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Encounter rates and distribution of *Inia geoffrensis* and *Sotalia fluviatilis* in the middle Juruá region, western Amazonia, Brazil

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Abstract

The Amazon Basin and its floodplains are a highly productive ecosystem that habitats many of the world's freshwater species. The flood pulse which seasonally inundates the flooded forests creates dynamic environments with varied degrees of adaptations within fauna species. River dolphins in the Amazon are facing different threats, although their abundance and encounter rates seem to be at a high level still. There is a large difference in preferences for distribution between *Inia geoffrensis* and *Sotalia fluviatilis*, where encounter rates of *I. geoffrensis* is higher than *S. fluviatilis*, but group sizes show an opposite distribution. The environmental variable confluence has a high effect on the encounter rates of both dolphin species, where the presence of this habitat on a transect line, leads to an increase in encounter rates. The anthropogenic variables tested for this thesis showed little effect on encounter rates, although the distance from a community showed a negative effect on encounter rates on *I. geoffrensis*, and motor traffic had a positive effect on *S. fluviatilis*. The psychological traits of these river dolphins show that the riverine habitat preference of these species is also different, where *Inia* prefer habitat along the river margins, and *Sotalia* prefers to be in the center of the river.

Keywords: Encounter rate, *Inia geoffrensis*, *Sotalia fluviatilis*, distribution, habitat preference, group size

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1 Introduction

The Amazon basin covers around 7 million km² and includes the largest remaining tract of tropical forest (Sioli, 1984). It is the largest hydrographical basin in the world and contains approximately one-fifth of all free-flowing fresh water in the world (Goulding, 1993; Salati & Vose, 1984). Yet, all the rivers in the Amazon are not the same. Some rivers are white-water rivers that carry a large amount of suspended inorganic sediments from the Andes, while others are black- or clear-water rivers that contain little or no sediments (Martin et al., 2004; Osborne, 2012b). This variety is reflected in the freshwater species richness where 15% of all freshwater fish species on Earth occur in the Amazon (Junk et al., 2007).

The Amazon River and many of its tributaries form braided meanders over extensive floodplains (Junk et al., 2011b). The low-lying topography of the basin and rainfall seasonality inundate these floodplains for up to 8 months of the year, covering more than 750 000 km² (Junk et al., 2011a) and with a seasonal rise in water levels up to 11-15 meters in amplitude (Resende et al., 2020). These floodplains can be classified according to the type of water that inundates them - *várzea* forest is inundated by white-water rivers and *igapó* forest by black- or clear-water rivers, respectively (Junk et al., 2011a). *Varzea* forests are highly productive due to the annual deposition of sediments from river waters in these forests every year (Furch, 1997), and contains more plant species than any other wetland forest type (Wittmann et al., 2006)

Floodplains along meandering rivers normally contain large numbers of oxbow lakes that are old meander cut-offs (Osborne, 2012a). During the high-water season, the submerged floodplain forms a vast aquatic environment connecting the main rivers and lakes – offering an important habitat for aquatic species (Osborne, 2012b). These floodplain areas are for example extremely important as spawning grounds for fish and are heavily utilized by the Amazonian aquatic megafauna, including the pirarucu (*Arapaima gigas*), black caiman (*Melanosuchus niger*), giant otter (*Pteronura brasiliensis*), neotropical otter (*Lontra longicaudis*) Amazonian manatee (*Trichechus inunguis*) river turtles (e.g. *Podocnemis expansa*) and freshwater dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) (Brum et al., 2021; Campos-Silva et al., 2019; Cook et al., 2022).

The Amazonian river dolphins, boto (*I. geoffrensis*) and tucuxi (*S. fluviatilis*), have a wide distribution across the basin within main rivers, tributaries, and lakes (Vidal et al., 1997). River cetaceans are some of the most threatened aquatic mammals, with a geographical range limited to South America and Asia, with the highest density in the Amazon Basin (Campbell et al., 2022; Marmontel et al., 2021). The boto is also the largest species of all river dolphins worldwide, but portrays great sexual size dimorphism between males and females, where males are significantly larger than females (Martin & da Silva, 2006). Even though the heavy body with enlarged limbs makes them slow swimmers, they are highly flexible, and can easily navigate between trees and floating vegetation (da Silva et al., 2018). They are mainly a solitary species but can be seen in groups of up to four individuals together, but mostly observed in mother-calf pairings, or with adults of different sexes living together (Best & da Silva, 1989). However, large groups of up to 37 individuals have been recorded on rare occasions (Gomez-Salazar et al., 2012a).

Tucuxi is a facultative freshwater species that are small and fast swimmers (Flores et al., 2018; Smith & Reeves, 2012). They are highly social dolphins and have been spotted in groups with 20 individuals, but mainly live in groups of 1 to 6. Like the boto, the tucuxi is also observed in groups consisting of mother-calf groups but portrays more cooperation between individuals and even between groups (Flores et al., 2018).

