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Abundance of the Bolivian River Dolphin (*Inia boliviensis*) in Mamore River, Upper Madeira Basin

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Abstract

The Bolivian river dolphin or bufeo (*Inia boliviensis*) is one of four species of river dolphins in South America restricted to fresh water. Endemic to the Upper Madeira Basin in the Bolivian Amazon region, this species is categorized as "Vulnerable" by the Bolivian government. To determine the relative abundance of river dolphins during two hydrological seasons (rising and low water), we used the strip-width transect method in a 233-km segment of the Mamore River. We recorded the number and group size of river dolphins sighted in downstream and upstream transects on the same river. In addition, we examined river dolphin habitat preference in relation to six variables: (1) pH, (2) depth, (3) temperature, (4) habitat type, (5) shore type, and (6) visibility. Overall abundance was 0.52 dolphins/km across both seasons. Because recent density estimates of river dolphins have been fluctuating, it is difficult to determine a population trend. Moreover, we documented a significant habitat preference of dolphins for river confluences and meanders ($p <$ 0.005), which affected the distribution and abundance of dolphins in this region.

Key Words: strip-width transect method, abundance, density, preference habitat, Bolivian river dolphin, *Inia boliviensis*

Introduction

River dolphins face numerous threats (e.g., overfishing, deforestation, and hydroelectric construction), and their populations are generally in decline. The lack of basic ecological information on river dolphins hampers the development and implementation of effective conservation action (Reeves et al., 2003). There are four species of dolphins restricted to freshwater in South America: (1) *Sotalia fluviatilis*, (2) *Inia geoffrensis,* (3) the recently described *I. araguaiaensis* (Hrbek et al., 2014), and (4) *I. boliviensis* (Ruíz-García & Shostell, 2009; Gravena et al., 2014). All are threatened, and recommendations of the "Action Plan for River Dolphins in South America 2010-2020" emphasize the immediate implementation of studies that estimate river dolphin abundance and population density in order to establish conservation activities (Trujillo et al., 2010).

The Bolivian river dolphin, locally known as bufeo (*I. boliviensis*), is found in some rivers of the Upper Madeira Basin of the Bolivian Amazon (Aliaga-Rossel, 2003; Aliaga-Rossel & McGuire, 2010). The species is categorized as "Vulnerable" in the *Red Book of Wild Vertebrates of Bolivia* due to habitat loss and degradation, low genetic variability, and possible reduction of their population size (Tarifa & Aguirre, 2009). After a continuing debate about the validity of results of morphological and molecular studies (Pilieri & Gihr, 1977; Ruiz-García et al., 2007, 2009; Martinez-Agüero et al., 2009; Ruíz-García et al., 2009; Hollatz et al., 2010), in April 2012, the Bolivian river dolphin was reclassified from a subspecies (*I. geoffrensis boliviensis*) to a species: *Inia boliviensis* (Gravena et al., 2014)

There are few published studies on the Bolivian river dolphin. Pilieri & Gihr (1977) were the first to collect basic information, including observations on the behavior of the species. Van-Bree & Robineau (1973) suggested possible morphological differences between populations of *I. geoffrensis* and *I. boliviensis*, McGuire & Aliaga-Rossel (2007) discussed reproductive seasonality, while Aliaga-Rossel et al. (2010) reported on their diet. Studies of dolphin abundance and distribution have focused on the sub-basin of the Mamore and Iténez Rivers (Aliaga-Rossel, 2002; Salinas, 2007; Gomez-Salazar & Trujillo, 2008; Aliaga-Rossel & Quevedo, 2011; Gomez-Salazar et al., 2011; Aliaga-Rossel et al., 2012; Morales, 2012).

By generating population estimates and conducting a preliminary analysis of environmental preferences, this study aims to compare and identify possible population trends or long-term seasonal fluctuations in the sub-basin of the Mamore River in Bolivia. This study also seeks to increase the knowledge of the Bolivian river dolphin populations and to contribute to the recommendations of the "South American Regional Action Plan for River Dolphins" (Trujillo et al., 2010).

