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REVIEW

Four decades of research on distribution and abundance of the Bolivian river dolphin *Inia geoffrensis boliviensis*

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ABSTRACT: The Bolivian river dolphin, known locally as the bufeo, is one of 4 species of river dolphin in South America. Endemic to the upper basin of the Madeira in the Bolivian Amazon region, the species is categorized as Endangered on the IUCN Red List. This article provides information related to the geographic distribution of the species, and a review of the studies of its abundance that have been conducted in Bolivia since the 1970s. We discuss the surveys, the analysis methods used in the different studies, and the ways in which these methods might influence the population estimates. We found 63 population abundance estimates for the Bolivian river dolphin across 17 reviewed publications. These studies report relative abundance data for rivers that range from 0.2 to 2.81 bufeos km^{-1}, and density ranges from 0 to 7.59 bufeos km^{-2}. The information presented here reflects the knowledge of the population size of the species in Bolivia obtained over 4 decades, and will be useful for developing conservation strategies and as a tool for decision makers.

KEY WORDS: Abundance · *Inia boliviensis* · Bolivian river dolphin · Upper Madeira basin · Bolivia

1. INTRODUCTION

There are several species of dolphins adapted to inhabit exclusively freshwater rivers in Asia and South America. This restriction to certain rivers or deltas makes them extremely vulnerable to habitat destruction and human impact, as has been observed for the Asian species that are particularly in danger of immediate extirpation. Two of the most endangered dolphins worldwide include the South Asian river dolphins *Platanista gangetica*, classified as Endangered, and the baiji *Lipotes vexillifer*, which is listed as Critically Endangered but is currently known from less than 10 individuals and needs to be reclassified to Extinct (Smith et al. 2017). During the last 10 yr, the threats to the South American river dolphins (*Inia geoffrensis*, *Sotalia fluviatilis*, and the recently described *I. araguaiensis*) have also been increasing, driven by the current governmental policies of natural resource extraction that are putting a lot of pressure on the habitat and resources of these animals.

The Bolivian river dolphin *I. geoffrensis boliviensis*, locally known as bufeo or Bolivian bufeo, is an endemic sub-species of the Madeira sub-basin rivers (Aliaga-Rossel 2003). The Bolivian population is geographically isolated from Amazonian river dolphin populations (*I. geoffrensis* and *S. fluviatilis*) by cascades or rapids on the river between Guayaramerin, Bolivia and Porto Velho, Brazil (Aliaga-Rossel 2002, Ruiz-García & Shostell 2009, Aliaga-Rossel & McGuire 2010, Gravena et al. 2015). Some studies have indicated that this isolation may have occurred as early as the Pliocene (5 to 6 million years ago), caus-

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ing an allopatric separation from the other *Inia* populations in the Amazon basin (Hamilton et al. 2001, Gravena et al. 2014). Comparative mitochondrial DNA sequence analysis has been used to clarify the relationship of species included in the genus *Inia* (Hamilton et al. 2001, Banguera-Hinestroza et al. 2002). Gravena et al. (2014) divided *I. boliviensis* into 2 isolate groups, including populations upriver (Madeira sub-basin) and downriver (in Brazil) that diverged approximately 122 thousand years ago. Despite all these publications that recognize the Bolivian river dolphin as a distinct species (*I. boliviensis*) (Ruiz-García et al. 2006, 2008), the Integrated Taxonomic Information System (ITIS) and the International Union for Conservation of Nature (IUCN) recognize only 1 species of *Inia* with 2 subspecies, including *I. g. geoffrensis* (Blainville, 1817) and *I. boliviensis* (d'Orbigny, 1834); in addition, the ITIS system does not recognize the recently described species *I. araguaiensis* (Gravena et al. 2014). W. Gravena (pers. comm.) is currently writing a response to the IUCN committee with the aim of clarifying the specific status of *I. boliviensis*. However, and irrespective of the current taxonomic melee, these river dolphin populations require immediate attention in terms of their conservation. The local name 'bufeo' is the only officially recognized name of these animals in the country; therefore, we will refer to this name throughout the rest of this paper. This differs from the name designated by the International Whaling Commission (IWC), 'boto', which is a word of Brazilian origin and is unknown in Bolivia, Colombia, Ecuador, Peru, and Venezuela.

In Bolivia, the bufeo has been declared a Natural Heritage of the Plurinational State of Bolivia (Law No. 284/2012). In addition, the local Regional Government of Beni (Decree No. 28/08) recognizes the need for additional protection and further understanding of the Bolivian bufeo, declaring it as a natural heritage and a symbol of the Santísima Trinidad City (Municipal Law No.12/2012). The Red List of Vertebrates of Bolivia lists these animals as Vulnerable (Tarifa & Aguirre 2009). Even with these actions and the designation as an endangered species, anthropogenic threats to the viability of bufeo populations throughout their range have increased, thus intensifying the pressure placed on this species. Notably in the last categorization of the Red List of Threatened Species the IUCN declared the bufeo to be Endangered (da Silva et al. 2018a), stating the necessity to increase the level of information about its population size, distribution, abundance, and population trends.

For any species of mammal, obtaining accurate estimates of population size is key for evaluating impacts, monitoring, and designing conservation strategies. Some attempts to estimate the total population number of bufeos living in Bolivia have been made by Ruiz-García (2009), and, based on molecular analysis, they proposed a range between 51 000 and 152 000 individuals. In contrast, Tavera et al. (2010) extrapolated an estimated population size between 80 000 and 100 000 dolphins, although they failed to detail the method used to make this estimation. For the area in Brazil where the Bolivian bufeo occurs, V. M. F. da Silva (unpubl. data) suggested the population is 8 to 10 times smaller than the Amazonian populations, while Gravena et al. (2014) estimated an effective genetic population size of 102 000 Bolivian bufeos in the entire region. These estimations may all present a bias because they do not consider differences in habitat quality or any threats that may be decimating the bufeo population. For example, the low numbers and even absence of bufeos in river sections within increasingly larger commercial/industrialized plantations for soybeans and sugar cane are caused by the reductions in water levels in rivers and perhaps also the unmitigated channelization and diversion of rivers with the sole purpose of providing irrigation water to agro-industrial crop plantations. These are zones where dolphins frequently get stranded and die without any record being made of the numbers (Aliaga-Rossel & Escobar-WW 2020).