Although both species of Amazonian river dolphins are a common sight across the basin, both *I. geoffrensis* and *S. fluviatilis* were classified as endangered in 2018 and 2020 (da Silva et al., 2018; da Silva et al., 2020) respectively. Dam construction along rivers and tributaries have increased rapidly in recent years and many new hydropower projects are being developed throughout the Amazon basin (Lees et al., 2016; Zarfl et al., 2019). These dams isolate dolphin populations, can separate gene pools, affect the fitness of these animals (da Silva & Martin, 2018; Gravena et al., 2014), and affect ecosystems in floodplains by interfering with the natural flooding, leading to loss of food resources (Castello & Macedo, 2016; Lees et al., 2016). Freshwater river dolphins in the Amazon are currently prohibited from intentional harassment, but the regulations of by-catch are lacking (Marmontel et al., 2021). River dolphins are under threat by entanglement in fishing nets where they either get wounded, drown (Martin & da

Silva, 2022), or killed to be used as bait for fishing large catfish (Alves et al., 2012). There have also been discoveries of river dolphin carcasses with intact bodies, most likely killed as pests considered a threat to local fisheries (Loch et al., 2009; Smith & Reeves, 2012). In addition, increased development in rural Amazonia and climate change can lead to an intensified search for food resources both for humans and dolphins, and this may in turn lead to stronger competition between humans and cetaceans in the Amazon.

Few dolphin surveys have been performed in the Amazon, but the highest density of freshwater cetaceans ever observed worldwide was found in the Mamirauá Reserve in Brazil with 18 *I. geoffrensis* per km² in floodplain channels (Martin & da Silva, 2004b). In fact, high-density estimates for river dolphins are often found inside well-protected areas (Gomez-Salazar et al., 2012a; Mintzer et al., 2016; Mintzer et al., 2020), and in areas with low boat traffic (Aliaga-Rossel et al., 2006). However, visual dolphin survey methods are not standardized and it is therefore difficult to compare across regions and studies (Gomez-Salazar et al., 2012a; Oliveira-Da-Costa et al., 2020; Paschoalini et al., 2021; Vidal et al., 1997). In addition, density estimates and group sizes for river dolphins in South America differ significantly between the high-water season and the low-water season and between species (Aliaga-Rossel et al., 2006; Gomez-Salazar et al., 2012a; Martin & da Silva, 2004b; Paschoalini et al., 2021; Trujillo et al., 2010; Vidal et al., 1997). Indeed, their distribution is influenced by seasonal flooding, as both species move into channels and lakes during high water levels. Only boto is frequently found inside flooded forests (da Silva & Martin, 2018; Flores et al., 2018). There is evidence that habitat selection the two Amazonian dolphin species differ, the boto preferring river margins and the tucuxi having higher occurrence in the center of the river (Gomez-Salazar et al., 2012a; Martin et al., 2004), but high densities of both are found in river margins, confluences and lakes (Best & da Silva, 1989; Pavanato et al., 2019). Especially important are confluences, which is often visited by humans with net gill deployment because of high fish abundance (Martin et al., 2004).

In this study, I build on previous studies by investigating the encounter rates of *I. geoffrensis* and *S. fluviatilis* in the middle Juruá river and the occurrence of both dolphin species in floodplain lakes located along the Juruá river. I also investigate potential effects of environmental and anthropogenic factors on encounter rates and presence of dolphins in floodplain lakes to assess potential sites of preference or avoidance. I discuss the results in

light of previous research and known physiological and social differences between the species that could affect their abundance, habitat preferences and group sizes.

2 Methods

2.1 Study species

I. geoffrensis, or boto, is identified by the very pink color of their skin, which is caused by many capillaries close to the skin's surface. This coloration is stronger in older individuals because of scars from intraspecific aggression and fighting (Martin & da Silva, 2006). The non-fused cervical vertebrae ensure the ability of the head movement in many directions, and with the long, sturdy mandible, they are good hunters in the water and can navigate easily through trees in floodplains. Despite having small eyes, their eyesight is good both above and underwater (da Silva et al., 2018).

S. fluviatilis, or tucuxi, are grey in color with have large eyes and fins that are evolved for the jumps and acrobatics they often perform in the water (Flores et al., 2018). Both dolphin species prefer fish living pelagically, but tucuxi has a more specialized diet than boto (Rosas et al., 2010). Although they show extensive intra- and interspecific aggressive behaviour, they portray an ability to cooperate around feeding and epimeletic behaviour with caring of each other's injured or ill offspring (Flores et al., 2018). Both species use echolocation for navigation through waters, which is especially beneficial with murky waters high in sediments (Tyack & Miller, 2002).

2.2 Study area

This study was conducted in the Juruá river basin located in the western Brazilian Amazon (Figure 1). The Juruá River is a large meandering white-water river entering the Amazon/Solimões from the south. This river is bordered by a vast floodplain covered by seasonally flooded várzea forests (Hawes et al., 2012). The seasonal flooding of these floodplains occurs between January and June, with a low-water season in (Hawes & Peres,

2016). Bordering the várzea, there is an upland forest (terra firme) located above the maximum flood levels.

