, most of the data gathered by licensing and monitoring programs realized for the EIR are difficult to properly analyze, due to bias in the applied methodologies.

In this study, BRF and ARF data could not be statistically compared, due to a non-standardized methodology. Additionally, a lack of unified training of the team to register the data may have led to different counts due to visual acuity. Implementing a standardized methodology performed by experienced specialists (preferably the same ones) during the

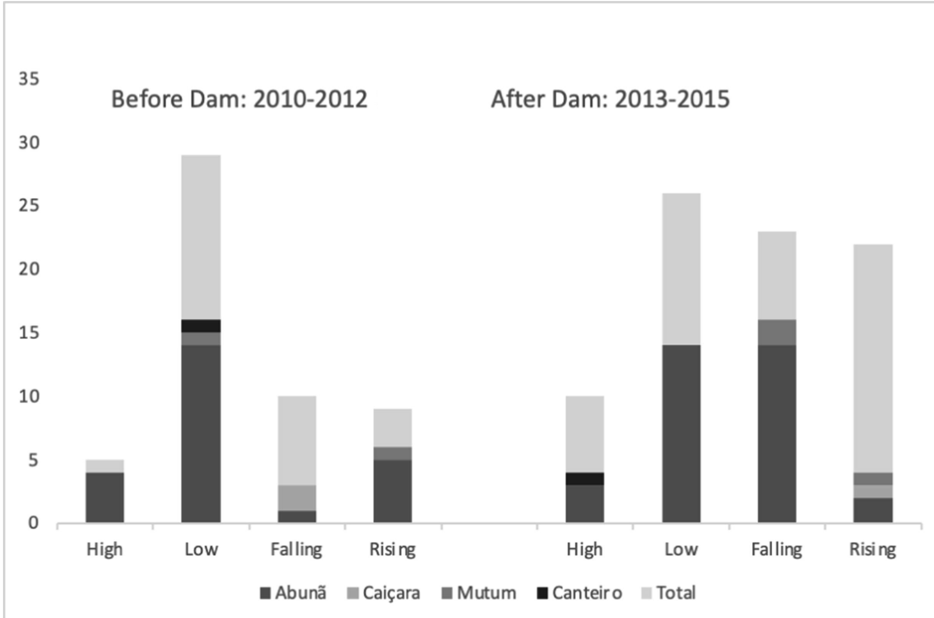

Fig. 3. Number of boto groups records before (BRF) and after (ARF) the Jirau dam construction per hydrological season per sector in Madeira River.

entire survey period is, thus, essential to provide adequate estimates for dolphin monitoring.

Problems with no updated and lack of standardization methodology, in addition to little experience of some consultants can generate questionable results. Those inaccurate results served as a basis for the elaboration of a technical document that was presented by the hydroelectric company to obtain two of the licenses to build the dam, the prior and the installation licenses. Because of the problem described above, it is difficult to evaluate the level of impact on which the botos are being affected. Standardization of the methodology, hiring of specialist consultants and maintenance of the team throughout the whole study are measures that may provide a better assessment of the impact. Yet, it is necessary to establish a committee whose experts not only facilitate dialogue between different social sectors, but also help to improve the designs of monitoring programs for the conservation of key species and ecological communities (Alho, 2011). Government agencies, scientists, NGO managers and large-scale companies together with society agents must be truly representative, combining their needs and policies with less impact on the environment. Through adequate management, we can ensure the maintenance of boto populations over time and along their original distribution.

The protective measures are urgent. In addition to these two dams that are already operating in the Madeira River, Santo Antônio and Jirau Dams, there is still the intention of the Brazilian government, together with the government of Bolivia, to build two other dams upstream, in the Mamoré and the Beni Rivers. The two proposed HPPs are the Ribeirão Dam, also called Guajará-Mirim Dam, which will be built on the Ribeirão rapids located downstream from the Guajará-Mirim municipality; and the Esperanza Dam, located under the Esperanza rapids or Cachuela Esperanza, on the Beni River, in Bolivia (Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2020). If these two additional dams are built, *I. boliviensis* populations will be even more fragmented, and divided into three distinct reservoirs, which will again restrict their movements and gene flow (Gravena et al., 2014a). This already occurs with *I. araguaiaensis* populations that inhabits Araguaia-Tocantins Basin (Hrbek et al., 2014). Along the Tocantins River there are seven HPPs in operation and four proposed HPPs, all of them overlapping the distribution of the Araguaian river dolphin. According to Araújo and Wang (2014), nowadays botos from Tocantins River are fragmented into eight groups, and if these four proposed dams were constructed, they will be fragmented into 12 separate units (Araújo & Wang, 2012). River dolphins along the Amazon basin are endangered species and among several threats faced by those species, the fragmentation and isolation of populations caused by the constructions of hydroelectric dams are one of the most relevant (da Silva et al., 2018). Small populations that are restricted to certain environments tend to have high levels of inbreeding due to the lack of gene flow with other populations. This can reduce their genetic diversity and cause them to enter the vortex of extinction. This happens when a stochastic event, such as variations in the rates of birth and death or in the sexual proportion of the population, environmental or epidemic catastrophes, all can lead to an accelerated population decrease that can even reach extinction (Frankham et al., 2010).

Other river dolphin's species around the world are threatened by similar anthropogenic impacts and little is known about it. Hydroelectric Dams and irrigation barrages constructed along the rivers severely impact both the Indus River Dolphin (bhulan) (*Platanista minor*), and the Ganges River susu (*Platanista gangetica*) (Braulik et al., 2021), which are classified as endangered (EN) by the IUCN (Braulik and Smith, 2019). The extinction of the Chinese baiji (*Lipotes vexillifer*) (Turvey et al., 2007) were probably caused by extensive modifications of the Yangtze River, which includes dam building, unregulated boat traffic, noise pollution and fishing practices (Peixun and Yuanyu, 1989).

Understanding the effects of dam constructions, the habitat modifications and what fragmentation caused by the dams, can help us to minimize the already impacted populations of botos. Therefore, we recommend long-term monitoring in all the influence areas of the reservoir, even after the HPP starts to operate. Since the water levels influence the availability of fish prey, fluctuations on that particular environmental parameter through time can contribute to evaluation of the boto distribution patterns.

5. Conclusions

A higher number of boto records were observed after the Jirau reservoir filling, in the Abunã sector, during the falling and low hydrological seasons. This is probably due to the fact that this is the most preserved area in the 125 km Madeira river stretch assessed here. In addition, available and abundant food resources due to the presence of a blackwater and whitewater confluence in the Madeira and Abunã rivers was also noted, while decreased water levels due to the dry season also led to higher prey availability, thus concentrating the botos in these areas. Also relevant to the Abunã sector is the construction of a bridge connecting the states of Rondônia and Acre, and consequently the closure of ferryboat operations in May 2021. In the long-term, this change may result in less impact for the botos that occur in this important confluence area. Thus, we suggest that the Abunã sector can be a priority area for conservation in the influence area of the dam.

A standardized methodology executed by aquatic mammal specialists during the entire survey period is also essential to provide adequate estimates for the monitoring of riverine dolphin population. We recommend long term monitoring to study how the dam construction affects boto occurrence patterns and prey distribution.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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