This review includes aspects related to the geographic distribution and abundance of this threatened species and contains data from a recent survey, a description of the methods used in all the studies, and a review of population sizes in Bolivia. In addition, we discuss evidence of a possible decline in the density of the bufeo. The information presented here comprises a synthesis of more than 4 decades of studies and the current knowledge concerning the population status of the species in Bolivia. This information is essential for the development of conservation strategies and constitutes a tool that is available for decision makers.

2. METHODS

2.1. Literature review

We reviewed published literature (n = 11), theses (n = 4), and doctoral dissertations (n = 2) in English, Spanish, and Portuguese relating to the abundance of Bolivian bufeos. Using the compiled information,

we discuss the methods frequently employed, the rivers surveyed, and the population index that can be derived from these sources.

2.2. Survey conducted in one river to update information

To obtain more up-to-date information about the bufeo population, we conducted new survey transects using standardized methods applied to river dolphins, as detailed in Section 3. This data is presented in Table 3 as E. Aliaga-Rossel et al. unpubl. data.

3. RESULTS

We reviewed 17 publications containing data on Bolivian river dolphin abundance that described 63 surveys (sampling events) located in 20 different rivers. We summarize statistics of the information generated in the span of approximately 40 yr of studies on the Bolivian bufeo throughout the area of its distribution.

3.1. Survey and analysis methods

3.1.1. Methods used in river dolphin surveys

The methodologies used most often for abundance estimations of bufeo populations in Bolivia include (1) strip-width transect, (2) line transect, and (3) a combined method transect. All studies were conducted from boats and, in the majority of studies, the boat travelled at a constant velocity from 7 to 10 km h^{-1} in tributaries and 10 to 16 km h^{-1} in main rivers. The velocity was related to the water current and outboard motor power. Depending on the season, the majority of transects were conducted from 07:00 to 18:00 h, with a resting period of 1 to 2 h at noon. Transects depended on good visibility and were suspended if climatic conditions were unfavorable, such as rain or strong winds (>13 km h^{-1}) that might impair visibility (the majority of the Bolivian studies followed the method detailed by Aliaga-Rossel 2002). For each encounter with bufeos, the number of individuals was recorded, and multiple individuals within a radius of 25 m were considered a group.

The strip-width method is used when the river margins are less than 200 m wide, as in tributaries and channels. The vessel navigates through the center of the waterway and the average strip-width is calculated. Two observers are stationed on each side of the bow of the boat, giving 120° total coverage, each with a 60° angle of detection. In order to confirm encounters, a third person observes dolphins behind the boat.

The modified line transect method consists of straight navigation of the river (with temporary course alteration if needed) and is used in main rivers wider than 200 m. Generally, this method divides samples into 2 transects: one upstream and one downstream. (Aliaga-Rossel 2002, Aliaga-Rossel et al. 2006, Salinas 2007, Aliaga-Rossel & Quevedo 2011, Guizada 2011). In general, 2 platforms are used, one at the bow in front and one astern. Two observers in the bow, or front, of the boat record bufeo encounters, a field assistant registers data such as sighting data, habitat characteristics etc., and a further one or more observers are stationed at the stern who independently register and/or confirm encounters. Gomez-Salazar et al. (2012) divided every 50 to 200 m with respect to the shore to categorize the bands. Depending on the river width, the 200 m transects were parallel to the banks along the river margins of each river, maintaining an average distance of 100 m from the shore.

A variation of the line transect method was performed by Morales (2012), who divided the main transect into sub-transects according to distance or time traveled on the main transect (sub-transects of 1.5 km each).

The combined method involves a combination of transects running parallel (200 m strip-width transects) and at 45° (cross-channel line transects) to the shore (Guizada & Aliaga-Rossel 2016). Strip-width transects of 200 m run parallel to the banks along the margins of each river, maintaining an average distance of 100 m from the shore. When the river margins are <200 m wide in some tributaries and channels, the vessel navigates through the center of the waterway and the average strip-width is calculated by measuring the distance to each shore with laser range finders. Cross-channel line transect routes are conducted by selecting a starting point for the vessel to turn at an angle of approximately 45° towards the other bank, where another 200 m strip-width transect begins. These turns are made when at least 1 strip transect is complete and in places where the boat captain considers it safe and convenient to cross the river in order to avoid obstacles such as rocks, islands, large floating objects, and shallow areas (Vidal 1997, Trujillo 2000, Gomez-Salazar et al. 2012).

Some studies (Painter 1994, Anderson 1997, Salinas 2007, Aramayo 2010, Morales 2012) did not detail

methods or did not use a standardized method and cannot be compared with other studies carried out in the same areas or years.

3.1.2. Methods used to obtain river dolphin abundance

The most traditional and conservative analysis used in the surveys was direct calculation. In these analyses, the relative abundance index (AB_{rela}) and the absolute density (D) were calculated using the following formulas:

$$AB_{rela} = \frac{\text{no. sighted}}{\text{route}}; D = \frac{\text{no. sighted}}{\text{area}} \quad (1)$$

where no. sighted is the number of sighted individuals, route is distance travelled in km, and area is the area covered.

In the latest studies carried out elsewhere, the software 'Distance®' is widely used to estimate animal population densities (Buckland et al. 2001, Thomas et al. 2010), but this was not used in the majority of the studies reviewed for Bolivia. It is therefore necessary to standardize and understand the basic and essential assumptions for estimations of density: (1) all animals on the trackline were detected with certainty, (2) dolphins did not respond to the vessel (the speed was constant and fast enough to prevent bufeos following the boat), (3) distances were measured accurately (Thomas et al. 2010). Distance® contains the 'Mark Recapture Distance Sample (MRDS)' package, which is used for those studies that violate the first assumption of the method, as is the case for studies of cetaceans such as bufeos given the inherent difficulties in observing them and their discrete behavior. However, this package is also recommended for studies with a double observation platform (Gomez-Salazar et al. 2012).

The program Distance® considers some parametric key functions (i.e. the half-normal, the hazard-rate, or the uniform), and adds some adjustment terms (cosine or polynomial) to these to improve the model fit to the data (Thomas et al. 2010). By using the standard model selection tool, it is possible to find a model that fits well with the data and then proceed to estimating density.

Distance® is a good tool for standardization in data collection and facilitates the calculation of population size and local density, although in addition to abundance, it is necessary to take more measurements with respect to the observer. There is still some controversy concerning the adequate use of the software, mainly due to the assumptions required by the method (Buckland et al. 2001). Distance® provides different statistical packages to make estimates based on data. These include CDS (Conventional Distance Sampling), MCDS (Multiple-Covariate Distance Sampling), MRDS, and DSM (Density Surface Modelling). Depending on the package used, the data are adjusted with different detection functions that generate models that can be selected based on Akaike's Information Criterion (AIC) (Thomas et al. 2010).