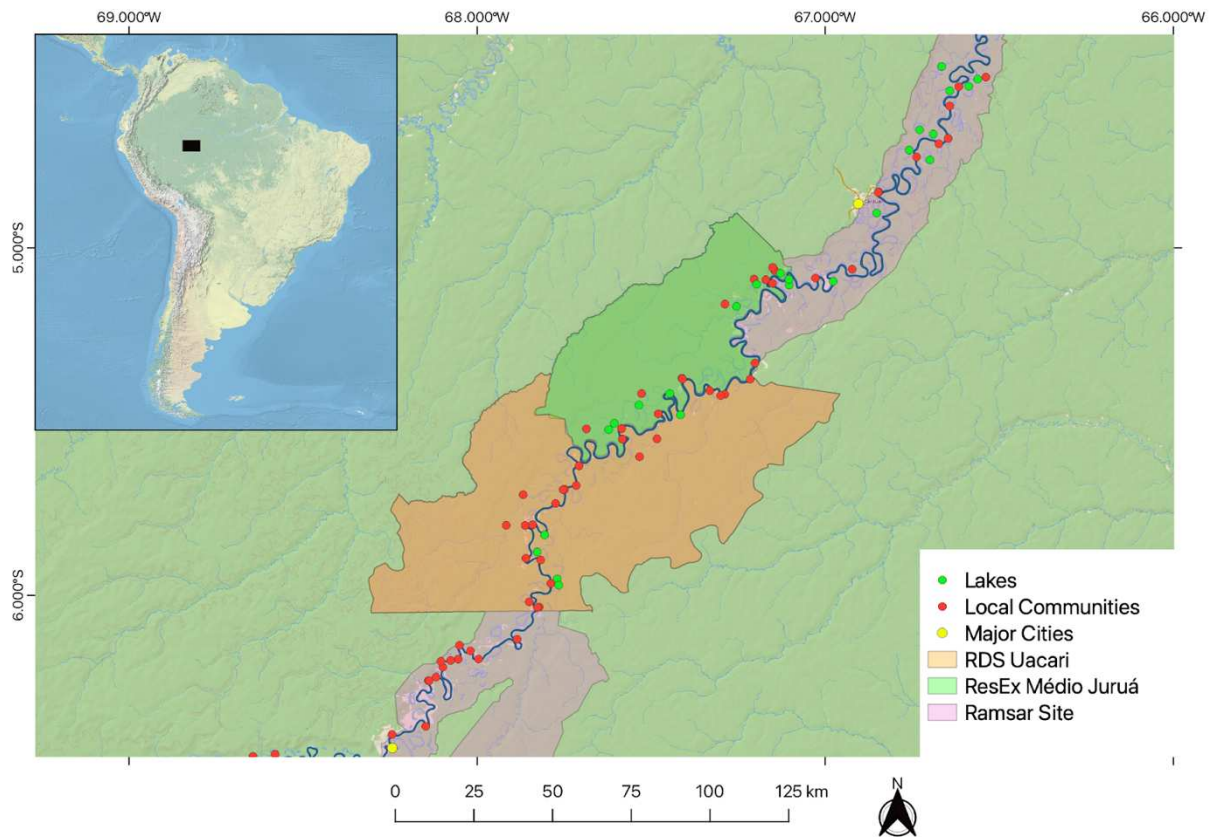


Figure 1: Location of the Juruá River basin (inset) and the middle section of Juruá River with the respective protected areas. Red, yellow, and green dots denote communities, towns, and lakes, respectively.

Dolphin surveys (see below) were conducted from 21st of September to 10th of October, during the low-water season, along a 2000-km stretch of the middle Juruá river, between the towns of Juruá and Itamarati. Surveys were also performed in 24 selected oxbow lakes on the floodplain adjoining the river (Figure 1). In the low-water season, these lakes are discrete units in the landscapes and are largely cut off from the main river. The wetlands along this stretch of the river was categorized as a Ramsar site in 2018 due to the importance of the wetlands containing high fish species diversity and providing habitat for threatened species (RIS, 2021). In addition to the Ramsar site designation, the middle part of Juruá River contains two contiguous protected areas: the Médio Juruá Extractive Reserve (ResEx Médio Juruá) and the Uacari Sustainable Development Reserve (RDS Uacari), established in 1997 and 2005, respectively. Both support the sustainable conservation of nature and bring

improvements to the quality of life for the human population living inside each protected area (Newton et al., 2012). The study landscape is constructed by many lakes under community-based management where sustainable fisheries of Pirarucu (*Arapaima gigas*) are important for many of the local communities (Campos-Silva & Peres, 2016). Within the middle region there are approximately 53 communities with approximately 4,000 local people living along the riverbanks in addition to the three larger towns (Juruá, Carauari, and Itamarati). There is therefore a significant amount of boat traffic for transporting goods, and small-scale agriculture. The people living in the Juruá are heavily dependent on fishing as a resource for both food and income and therefore are often seen fishing in this river with the main technique of casting fishing nets (Newton et al., 2012).