Methods

Study Area

The Mamore River, located in the Department of Beni in Bolivia (9.5° to 18° S; 62.5° to 67° W), is the main tributary of the Upper Madeira Basin in Bolivia, which flows to the Amazon River (Pouilly & Beck, 2004). The Mamore sub-basin (568,000 km^2) represents 66.7% of the Upper Madeira River Basin and constitutes 47.7% of its volume (Pouilly & Beck, 2004).

This study was conducted in a 233-km segment of the Mamore River, between the confluence of the Rivers Apere and Ibare, in the area known as "Los Llanos de Mojos-Beni" (Figure 1). This sector of the river has a weak slope that increases the amplitude and radius of several meanders and decreases the transport capacity of sediment in the river (Charrière et al., 2004). The Mamore River is a typical white water river—rich in small particles and inorganic suspended solids that limit water visibility thus giving the river a distinctive yellowish brown or turbid color (Loubens et al., 1992; Aliaga-Rossel, 2002).

This study area has a tropical climate: the average annual temperature is 25.5° C, and the annual rainfall is 1,861 mm (Pouilly & Beck, 2004), while 60 to 80% of the annual rainfall (350 to 400 mm) occurs between December and March when the temperature reaches as high as 34° C. The hydrological regime is closely related to precipitation, showing a unimodal curve with a high-water period between December and April and a low-water period from June to October. Fluctuations in water level of up to 10 m result in flooding of the forest or surrounding area (Loubens et al., 1992; Aliaga-Rossel, 2002); therefore, it is important to consider the water level and hydrological season of the entire neotropical system.

Subsistence farming and the raising of livestock are carried out by indigenous and rural communities, and cattle ranches occur along the river shore. The Mamore River serves as the main means of communication and transport between different local communities and nearby cities of the Llanos de Mojos. Fishing and naval activities occur to a lesser extent along the river but are still significant.

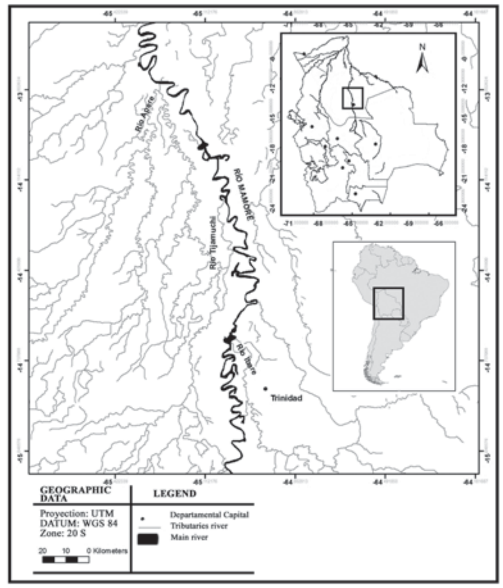

Figure 1. *Study area:* Mamore River, Bolivia, from the confluences of the Rivers Apere and Ibare (Department of Beni, Bolivia)

Field Methods

In this study, the average river width was 233 m—a distance for which sightings can be reliably made by the methods used herein. When the width is increased in the high-water season (in this study, up to 413 m), the detection of dolphins that are near the opposite shore is more difficult, which increases the possibility of underestimation. Nevertheless, these issues that may cause bias can be partly prevented by using larger vessels (20 to 25 m) (smaller vessels of 10 m were used during the low-water season), which can be more easily navigated in stormy or deeper waters such as the vessels used in studies of river dolphins by McGuire (2002) and Gomez-Salazar et al. (2011). The use of this kind of vessel also may have an effect on the behavior of the dolphins as suggested by Aliaga-Rossel & McGuire (2010).

Fieldwork took place during two hydroclimatic seasons: (1) rising-water season (December 2009) and an extremely dry (low) season (October 2010) at an average of 226.5 km surveyed for both seasons. Surveys utilized cross-channel line transect routes by selecting a starting point for the vessel to turn on a ~45° angle towards the other bank due to the characteristics of the river (width > 200 m; higher speed on the river channel). These turns were places where the captain considered it to be safe and convenient to cross the river in order to avoid obstacles such as large floating objects and shallow areas (Vidal, 1997; Gomez-Salazar et al., 2011).