3.2. Synthesis of information on the abundance and distribution of bufeos

3.2.1. Distribution and habitat of *Inia* in Bolivia

The distribution of bufeos in the tropical rivers of Bolivia is limited to 3 sub-basins: Mamoré, Iténez, and Abuna (see Fig. 1). They are not present in the Beni sub-basin due to the inaccessibility of the Beni above the rapids at Cachuela Esperanza. The rivers where bufeos were found consisted mainly of 2 water types: (1) whitewater, turbid rivers of Andean origin that are high in nutrients, with a neutral pH and suspended load; (2) clear waters, characteristically low in nutrients and low in dissolved or suspended solids (Albert & Reis 2011). The clear waters typically flow from dense rainforest, and the transparent water is stained dark from the tannic acids of decaying vegetation (Aliaga-Rossel 2002). The main habitat characteristics described or mentioned in all the studies are detailed in Table 1.

Throughout the entire studied area, the mean temperature is 26.5°C and precipitation varies from 1200 to 2400 mm yr^{-1}. The rainy season usually extends from November to early April. The hydrologic regime is tightly linked to precipitation, presenting a unimodal curve with the highest water levels occurring between December and March, while the lowest water levels are observed from June to early October (Loubens et al. 1992, Pouilly & Beck 2004). This variation in seasonal precipitation leads to correlated dramatic changes in water levels in the river systems throughout the year (Aliaga-Rossel & McGuire 2010). Several of the studies indicated that bufeos concentrate near the confluences of rivers during the low-water season (Best & da Silva 1989, McGuire & Winemiller 1998, Aliaga-Rossel 2002, Aliaga-Rossel et al. 2006, Gomez-Salazar et al. 2012, Guizada & Aliaga-Rossel 2016), while during the high-water season, they move into lakes, flooded forests, or small tribu-

Table 1. Habitat types in the studied rivers in Bolivia. Definitions based on Aliaga-Rossel (2002), Aliaga-Rossel & McGuire (2010), Trujillo et al. (2010), Albert & Reis (2011), and Gomez-Salazar et al. (2012)

Habitat type	Main characteristics
Main river	Rivers of Andean origin. Waters are typically white, dark, or a yellowish-brown color, with little transparency due to the large quantity of suspended sediment. In Bolivia: more than 200 m wide. Examples: Rivers Mamoré and Iténez.
Tributaries, affluent	A stream or river that flows into a larger stream, main stem, main (or parent) river, or a lake. Water in tributaries is usually black and clear, originating from the flooded forest plains, with few suspended sediments and relatively acidic, high in tannins and particulate organic matter. Examples: Rivers Ibare, Tijamuchi, Niquisi, and Yacuma.
Confluences	Where 2 or more bodies of water meet. These are areas where a tributary discharges its water into a main river. May or may not present a mix of 2 types of water, for example, white and blackwaters.
Curves or bends	Places where the river bed is wide and has a higher than average current.
Lakes and lagoons	Area of variable size filled with water, surrounded by land, apart from any river or other outlet that serves to feed or drain the lake. Have unique physical and chemical characteristics (e.g. water color, pH, transparency) and geomorphology, and are therefore classified as distinct habitat and ecosystem types. Some are old river channels that have become isolated over time.

taries (Aliaga-Rossel 2002, Martin et al. 2004), which become significant habitats due to their high productivity and prey diversity (da Silva 1994, Martin et al. 2004).

The Bolivian bufeo was found in tropical rivers of the departments of Cochabamba, Santa Cruz, Beni, and Pando (Fig. 1). However, approximately 90% of the distribution area was in the Beni rivers (Aliaga-Rossel & McGuire 2010). To date, all the studies have focused on 2 main sub-basins, the Mamoré River and the Iténez River (Fig. 2). It is important to emphasize that 67.7% of the studies were carried out during the last decade (2008–2018).

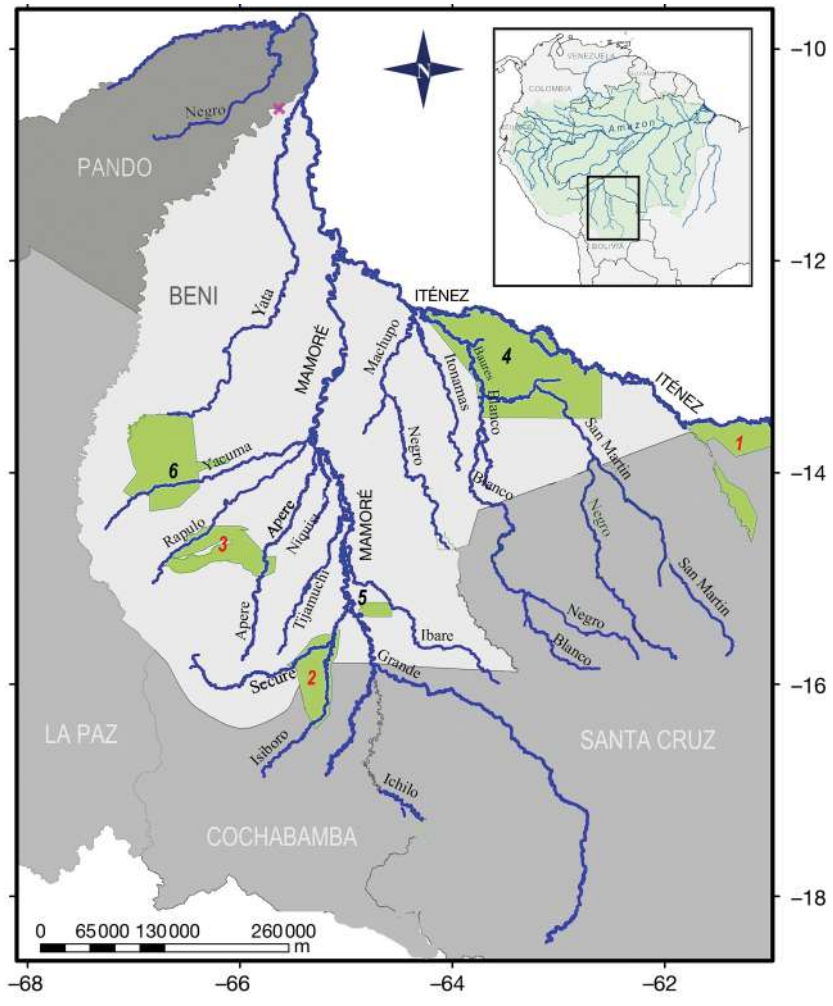


Fig. 1. Distribution of Bolivian river dolphin (bufeo) in Bolivia in the Departments of Pando, Beni, Santa Cruz, and Cochabamba. Protected areas are indicated in green. 1: Noel Kempff Mercado National Park; 2: Indigenous Territory and National Park Isiboro-Securé (TIPNIS); 3: Beni Biological Biosphere Reserve (EBB); and the 3 subnational areas 4: Departmental Park (PD-AMNI Iténez); 5: Ibare Mamoré Municipal Protected Area; 6: Pampas de Yacuma Municipal Protected Area. The pink cross indicates Cachuela Esperanza. This is a rocky area with rapid waters, and constitutes a barrier for bufeos in the Beni and Madre de Dios rivers