2.3 Dolphin surveys in the river

Dolphin censuses were performed by motorized boats ranging between 10-15 meters in length with a mean velocity of 10 km/h. A total of 69 linear transects were conducted and each survey lasted for 20 minutes. This equates to an approximate distance of 2.85 km per survey, covering approximately 196.6 km of the Juruá river. The surveys were done with the naked eye and binoculars between 3 meters and 7 meters above the water line. This depended on the height of the boats and the possibility to do the surveys from the platform or on the roof as it was necessary to switch boats during the fieldwork. Transect surveys were conducted with five or six observers, with two or three observers in the front of the boat and the same number in the rear. In each case, one or two observers orally described the information needed and one observer recorded the data. For transects with only five observers, it was decided to have two observers in the front, where the least dolphins had been observed previously, and three in the back where the majority of dolphins were observed.

The information collected from each observation was the distance from the boat the dolphins were sighted, the angle in degrees (0-180) confirmed by a protractor the observers kept with them, the number of individuals, what habitat they were observed in (e.g. center, bank, beach, channel, backwater), other observations (e.g. calf or near something that could be helpful in identifying each individual or group), and time of each observation. GPS coordinates, time at the start and end of the transect, weather and water conditions, number of boats and

fishermen, and other observations (e.g. near something of importance, fishing nets, community, confluence) were also noted.

The linear transects dolphin surveys were always done in the middle of the river if there were no obstacles present. If so, it was necessary to maneuver to either side of the river (Vidal et al., 1997). Speed was controlled by using Garmin GPS, but the velocity varied between 8-12 km/h because of water volume and velocity naturally changing at different sites of a river (Osborne, 2012c). If the velocity deviated greatly from 10k/h, the speed of the boat was adjusted. Transects were carried out both up- and down-river, but the speed at which the boat traveled did not differ.

Dolphins' group size was determined as the number of individuals surfacing together in a time span of >10 seconds and a maximum of 5 meters apart. The distinction between the two dolphin species is not very complicated because of their very different size, coloration, and characteristics, especially when comparing the dorsal fin (Flores et al., 2018). Our observers are skilled fishermen and hunters and have lived in this area of the Amazon their whole life. They are very experienced in observing different wildlife around the river, although never surveyed dolphins before. That is why all observation was confidently confirmed as either *I. geoffrensis* or *S. fluviatilis*.

We characterized weather and water conditions from 1-3 after Gomez-Salazar's method (Gomez-Salazar et al., 2012a). Behind the boat, there are always ripples in the water from the propeller, making the condition a little bit more difficult to spot dolphins than in the front. The water condition would change during the 20-minute transects from calm to agitated, but we used the classification from what the condition stayed for the longest by observing this during the transects. We didn't have any transects with weather and water levels at 3, and therefore used all transect surveys.

When the river survey was terminated, the notes of observations between front and back were compared to make sure there was no double-counting of individuals. To confirm that an observation was already collected from either platform, it was checked for alignment in the time of observation, specie, number of individuals and angle. If the information from both platforms aligned, the observation was recorded as a singular observation.

2.4 Dolphin surveys in lakes

In total, information from 24 lakes laying near the Juruá River was used for this thesis. It was only performed dolphin surveys in lakes where there had been oral confirmation from local people that dolphins occurred, and access to visit was granted by the landowners. Lakes were surveyed in a similar way to that of the river, where transects were done by canoe in the center of the lake, but with one observer at each end of the canoe, front and back, and one observer in the middle. The transects were done by rowing the canoe for 500m, navigating by GPS. After 500m rowing, there was a 5-minute break before a new 500m transect. If there was a motor available on the canoe, the break held with the motor on. The same information for the river transects was gathered for the lakes if there were dolphins present.

The number of transects for each lake was pre-decided according to the size of the lake. There is a great variation in the sizes of each lake, but for simplifying the method, lakes were categorized into small (mean: 0.32 km²), medium (mean: 1.27km²), and large (mean: 2.32km²). There was established a standardized number of transects for each size; 2, 4, and 6 respectively. To conduct the analysis, it was necessary to have GPS coordinates for each lake. This was done by inserting points into QGIS according to the polygon in Hydrosheds (Messenger et al., 2016) and according to notes done on-site.

Unfortunately, it was not possible to determine dolphin encounter rates in lakes as dolphins followed the canoes, and due to the slow speed at which the canoes traveled there was a strong risk of counting the same individuals multiple times during a transect (Aliaga-Rossel et al., 2006; Gomez-Salazar et al., 2012a; Paschoalini et al., 2021).

2.5 Statistical analysis

2.5.1 Environmental and anthropogenic effects on encounter rate in the river transects and presence in the lakes

The estimation of the encounter rate of the dolphin species was done by dividing the number of dolphins observed in each transect by the length of each transect in kilometers, which was

measured using QGIS. The GPS information from start to end was acquired for each transect during the field studies which therefore was possible to put into QGIS, which could give the length of each transect line in kilometers using the feature distance matrix. To check if there is a significant difference between the encounter rate of the two different dolphin species observed during the dolphin survey in the river, I conducted a t-test as there is an unequal variance between the encounter rate for the two dolphin species.