Surveys consisted of two transects on the Mamore River: (1) a transect downstream and (2) an upstream transect. To ensure optimal light conditions, both transects were conducted between 0700 and 1700 h with a 1 h break around midday. Surveys were suspended if weather conditions, such as strong winds (> 13 km/h), waves, or heavy rain (Aliaga-Rossel, 2002), were unfavorable for dolphin sightings.

Sightings were made from an outboard motor vessel with an observation platform 2.5 m above the water; two observers at the bow provided a combined detection range of 180° (90° each), and a third person recorded data. The boat travelled a constant speed of 15 km/h. When a solitary individual or a group of dolphins was sighted, the number of dolphins was recorded. A group was considered as an apparent aggregation of dolphins within a 15- to 20-m diameter circle but without social interactions necessarily involved (modified from McGuire & Winemiller [1998] and Aliaga-Rossel [2002]). Each encounter was considered a sighting. Double counts were avoided by maintaining constant communication between observers. The recorder noted geographic coordinates (using GPS), river width (using a range finder EDM), the distance to the nearest shore, the distance from the dolphins to the boat, sighting side, vessel speed, and weather conditions (Aliaga-Rossel, 2002).

To avoid underestimation caused by the characteristics of the route travelled by the vessel, in the present study, we considered each pair of upstream and downstream transects as subsamples, and the transect that had the largest number of sightings was chosen for analysis.

Habitat Suitability

A physical and chemical characterization of the river was carried out every 15 km by measuring pH (pH meter), surface temperature at 15 cm deep (portable digital thermometer), water depth (echo sounder), and water visibility (Secchi disk). We also noted the habitat category (i.e., river, confluence, and meander) and shore type based on the following characteristics: stream width, water flow, and associated vegetation. Habitat characteristics are summarized in Table 1.

Data Analysis

Bolivian river dolphin abundance for each season were calculated based on the direct count and summarized as number of sightings and number of river dolphins/km. Group size (number of dolphins/sighting) was also calculated for each season and for each habitat type.

R software was used for the preliminary habitat preference analysis. To determine the contribution of each habitat factor on dolphin presence and abundance, we performed a separate generalized linear model (GLM) for habitat. Subsequently, two GLMs were performed with all variables (habitat type, type of shore, transparency, pH, temperature, and depth): (1) for presence-absence data and (2) for abundance data. For each model, variables observed in independent GLMs with apparent collinearity were eliminated.

Using presence data, a GLM was performed using the characteristics of family: binomial and function: logit model. For the abundance data, a Poisson family and log function combination were used. In the categorical variables, the main factor levels were river in "Habitat types" with the default value of none included under "Shore types."

Table 1. Description of the categorical variables "Habitat types" and "Shore types" along the Mamore River, Bolivia

Habitat types	
Label	*Description*
River	Main river course, with varying depth and width denoting an absence of confluence and meander
Confluence	Area of intersection of the main canal with other bodies of water
Meander	Place where the river course shows a curve in any direction, with less flow and greater depth
Shore types	
Label	*Description*
Beach	Flat shores with soil or mud and succession communities of the pioneer stage (*E. polystachya* and *T. intergrifolia*)
Flooded forest	Mainland with mid-stage vegetation (*Cecropia membranous*) and mature forest
Ravine	Marked erosion of the river banks; slopes between 45° and 90°; little or no surface vegetation
None	Category by default when no observation was associated with a type of shore mentioned above

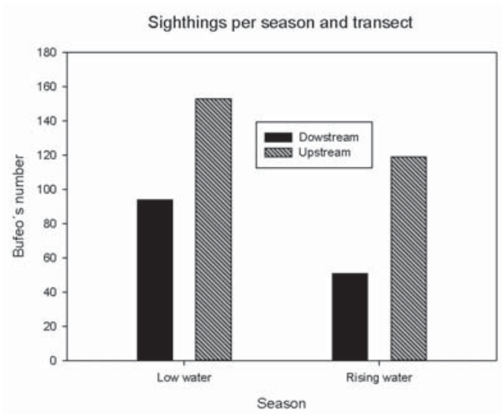

Figure 2. Total number of individuals sighted during two hydroclimatic seasons in the Mamore River, Bolivia