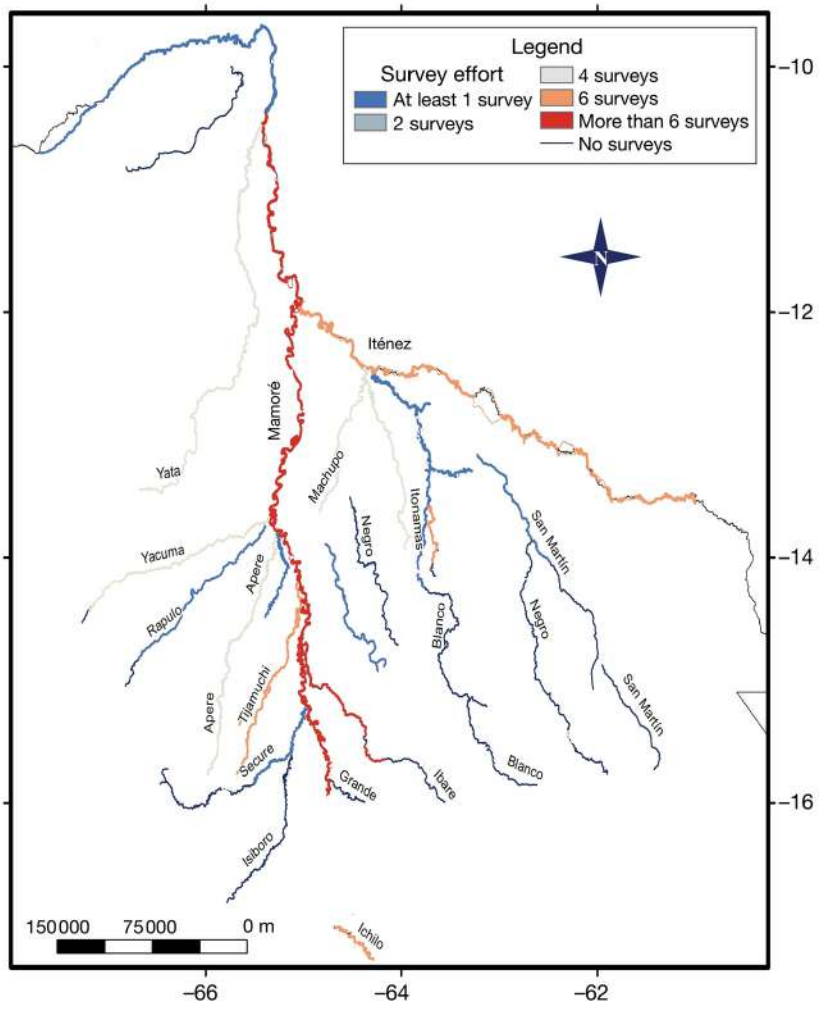


Fig. 2. Effort in each river based on the number of reported surveys. Segments of Mamoré River were the most surveyed (with more than 6 surveys), followed by the Tijamuchi River, with 6 surveys

Table 2. Surveys from different years and the systems evaluated. (a) Percentage of published studies on the Bolivian bufeo (*Inia geoffrensis boliviensis*) that were conducted in each habitat type (lagoon, tributary river, main river), and the percentage of the total number of rivers evaluated with respect to total rivers with bufeos in Bolivia. Lagoons were surveyed independently. (b) Percentage of studies conducted per period of time

(a) Habitat	Percentage of studies (N)	Percentage of no. of rivers
Lagoon	4.7 (3)	Not evaluated
Tributaries	67.2 (43)	35.4
Main river	28.1 (18)	7.8
(b) Time period	No. of studies	Percentage of studies
Before 2000	5	7.8
2000–2007	15	24.6
2008–2018	43	67.7

Of the 63 surveys investigating population size in Bolivia, which together accumulated more than 5000 surveyed kilometers, 67.2% studied tributaries (corresponding to 35% of the tributaries in the country in which the species has been recorded), 28.1% studied main rivers, and 4.7% lagoons (Table 2).

In Bolivia, there are 3 national protected areas where bufeos occur: the Noel Kempff Mercado National Park, Indigenous Territory and National Park Isiboro-Securé (TIPNIS), and Beni Biological Biosphere Reserve (EBB). There are also 3 subnational areas: the Departmental Park (PD-AMNI Iténez), Ibare Mamoré Municipal Protected Area, and Pampas de Yacuma Municipal Protected Area (Fig. 1). Only 21% of the area of bufeo distribution is protected by a conservation unit of the country. These protected areas are the only areas where the bufeo is relatively well protected; however, water quality in these areas is often reduced due to the contamination coming from upriver mining, extensive agriculture, or the discharge from big cities such as Cochabamba, Santa Cruz de la Sierra, and Trinidad (Aliaga-Rossel & McGuire 2010).

3.2.2. Abundance of *Inia* in Bolivia

The relative abundance found in the Bolivian rivers that were surveyed (Table 3) varied from the lowest registered in the Madeira River (0.02 bufeos km^{-1}) to the highest in the Rapulo River (2.64 bufeos km^{-1} in 2005). Other high encounters were found: 2.81 (Apere surveyed in 2005), 2.70 (Machupo in 2014), 2.54 (Niquisi in 2009), and 9.50 bufeos km^{-1} (Tijamuchi in 1998) (Fig. 3). However, some of the surveys were only a few km from the confluence, which can bias the results. The mean relative abundance of the total area was 0.92 ± 0.75 bufeos km^{-1} (mean ± SD), with a mean relative density of 1.02 ± 3.59 bufeos km^{-2}.