To measure distances from the nearest community or town to the river transects and lakes, it was necessary to conduct numerous distance matrices in QGIS. This was done by inserting GPS coordinates from start and end at each individual transect, or from a point projected for the lakes which were closest to the river transects, to the GPS location of each town and community which was located inside the study area. The lowest number produced by either start or end of the transect to each explanatory variable was used for the distance variables for river transects. The distance was presented in kilometers for both the river transects and lakes. The number of boats and fishermen present was counted according to visual observations on site. To see if the river transect was inside a protected area, polygons of the ResEx Médio Juruá and RDS Uacari were used to see if each transect line overlapped with these polygons in QGIS. For lakes, it was chosen to use protected area in form of lakes where management of pirarucu was happening. The Ramsar site was not included as a protected area in this thesis. Connectivity for lakes was assessed from maps of seasonal water levels in QGIS and figured out that there were channels leading from the river to the lake during high season (Pekel et al., 2016). Categorical values were chosen for protected area status, confluence, fishing nets, and landscape connectivity, where 1 means yes or present for transect or lake, and 0 means no or not present for transect or lake. The area of each lake are taken from polygon information in QGIS from layers acquired from HydroSheds (Messenger et al., 2016).

To understand the effect environmental and anthropogenic factors have on the encounter rates of boto and tucuxi in the main river, I did binomial negative generalized linear model (GLM) as these variables contained numerical values. The encounter rates of each species were used as response variable according to each transect. The explanatory variables for these models were the distance from the nearest town and community in kilometers, if there were confluence or fishing nets present at any point during the transect, if the transect was conducted inside a protected area or not, and the number of boats and fishermen present during each transect.

For understanding what anthropogenic and environmental variables explain the presence of dolphins in the lakes, I conducted a logistic regression analysis with a binomial family argument, as dolphin present or not in the lakes are categorical values. The presence of both dolphin species was combined into one response variable, using binary variables (0 or 1). The explanatory variables for the presence of dolphins in the lakes were the distance from communities, towns, and the main river in kilometers, the area of the lake in square kilometers, and if the lake was under community-based management and connectivity, with categorical values 1 and 0 for present or not.

After conducting the GLM analysis for both river transects and lakes, I needed to understand which explanatory variables could best explain how close the predictions from the model are to the actual data. I performed model selection using the Akaike Information Criterion with a correction for small sample sizes (AICs). To account for model uncertainty, I calculated model-averaged coefficients. Model averaging combines coefficients from multiple models, considering their relative likelihood. The averaged coefficients provide a more robust estimate of the relationship between the explanatory variables and the response variable. The AICc also considers the complexity of the models and chooses the model that most accurately explains the estimate with the least variables. The model with the lowest AIC values was chosen, and the estimates, and confidence interval for the variables in this model were plotted in RStudio.

2.5.2 Group sizes

The mean group sizes of the dolphins were estimated in R Studio. To check if there is a significant difference between the group sizes of the two different dolphin species observed during the dolphin survey in the river, I conducted a Mann-Whitney U test as there is an unequal variance between the group sizes of the two different dolphin species.

2.5.3 Habitat use

To understand if there are any preferences for which riverine habitats the boto and tucuxi frequently found in, the number of individuals were counted and classified to be present in different habitats during surveys in the river transects. A Poisson regression analysis with interactions was carried out, as count data were used (Jabeen, 2019). to determine if there

were any significance in the abundance of the boto and tucuxi in the different habitats, “Center” and “*Sotalia fluviatilis*” were used as defining variables. This way, it was possible to see which variable had any effect on the number of individuals found in each habitat and if the preference between species was significant.

The habitats in which each observation was present, were characterized by these definitions:

Center – In the middle of the river where there is a high river current.

Igarapé (channel) - Connection between the river and the lakes. These streams provide organic matter to the river.

Beach – Formation between river and land with levees stranded from flooding. Exposed sand and sedimentation without any vegetation near the waters.

Bank – Formation between river and land with a normal to steep decline into water.

Vegetation stretches out to the furthest point of land with the possibility of trees falling into rivers due to erosion.

Backwater – Waters close to land with reduced water currents often with the presence of fallen trees and floating vegetation.

Confluence - The connection between the river and the channel, where the water is mixed in a confined area.

3. Results

Dolphin surveys were performed along a total of 196,6 linear kilometers of the Juruá river. During 69 transect surveys, the main river censuses yielded 544 dolphin group observations consisting of 741 independent dolphin individuals. Of these, 431 individuals, equivalent to 58% of all observations, were boto and 310, equivalent to 42% of the observations were tucuxi. A single transect was completed without any dolphin observations, but 3 transects were completed without observing any individuals of boto, and 11 transects were completed without observing any individuals of tucuxi.