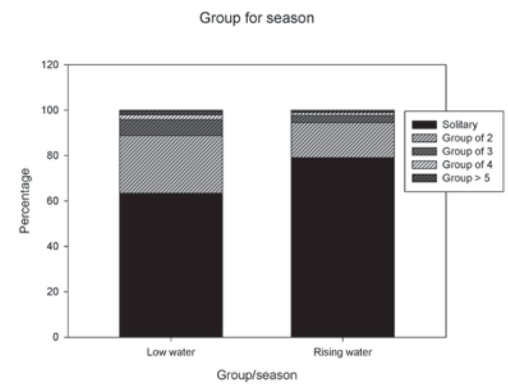

Figure 3. Group sizes of Bolivian river dolphins (*Inia boliviensis*) in the Mamore River, Bolivia, during two hydroclimatic seasons

The amount of variance explained by each model (deviance, D^2) was measured by comparing the deviance of the null model (Dev_null_model) with residual deviance (Dev_residual):

$$D^2 = \frac{Dev\_null\_model - Dev\_residual}{Dev\_Null\_model} \times 100$$

Results

Relative Abundance

The surveys in the rising- and low-water seasons covered 172.59 and 232.58 km of the Mamore River, respectively. The total sampling effort for both seasons was 66 h, with a total of 283 sightings and 417 dolphins counted.

During the rising-water season, 35 sightings were registered with a total of 51 dolphins observed when traveling downstream (0.30 dolphins/km), and 91 sightings were recorded with 119 dolphins observed when traveling upstream (0.51 dolphins/km) (Figure 2; Table 2). Throughout the low-water period, 58 sightings corresponding to 94 dolphins were seen on the downstream transect (0.45 dolphins/km), and 99 sightings with 153 dolphins were recorded when traveling upstream (0.52 dolphins/km) (Figure 2; Table 2).

Solitary individuals were the most frequent observations for both seasons; 79% solitary dolphins were observed during the rising-water and 64% in the low-water season. The maximum group observed was six dolphins together during the low-water season. During the low-water season, there were a greater number of sightings of two dolphins (25%) and three dolphins (7%) (Figure 3) than in the rising-water season. However, the habitat confluence shows a composition more representative of groups of one to four dolphins during both seasons (Figure 4).

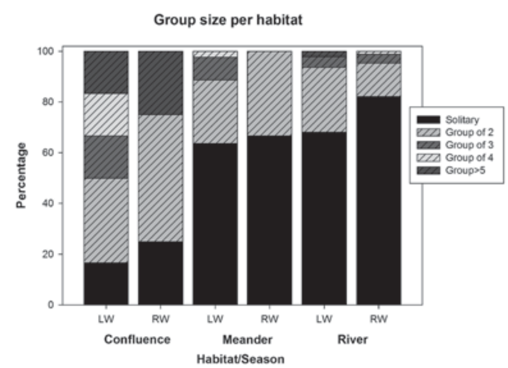

Figure 4. Group sizes of Bolivian river dolphins by habitat type in the Mamore River, Bolivia. RW = rising water; LW = low water.

Habitat Suitability

Of the factors considered, habitat type is the only variable that influenced the presence and abundance of dolphins (Tables 3 & 4). Meander and confluence variables were significantly more important predictors than the variable river (significance values less than 0.05); and in both the presence-absence and abundance models, the presence of the dolphins increased in meander and confluence habitats as compared to other habitat types (Tables 3 & 4). The final models explained 32 and 27.4% of the presence and abundance of dolphins, respectively.