Table 3. Abundance of the Bolivian river dolphin *Inia geoffrensis boliviensis* in Bolivian rivers (SD: standard deviation; Min: minimum; Max: maximum)

River	Variable	No. of surveys	Median	SD	Min	Max	Reference
Abuna[a]	Abundance	1	0.12	0	0.12	0.12	Salinas et al. (2010)
Apere	Abundance	2	2.04	1.09	1.27	2.81	Aliaga-Rossel et al. (2006), Aliaga-Rossel et al. (2012), Morales (2012)
Apere	Density	2	0.02	0.01	0.01	0.03	
Bajo Mamoré[a]	Abundance	1	0.35	0	0.35	0.35	Salinas et al. (2010)
Blanco	Abundance	3	0.67	0.82	0.16	1.62	Painter (1994)
Blanco	Density	1	47.70	0	47.70	47.70	
Blanco_baures	Abundance	1	0.13	0	0.13	0.13	Aliaga-Rossel & Guizada (2017), E. Aliaga-Rossel et al. (unpubl. data)
Blanco_baures	Density	1	0.01	0	0.01	0.01	
Ibare	Abundance	9	1.39	2.20	0.39	7.20	Pilleri (1969), Pilleri & Gihr (1977), Aliaga-Rossel & Quevedo (2011), Aliaga-Rossel et al. (2012)
Ibare	Density	7	0.05	0.07	0.01	0.02	
Ichilo[a]	Abundance	1	0.25	0	0.25	0.25	Pilleri & Gihr (1977)
Ichilo-Mamoré	Abundance	2	1.26	0.05	1.22	1.29	Tavera et al. (2011), Morales (2012)
Ichilo-Mamoré	Density	1	0.01	0	0.01	0.01	
Ipurupuru[a]	Abundance	1	1.17	0	1.17	1.17	Pilleri & Gihr (1977)
Iténez	Abundance	3	1.08	0.55	0.47	1.55	Gomez-Salazar et al. (2012), Tavera et al. (2011)
Iténez	Density	3	3.64	3.65	0.40	7.59	
Itonamas	Abundance	2	0.46	0.28	0.26	0.66	Aliaga-Rossel & Guizada (2017)
Itonamas	Density	2	0.01	0.0043	0.01	0.02	
Machupo	Abundance	2	1.40	1.84	0.10	2.70	Aliaga-Rossel & Guizada (2017)
Machupo	Density	2	0.02	0.02	0.01	0.04	
Madeira[a]	Abundance	1	0.02	0	0.02	0.02	Salinas et al. (2010)
Mamoré	Abundance	8	1.28	1.08	0.46	3.74	Aliaga-Rossel et al. (2006), McGuire & Aliaga-Rossel (2007), Gomez-Salazar et al. (2012), Guizada & Aliaga-Rossel (2016)
Mamoré	Density	7	1.11	1.43	0.001	3.37	
Negro[a]	Abundance	4	0.20	0.28	0.00	0.60	E. Aliaga-Rossel et al. (unpubl. data)
Negro de Caimanes[a]	Abundance	1	0.22	0	0.22	0.22	Painter (1994)
Niquisi	Abundance	1	2.54	0	2.54	2.54	Aliaga-Rossel et al. (2012)
Niquisi	Density	1	0.04	0	0.04	0.04	
Rapulo	Abundance	1	2.64	0	2.64	2.64	Aliaga-Rossel et al. (2006)
Rapulo	Density	1	0.04	0	0.04	0.04	
San Martin	Abundance	1	0.77	0	0.77	0.77	Salinas (2007)
San Martin	Density	1	21.40	0	21.40	21.40	
Secure	Abundance	1	0.67	0	0.67	0.67	E. Aliaga-Rossel et al. (unpubl. data)
Secure	Density	1	0.004	0	0.004	0.004	
Tijamuchi	Abundance	6	2.50	3.46	0.77	9.50	Aliaga-Rossel (2002), Aliaga-Rossel et al. (2006), Aliaga-Rossel & Quevedo (2011), Aliaga-Rossel et al. (2012)
Tijamuchi	Density	5	0.04	0.05	0.01	0.12	
Yacuma	Abundance	2	2.10	0.36	1.85	2.35	Aliaga-Rossel et al. (2006)
Yacuma	Density	1	0.03	0	0.03	0.03	
Yata[a]	Abundance	2	0.38	0.31	0.16	0.60	Salinas et al. (2010)

[a]The reported values do not have the area information necessary for the density calculation

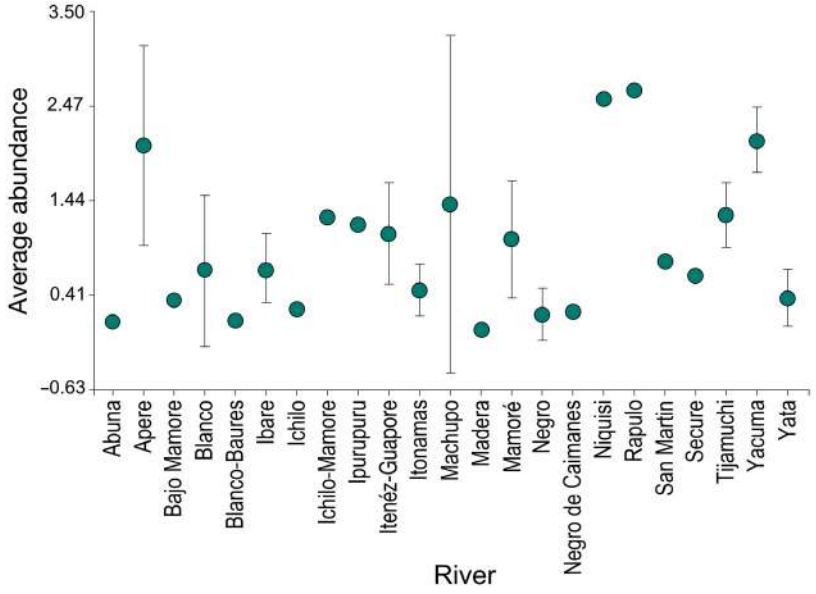


Fig. 3. Review of the average abundances of the Bolivian river dolphin reported from 1977 to the present. It is important to note that survey effort varied from river to river

3.3. Uncertainty and caveats

3.3.1. Surveys

The results that were collected by combining all studies showed considerable variation; therefore, it is important to consider some details before comparing them. Bufeos migrate seasonally between tributaries and main rivers (Aliaga-Rossel et al. 2006). It is of fundamental importance to consider the season when the surveys were done because this can affect variation in encounters and observations (Trujillo 2000, Aliaga-Rossel et al. 2006, 2012, McGuire & Aliaga-Rossel 2007, Gomez-Salazar et al. 2012). For example, there is an increased probability of detection during the reproductive season, possibly because males move farther and tend to congregate around females (Martin & da Silva 2004, McGuire & Aliaga-Rossel 2007). Likewise, there is a certain preference of habitat use in each fluvial system, thus biasing the results toward encountering larger groups of bufeos in or near confluences and meanders where the resources are constant and access to them is energetically less expensive (Guizada & Aliaga-Rossel 2016).