3.1 Group sizes

The mean group size for boto is 1.22 and for tucuxi, it is 1.68. This difference is significant ($P < 0.01$), where tucuxi has a significantly larger mean group size. Group sizes for boto varied between 1 and 3 individuals, and group sizes for tucuxi varied between 1 and 6 individuals. More than 200 observations of boto were of a single individual, approximately 1/3 of observations were of two individuals, with a maximum group size of 3 individuals observed together (Figure 2). Tucuxi has a higher group size variation but was largely seen as a single individual or in pairs. The largest group size was 6 individuals, but there were few observations with such large groups (Figure 2).

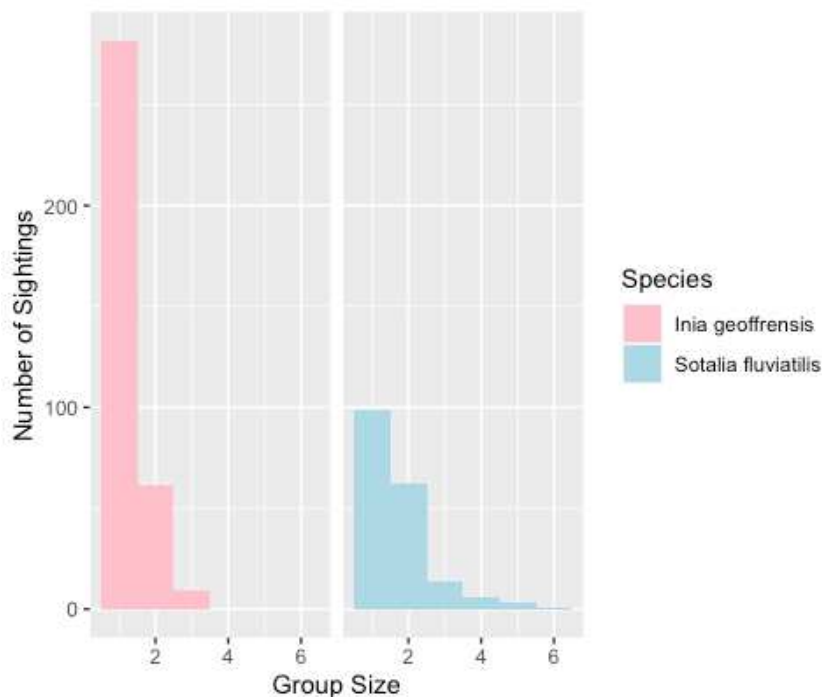


Figure 2: Number of sightings per group size of *I. geoffrensis* and *S. fluviatilis* in the middle Juruá river, Amazonia, Brazil.

3.2 Dolphin encounter rate in the river

The encounter rate of the two dolphin species in the Juruá River was 2.19 individuals per kilometer of boto and 1.58 individuals per kilometer of tucuxi, with a significantly higher encounter rate for boto ($P = 0.024$).

The generalized linear model shows that the distance to the nearest community had a significant negative effect on boto encounter rates ($P = 0.014$), where an increase in distance leads to a decrease in encounter rates. However, the presence of a confluence had a significant positive effect on boto encounter rates ($P < 0.001$). The presence of fishermen had no significant effect ($P = 0.45$). The overall model performance was assessed and indicates that 46.4% of the variation in the response variable can be explained by the predictors. It also indicates that the model is statistically significant where explanatory variables collectively have a significant effect on the encounter rate (F-statistics < 0.001 , $R^2=0.464$, $DF=61$). The model-averaged coefficients showed that distance from community and presence of confluence have a statistically significant impact on the encounter rate of botos, indicating a meaningful association. However, the number of fishers did not show a significant relationship to the encounter rates of boto, after accounting for all other variables (AIC=298.41) (Figure 2A).

The generalized linear model for encounter rates on tucuxi only yielded a significant positive effect of confluence present at transect ($P < 0.001$). The overall model performance was assessed and indicates that 47.2% of the variation in the response variable can be explained by the predictors. It also indicates that the model is statistically significant where explanatory variables collectively have a significant effect on the encounter rate (F-statistics < 0.001 , $R^2=0.472$, $DF=61$). The model-averaged coefficient analysis showed that the presence of confluence and number of boats ($P = 0.033$) have a statistically positive significant impact on the encounter rate of botos, indicating a meaningful association (AIC = 258.5).