Table 2. Number of sightings of Bolivian river dolphins (*Inia boliviensis*) and relative abundance obtained from a direct count in the Mamore River, Bolivia, during the rising- and low-water seasons per transect

Transect	Number of sightings	Number of dolphins	Range of group size (mean)	Relative abundance (# dolphins/km)
		Rising water		
Downstream	35	51	1-4 (1.3)	0.30
Upstream	91	119	1-4 (1.3)	0.51
		Low water		
Downstream	58	94	1-6 (1.5)	0.45
Upstream	99	153	1-6 (1.5)	0.52

Table 3. Estimator values and significance of habitat preferences of Bolivian river dolphins from a generalized linear model (GLM) based on presence-absence data

		Distribution model		
	Estimate	Standard error	Value *z*	Pr (> |*z*|)
Intercept	-27.36	21.29	-1.28	0.20
Confluence	5.57	2.72	2.05	0.04*
Meander	4.33	1.54	2.80	0.005 **
Depth	-0.23	0.18	-1.32	0.19
Temperature	0.96	0.81	1.19	0.23
Visibility	0.08	0.05	1.65	0.1

* Significance $p = 0.1$, ** Significance $p = 0.05$

Table 4. Estimator values and significance of habitat preferences of Bolivian river dolphins in a GLM based on abundance data

		Abundance model		
	Estimate	Standard error	Value *z*	Pr (> |*z*|)
Intercept	7.09	7.73	0.92	0.36
Confluence	1.50	0.58	2.61	0.009**
Meander	1.40	0.44	3.19	0.001**
Depth	-0.01	0.045	-0.23	0.82
Temperature	-0.31	0.30	-1.03	0.30
Visibility	0.02	0.016	1.11	0.27

** Significance $p = 0.05$

Discussion

This study provides information on the abundance of the Bolivian river dolphin in the main area of its distribution (Aliaga-Rossel & McGuire, 2010). Due to the differences between river flow patterns along the surveyed region, a comparative analysis of upstream and downstream transect areas was conducted. These differences may suggest a possible bias in the data collection caused by limitations due to logistics and navigation. In the upstream transect, we observed a greater number of dolphins compared to what was observed in the downstream transect. This likely occurred because the upstream transect passed through places with calmer waters (shores and streams where there was less current). The dolphins seemed to prefer habitats with less current where the water masses collide and create small eddies in the streams, which disorient their prey (Best & da-Silva, 1993; Aliaga-Rossel, 2002; Aliaga-Rossel et al., 2006; McGuire & Aliaga-Rossel, 2007).

Our results, together with those published previously for the Mamore River, demonstrate one of the highest abundance of dolphins in Bolivia and confirm a higher number of sightings during the low-water season. This may occur because the water level of the tributaries decreases, leaving a reduced water channel and unflooded forests. As a result, a greater availability of resources is found in the main channel which probably encourages dolphins to migrate to the main river (Aliaga-Rossel et al., 2006; Aliaga-Rossel & McGuire, 2010). In addition, the low-water season occurs concurrently with the birth season (May through October) (McGuire & Winemiller, 1998; McGuire & Aliaga-Rossel, 2007). For all the above-mentioned reasons, as recommended by Aliaga-Rossel & McGuire (2010) and Trujillo et al. (2010), it is essential to continue generating information on the demography of dolphins (especially birth and death rates) to observe the population fluctuations over time.

Solitary individuals and pairs represent the largest percentage of sightings for both seasons (80 and 15% in the rising-water season, and 64 and 25% in the low-water season). The proportion of dolphins encountered in pairs is higher during the low-water season, which is concurrent with the birth season in Bolivia as indicated by McGuire & Aliaga-Rossel (2007); Martin & da-Silva (2004) also indicated that most pairs are usually formed by a lactating female and its offspring. The results are an apparent sexual segregation by habitat preference since these pairs seem to prefer sites with lower flow such as meanders and confluences (Figure 4). These areas are probably preferred because they provide more favourable feeding and breeding conditions (Aliaga-Rossel et al., 2006; Hollatz et al., 2010). This group size characteristic has been described in several studies in different Bolivian rivers: Tijamuchi (Aliaga-Rossel, 2002; Aliaga-Rossel & Quevedo, 2011); Apere, Yacuma, and Rapulo (Aliaga-Rossel et al., 2006); Blanco and San Martin (Salinas, 2007); Mamore and tributaries (Aliaga-Rossel et al., 2006, 2012; Morales, 2012); and Yacuma (Aramayo, 2010).