Studies of the Bolivian river dolphin have been increasing; however, the expeditions carried out by different researchers differ considerably, increasing the difficulty in making comparisons between river systems. Focusing efforts during the transition periods (April to June, October to December) will facilitate sightings in all river systems and could mitigate the error of underestimation that occurs during high-water seasons when bufeos disperse throughout the flooded forest (Hurtado 1996, McGuire & Winemiller 1998, Trujillo 2000, Aliaga-Rossel 2002).

3.3.2. Methods

The population comparison between the different publications was complex to analyze due to the differences in the methods used to obtain data (number of hours sampled, types of vessels, and length of trips) and, in some cases, the absence of information about the methods used (Pilleri 1969, Pilleri & Gihr 1977, Painter 1994). The present review was limited to reporting the relative abundance and density in the rivers studied, with an exploratory analysis using elementary statistics of averages and standard deviations.

Some studies reported their results as densities of bufeos, but the type of analysis and reported results were not standardized for Bolivia. The minimum information presented in these studies was the encounter rate, but since information on the sampled area was missing, we used satellite images for each specific period of sampling. For future publications or reports, we suggest reporting the start and end point coordinates of the transect surveys.

The low abundance in some rivers, and the detected possible decrease (Fig. 4) could be attributed to the difficulty in observing distant or shy animals or to a real decline in the population. If a population decline is occurring, then the line transect methods (which assume a homogeneous distribution) will overestimate the abundance of the species, in contrast to the strip-width method, which does not make this critical assumption, and could underestimate the values. Consequently, as proposed by Zhao et al. (2008), the strip-width method could provide minimum estimates, while complex methods (zig-zag or sections) could produce maximums. Martin et al. (2004) indicated that the most efficient and simplest method used in the Amazonian basin is to utilize the strip-width method and to incorporate a correction factor to the low number of dolphins in the middle of the river. At the same time, the minimum height of

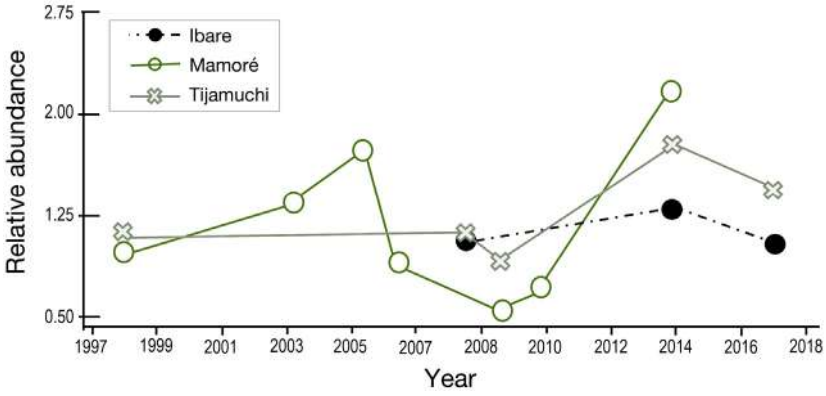


Fig. 4. Long-term variation in the relative abundance of the Bolivian river dolphin in 3 rivers: Mamoré, Ibare, and Tijamuchi, from 1998 to the present

vessels used for the data collection throughout the whole domain of the entire river width was 1.5 to 2 m. These minimum-height vessels were the only ones used in tributary river systems and lagoons (which are the most studied systems).

Also, Aliaga-Rossel et al. (2006) indicated that some of their abundance and density estimations must be interpreted carefully, as their surveys in the Tijamuchi, Yacuma, and Rapulo rivers were relatively short, near the confluences, and carried out during the mating season. Short surveys can lead to over- or under-estimations, and it is also important to consider the biology and natural history of the species that can affect detection (e.g. bufeos gathering at confluences). Therefore, reported differences in group size may actually be artifacts of uneven sampling between rivers.

The outliers reported for some rivers are mainly due to sampling small areas based on 3 to 20 km traveled and focusing on habitats with a higher probability of sightings, such as close to the mouth of the river (Fig. 3, Table 3). In these cases, a possible solution is sampling stratification according to the type of habitat or to establish a minimum study area in order to allow comparison of the estimates and avoid drawing conclusions that present a bias and an overestimation.

At the regional level, important advances have been made in the methods for population estimation of the species, but it is important to find alternative methods to improve these estimations.

3.3.3. Distribution and habitat of *Inia* in Bolivia

As mentioned in Section 3.2.1., bufeos are not believed to be present in the Beni sub-basin. Pilleri & Gihr (1977) and Tello (1986) have indicated the occurrence of bufeo in the Beni River (Beni sub-basin). However, as they did not provide the location coordinates, these reports might be incorrect registers. There are small tributaries of the Mamoré sub-basin just a few kilometers from the Beni River (Anderson 1997). Also, there is a small area where water flows from the Mamoré River to the Beni River, between the rapids, and it is possible that they were referring to this area. A series of rapids and cascades provides a real geological barrier that isolates the species to the Mamoré sub-basin (Aliaga-Rossel & McGuire 2010, Gravena et al. 2014).

For the Madre de Dios sub-basin, approximately 472 km of the Madre de Dios River have been surveyed without any encounter of bufeos. This survey was carried out from Puerto Perez (close to the border with Peru) to the confluence with the Beni River near the town of Riberalta during the dry season. This natural absence of bufeos was probably due to the rivers of this sub-basin being isolated by a series of rapids, principally in the 'Cachuela Esperanza' area, which forms a natural barrier to the Mamoré River (Anderson 1997, Aliaga-Rossel 2003). When inhabitants of the studied area, such as the boat crew, were interviewed, they all confirmed the total absence of the species in this river in all seasons. The survey of the Madre de Dios River conducted for the present study puts an end to claims and controversies concerning the presence of bufeos in the area. Therefore, the location (11° 14′ S, 66° 54′ W) of the bufeo reported in the Red List of Vertebrates of Bolivia (Tarifa & Aguirre 2009) could be a false positive due to the presence of another large aquatic species such as the fish *Arapaima gigas*, which is invasive in Bolivia and for which it could have been mistaken.