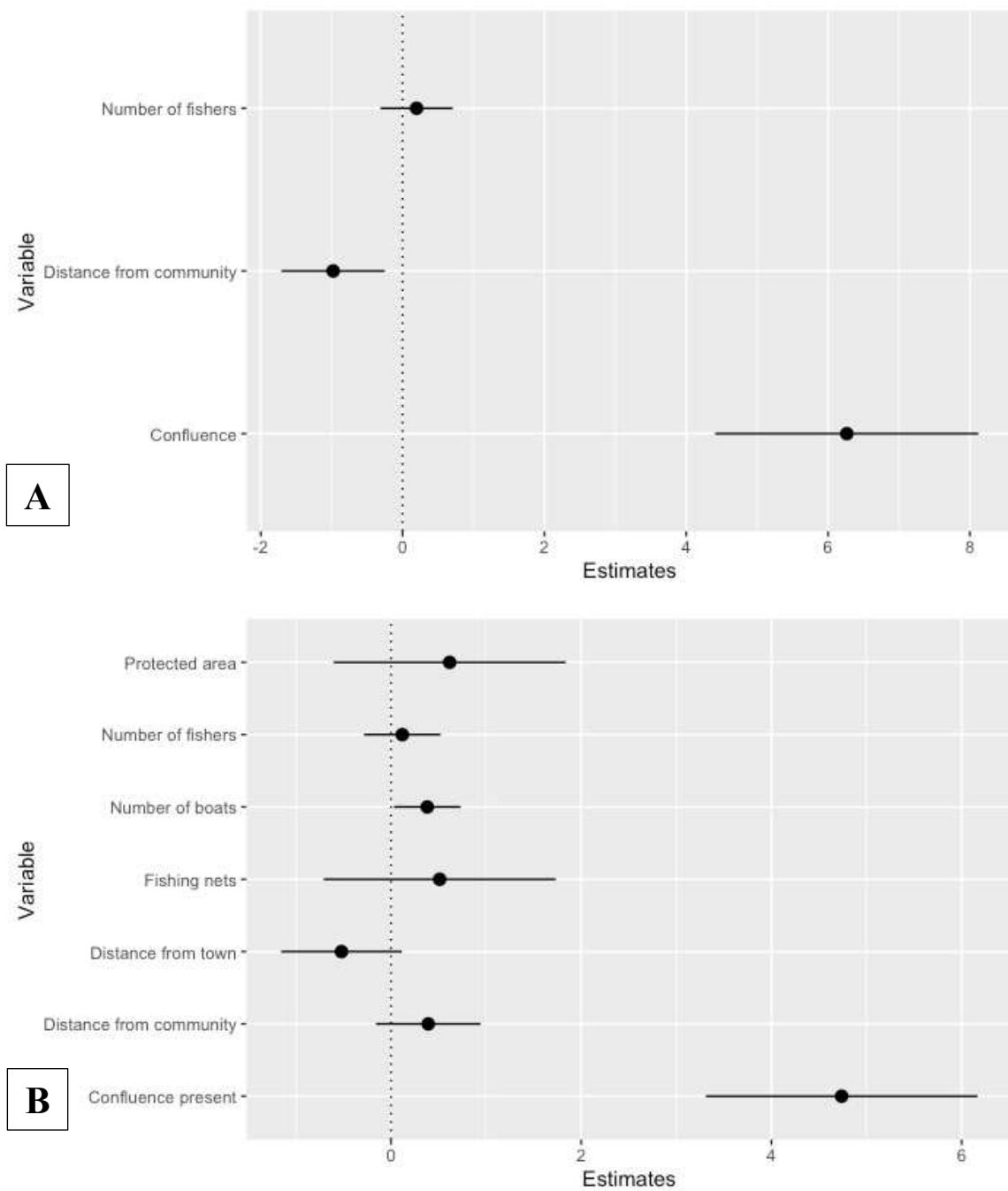


Figure 3: Variables explaining the encounter rate of *Inia geoffrensis* (A) and *Sotalia fluviatilis* (B) in river transects. Dots visualize the mean estimate effect of each variable, and lines represent the 95% confidence interval. Variables that have confidence intervals overlapping 0, do not have a significant effect on encounter rates.

3.3 Habitat use

Results show that there is a significant difference between riverine habitat preferences of boto and tucuxi, where the highest number of botos are observed in banks, and the highest number of tucuxi is found in the center. The Poisson regression analysis shows a significant p-value when comparing all habitat types against “Center” and *S. fluviatilis* against *I. geoffrensis*. In total 27% of all dolphins were found in the center, 43% along banks, 26% by beaches, 2% by channels, and 2% in backwater habitats. Habitats beach and bank constitutes the river margin, where 69% of all observed individuals were found. However, there were some differences between species. The tucuxi is more commonly found towards the center of the river (38% of all individuals observed). Other habitats also used prominently were next to the riverbank (31%) and outside river beaches (29%; Figure 4). The boto was more commonly observed close to the riverbank (52% of all individuals) and alongside river beaches (25%). The center of the river was used by 18% of the individuals (Figure 4).