As described in the GLM analysis (habitat suitability), the variable habitat type is the only one that had a direct effect on the presence and abundance of the dolphins. Following these results, it is recommended that future studies evaluate other variables that may be more important for the dolphin (e.g., prey abundance, pollution, and human activities).

We found no correlation between the abundance of dolphins and water characteristics, although there are studies elsewhere that report slightly higher number of sightings in deeper sites (Leatherwood, 1996). We considered that perhaps there is not truly a preference for greater depth, but, rather, for food availability, possibly exemplified by the pattern of dolphin movements into flooded forests and their ability to move in water with a depth of less than 1 m (Aliaga-Rossel, pers. obs.). Supported by Trujillo (2000), water depth could have greater influence on the distribution of fish, causing an indirect positive effect on dolphin distribution. McGuire (2002) reported that a decrease in transparency is associated with the abundance of *I. geoffrensis*, but other studies (Best & da-Silva, 1989; Hurtado, 1996; Aliaga-Rossel et al., 2006; Aramayo, 2010) did not find this kind of relationship. Moreover, while dolphins use an echolocation system that allows them to navigate and hunt in complete absence of light, it is unknown whether this system is affected by suspended or dissolved materials in water. Best and da-Silva (1989) noted that visibility and the pH inversely affects *Inia* density but not distribution due to increased foraging in more turbid waters where more nutrients are available. Hurtado (1996) pointed out that river width, water temperature, and transparency did not seem to affect the distribution of *I. geoffrensis* in the Colombian Amazon. Findings by Aliaga-Rossel (2002) supported a positive association between the river width and the bufeo abundance, but Aliaga-Rossel argued that a correlation between transparency and pH does not exist, explaining that dolphin preferences would be directly associated with the availability of food resources, a factor not evaluated in this study (Aliaga-Rossel, 2002, 2012; Aliaga-Rossel et al., 2006; McGuire & Aliaga-Rossel, 2007).

The habitat suitability model (GLM, general model) shows that the Bolivian bufeo prefers a specific habitat type. Aliaga-Rossel (2002) and Aliaga-Rossel et al. (2006) reported an increased number of sightings (preferences) in habitats such as confluences, meanders, and shores with aquatic vegetation and flooded forest; however, their results were analyzed in a different manner. Aliaga-Rossel (2002) found significant differences between the abundance of dolphins and different types of habitats in which the preferred habitats were lagoons < confluences < meanders < river. Aramayo (2010) found significant differences in the rates of bufeo encounters and habitat types as well as between the encounter rates and shore types, and encounter rates and season. However, Aramayo (2010) could be making a statistical error, a multicollinearity problem, by performing chi-squared tests for each independent variable, resulting in *false significances* or Type I error.

In the current study, the general habitat suitability model does not reflect all the preferences (e.g., depth, transparency, pH, type of habitat, or type of shore) mentioned by other authors. This could be explained because of the multicollinearity that was found between variables such as habitat type, shore type, pH, and depth, and probably would be found with other variables such as the distribution of fish (biomass) and/or flow characteristics, although these variables were not measured in this study. The multicollinearity problem should be remedied with more specific studies on habitat use, performing detailed measurements of the environment to eliminate such strong relationships between measured variables and to determine the most appropriate analysis.

Even though the Bolivian river dolphin's abundance in the Mamore River is high compared to other aquatic systems, threats to this species in the study site are increasing. The apparent preference to confluences and meanders make these important sites priority areas for conservation, especially because during the fieldwork, we received reports that some fishing communities were killing dolphins because they are considered to be resource competition with fisheries or because the dolphins are used as bait. These reports highlight the importance of continuing studies on the ecology and threats to Bolivian river dolphins for long-term population monitoring and for implementing conservation strategies in the area.

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