3.3.4. Abundance and group sizes of *Inia* in Bolivia

The Bolivian population of bufeos shows a relatively high abundance at 0.92 bufeos km^{-1} (range 0 to 2.81 bufeos km^{-1}) compared to the estimates reported for *Inia* in Colombia (mean: 1.64 bufeos km^{-1}), Ecuador (mean: 0.27 bufeos km^{-1}), Peru (mean: 0.82 bufeos km^{-1}) and Venezuela (1.2 bufeos km^{-1}) (Table 4). Nevertheless, abundance values for individual rivers show wide variation, ranging from 0.02 to 4.49 (Venezuela, CV = 107.73), 0.15 to 3.54

Table 4. Estimation of the abundance of river dolphins of the genus *Inia* in the South American region. Updated from Trujillo et al. (2010)

Country	River	Abundance	Reference
Venezuela	Orinoco	0.02	Pilleri & Pilleri (1982)[a]
	Caño Casiquiare	0.03	Pilleri & Pilleri (1982)[a]
	Apure	1.16	Rodriguez & Rojas-Suarez (1999)[a]
	Apure	0.56	Schnapp & Howroyd (1992)[a]
	Apurito	1.15	Schnapp & Howroyd (1992)[a]
	Guariquito-Apurito	0.19	Rodriguez (2000)[a]
	Aguaro	1.29	Rodriguez (2000)[a]
	Suripá	1.68	Escovar (2002)[a]
	Orinoco	1.57	Trujillo et al. (2010)
	Orinoco	4.49	Gomez-Salazar et al. (2012)
Colombia	Meta	0.15	Trujillo et al. (2010)
	Amazon	0.67	Trujillo et al. (2010)
	Meta	2.2	Gomez-Salazar et al. (2012)
	Amazon	3.54	Gomez-Salazar et al. (2012)
Peru	Marañon	0.2	Leatherwood (1996)
	Marañon	0.3	McGuire et al. (2002)
	Samiria	0.5	Leatherwood (1996)
	Samiria	0.7	Leatherwood (1996)
	Samiria	0.5	Henningsen (1998)[a]
	Samiria	1.5	McGuire et al. (2002)
	Samiria	0.5	McGuire et al. (2002)
	Reserve Samiria	0.7	McGuire et al. (2002)
	Amazon (several rivers)	2.49	Gomez-Salazar et al. (2012)
Ecuador	Lagartococha	0.38	Utreras (1996)[a]
	Lagartococha	0.44	Utreras (1996)[a]
	Lagartococha	0.27	Denkinger (2001)
	Lagartococha	0.21	Denkinger (2001)
	Lagartococha	0.32	S. Jalil et al. (unpubl. data)
	Lagartococha	0.3	S. Jalil et al. (unpubl. data)
	Cuyabeno	0.47	Denkinger (2001)
	Cuyabeno	0.04	Denkinger (2001)
	Tipurini	0.03	Utreras (2001)[a]
	Yasuni	0.3	Utreras (2001)[a]
	Yasuni	0.08	S. Jalil et al. (unpubl. data)
	Yasuni	0.09	S. Jalil et al. (unpubl. data)
	Amazon (several rivers)	0.7	Gomez-Salazar et al. (2012)
Brazil	Solimoes	0.19	Magnusson et al. (1980)
	Amazon	2.88	Vidal et al. (1997)
	Central Amazon	0.68	da Silva & Martin (2010)
	Central Amazon	0.49	da Silva & Martin (2010)
	Central Amazon	0.76	da Silva & Martin (2010)

[a]Cited in Trujillo et al. (2010)

(Colombia, CV = 93.7), 0.2 to 2.49 (Peru, CV = 88.68), 0.03 to 0.7 (Ecuador, CV = 69.48), and 0.19 to 2.88 bufeos km^{-1} (Brazil, CV = 107.36), causing higher coefficients of variation compared to Bolivia, except for Ecuador which seems to have more similar values. However, comparing global averages can be misleading since each river system is different, and the distribution and habitat use of the bufeo is uneven. These descriptive abundances must be treated independently by river and monitored over time. Also, considering the information available, it is tempting to directly extrapolate the information to estimate the total population in Bolivia; however, extrapolation does not consider the intrinsic variations in each habitat, seasonal use, or the different threats for each region or river system. Therefore, it is highly likely that numbers would be overestimated.

As reported by da Silva et al. (2018b), river dolphins in South America are relatively abundant, and threats and mortality are relatively neglected or ignored. However, due to the low rate of natural reproduction, increasing habitat destruction, and lack of enforcement of laws preventing overfishing (including poor regulation of gillnet use), the bufeo

might follow the extinction fate of Asian river dolphins. Our concern is shared by da Silva et al. (2018a), who suggest that the population size is currently decreasing due to high levels of habitat exploitation and subsequent habitat destruction.

In all the studies, bufeos were generally encountered as solitary animals or in pairs. Pairs frequently consisted of a mother and a calf or yearling. Occasionally, the mother was accompanied by a calf and a juvenile, which was likely to be 2 yr old (Martin et al. 2004, Aliaga-Rossel & Escobar-WW 2020). All the studies reported solitary bufeos or pairs during the high-water season. However, as expected, larger groups were encountered during falling- and low-water seasons, in lagoons, and in the small discharge of tributaries in the main river. The largest group registered was 19 individuals in a confluence of the Tijamuchi River with the Mamoré River (Aliaga-Rossel 2002).

During the last 10 yr, the number of published studies estimating bufeo population sizes in Bolivia has increased. This phenomenon is not only seen on a local scale, but several regional efforts have also increased in Colombia, Brazil, and Peru, as well as the implementation of long-term monitoring projects (Gomez-Salazar 2004, Gomez-Salazar & Trujillo 2008, da Silva & Martin 2010, Gomez-Salazar et al. 2012, Gravena et al. 2014, Hrbek et al. 2014, Gravena et al. 2015, Mosquera-Guerra et al. 2015a,b). Nevertheless, due to the recent change of IUCN conservation status to Endangered (da Silva et al. 2018a), there is a greater need to focus efforts on evaluating population trends in key areas, instead of determining the exact numbers of animals, or their complete distribution in a few small tributaries. Modeling work carried out by Huang et al. (2012) has indicated that census survey techniques (for freshwater cetaceans) do not detect early signs of population decline before a critical level is reached. However, it is also important to continue with the efforts to standardize large-scale and long-term monitoring programs in order to detect variation in the presence, abundance, and distribution of bufeo populations and to understand the impact of increasing anthropogenic factors, before the populations of bufeo reach critical, non-reversible, or non-recoverable levels.

3.3.5. Indicative trends in abundance of *Inia* in 3 Bolivian rivers

The IUCN Red List (da Silva et al. 2018a) and the regional action plans for the conservation of freshwater dolphins recognize the importance of evaluating the population within their range of distribution. Due to the serious and uncontrollable increase in threats for the Bolivian bufeo, it is imperative to start monitoring population trends at priority sites (Trujillo et al. 2010, V. da Silva & A. Zerbini pers. comm.).

On the other hand, and based on information gathered over 15 yr in the same rivers using the same method, it is possible to determine an indication of the population trend, and to compare 3 fluvial systems, the Mamoré, Ibare, and Tijamuchi rivers, in which the same area has been sampled for each river.

Ibare River: The abundance of bufeo reported for this river was the lowest detected throughout the distribution area in Bolivia, but it was relatively constant (Fig. 4). Over a total of 388.92 km during 10 yr, we found diverse groups with a relative abundance range between 0.30 and 1.32 bufeos km^{-1}. The highest number of total sightings was recorded during the high to low season transition, with a maximum value of 99 bufeos in 2014, and the lowest occurred in 2013 during rising water (n = 9). However, there appears to be a slight decreasing trend in the population compared to the observations of Pilleri & Gihr (1977), who registered 1 bufeo km^{-1}.

Mamoré River: The main river has had continuous estimates made over the last 15 yr (Fig. 4), with a constant number of 1.01 ± 0.64 bufeos km^{-1} (range 0.26 to 2.21 bufeos km^{-1}). The highest number of total sightings (384) was recorded during the dry season of 2006 and it the observations appear to show a trend toward a decreasing population density over the years.

Tijamuchi River: The average relative abundance reported for the Tijamuchi was 1.28 ± 0.35 bufeos km^{-1} (0.92 to 1.81 bufeos km^{-1}) over a total of 719.399 km of transects. The highest number (n = 289) of bufeos observed was recorded during the low water season of 1998 and the lowest in 2009 (n = 55). In general, it appears that natural population fluctuations may be occurring in this river, which while not very marked, may be due to natural causes.

An apparent population reduction can be observed (Fig. 4) that could possibly be attributed to the incrementally increasing anthropogenic threats. The low but constant number of sightings (relative abundance and encounter rates) recorded for the Ibare River seems to be influenced by the various human activities that occur in the system. It is the main river access for about 8 communities that depend on it entirely for transport, fishing (including commercial fishing), and tourism. The high frequency of boat traffic makes the site vulnerable as it reduces the number of bufeos present.

Finally, we can expect a natural temporal fluctuation in populations (due to climate change or habitat related issues). For example, bufeo populations fluctuated during atypical El Niño and La Niña phenomena (severe floods of 2007–2008 and 2014, and extreme drought in 2010).

3.4. Threats facing *Inia* in Bolivia

Published papers include information about the main threats to bufeos, such as bycatch in unregulated and unselective fishing, hunting as bait for fishing, different types of pollution, including large quantities of garbage disposed directly into rivers and noise pollution, and habitat degradation through increasing commercial agriculture and intensive deforestation (Ruiz-García 2009, Aliaga-Rossel et al. 2010, da Silva & Martin 2010, McGuire & Aliaga-Rossel 2010, Trujillo et al. 2010, Aliaga-Rossel & Quevedo 2011, Hollatz et al. 2011, Ministerio de Medio Ambiente y Aguas [MMAyA] 2012).

The studied area contains several human settlements and is subject to various human activities which directly and indirectly affect bufeo populations. The oil/fat of bufeos is used as a traditional treatment for respiratory ailments (cough, tuberculosis), and is sold at several indigenous markets in the tropics (Aliaga-Rossel 2003). However, Bolivian people do not specifically seek bufeos as a source of animal protein for direct consumption (Aliaga-Rossel 2003).

One of the direct causes of mortality of bufeos is accidental death by entanglement in fishing nets, similar to cases reported for other countries with river dolphins (Trujillo et al. 2010). Fishermen sometimes release the dolphins trapped in their nets, but most frequently leave them to die or, to prevent the destruction of the nets, kill them (Aliaga-Rossel & McGuire 2010). One of the practices which poses the greatest threat to the conservation of bufeos is the use of their meat as fish bait. Although most fishermen do not consider themselves to be in conflict with bufeos, cattle ranchers from the same area accused fishermen of deliberately killing bufeos in 2017 (authors' pers. obs.). We could not find any evidence for these killings, but we suspect this could be one reason for the reduction in bufeo numbers detected in the area that year.

Comparing previous reports with our current observations of the Tijamuchi, Ibare, and Mamoré rivers, there has been an increase in pollutants such as plastic bags and other solid residuals that has not been detected on this scale before, reflecting reports of pollution causing wildlife mortality in the oceans. Also, although the number of cattle ranches remains the same, the number of human settlements has increased without the establishment of municipal facilities such as waste management, resulting in waste and sewage being dumped directly into the river.

4. RECOMMENDATIONS

It is a priority to continue long-term studies of the abundance, distribution, social organization, migration patterns, behavior, and mortality of bufeos throughout their range. We recommend that standardized techniques be used in new studies so that the results can be replicated and easily compared to identify both short-term and long-term population trends.

Better understanding of the abundance of bufeos could contribute to the design of more effective conservation actions, primarily by enhancing fisheries management. In some areas, restrictions on certain fishing practices during the reproductive season and in critical habitats are urgently needed. The information presented in this review could provide the baseline for establishing evidence-based strategies to promote and declare priority sites for the conservation of Bolivian bufeos.

The Upper Madeira River basin in Bolivia contains the only population of Bolivian bufeo. This population is geographically isolated within a smaller range than *Inia geoffrensis*, and this isolation makes them vulnerable. The threats affecting the Bolivian bufeo are increasing rapidly, jeopardizing their numbers (Aliaga-Rossel et al. 2010); therefore, it is imperative to continue generating information on the basic ecology of the species, to make conservation measures more effective.

Immediate and urgent actions to protect bufeo habitat are needed. Measures should focus on reducing threats in areas of low abundance but should prioritize monitoring of the areas with the highest abundances as established in this review (Table 3). These basic actions should be implemented as soon as is feasible, and in this way, the Bolivian bufeo may have a chance of survival over the long-term. The protected areas are undoubtedly key areas where threats can be minimized, greatly reduced, or at least mitigated and managed.

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