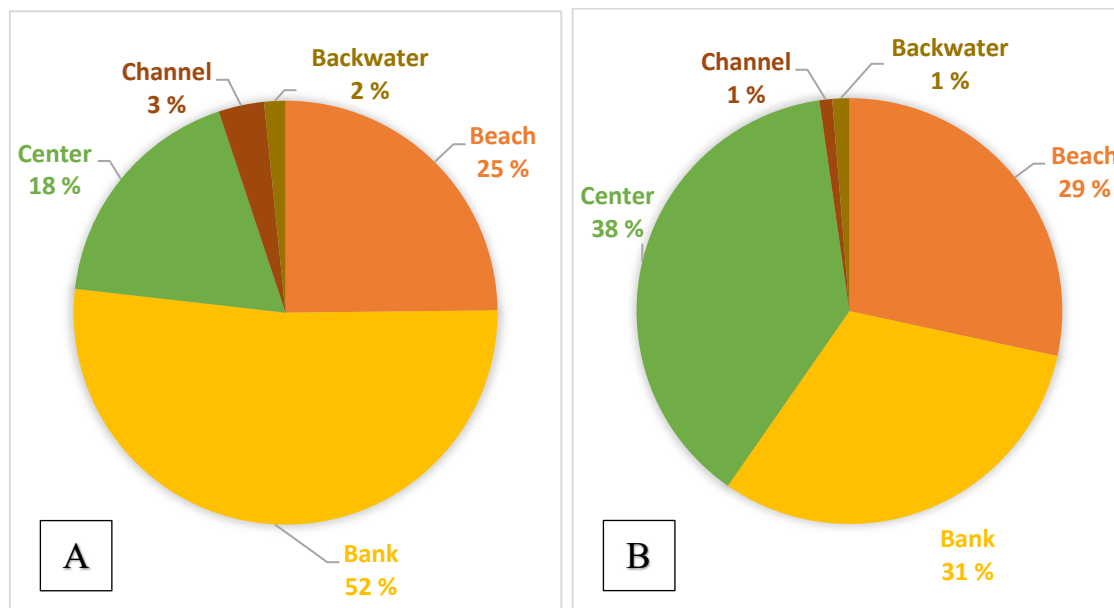


Figure 4: Habitat preference of (A) *I. geoffrensis* and (B) *S. fluviatilis*, showing % of individuals observed in each river habitat.

3.4 Dolphin presence in lakes

Dolphins were present in 11 in lakes, whereas 13 lakes had no dolphins. The 11 lakes with dolphins all contained boto, but only three of these lakes contained tucuxi. None of the variables I chose to explain why there are dolphins in lakes, showed to have any significant

effect when conducting a generalized linear model. The model-averaged coefficient analysis showed that distance from communities and the area of lakes had a positive effect on the likelihood of the presence of dolphins. However, the effect on distance from distance was small and non-significant (AIC=27.532) (Figure 4).

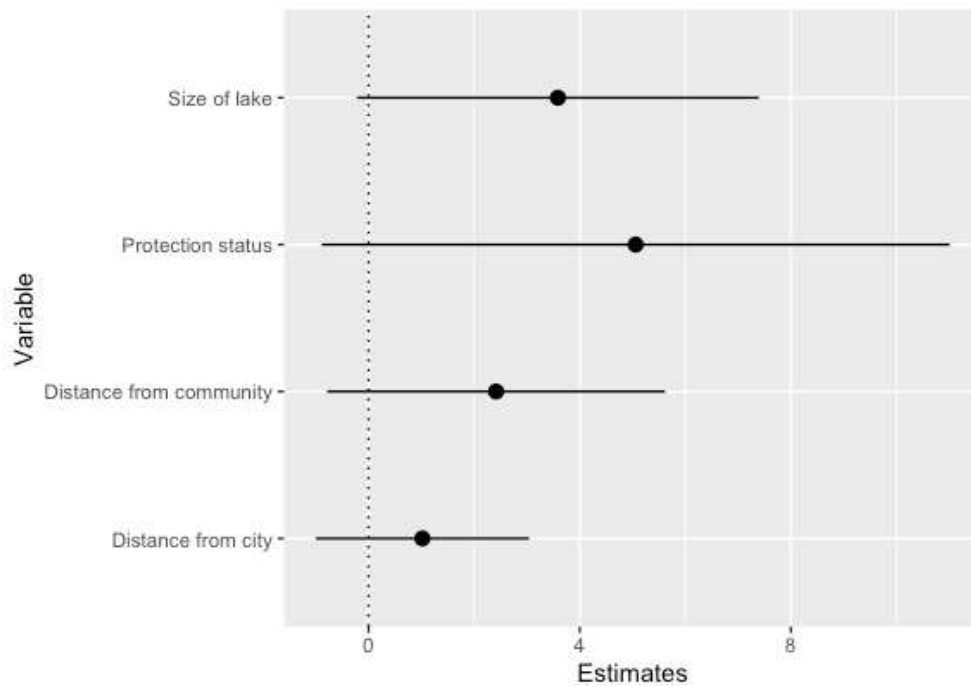


Figure 4: Variables explaining the presence or not of dolphins in lakes. Dots visualize the mean estimate effect of each variable, and lines represent the 95% confidence interval. Variables that have confidence intervals overlapping 0, do not have a significant effect on encounter rates.

4 Discussion

Amazonian river dolphins have previously been surveyed in the Juruá river as a part of a project investigating the usefulness of unmanned aerial vehicles in dolphin surveys and comparing these to conventional boat surveys (Oliveira-Da-Costa et al., 2020). However, this is the first study to investigate dolphin group sizes, encounter rates, distribution, and habitat preference in the Juruá, and what variables may influence these attributes.

Studies on river dolphins have increased during the 21st century as many of these species have become threatened, endangered, or extinct (Rojas-Bracho et al., 2006; Turvey et al., 2007). The river dolphins are the least known and studied of the cetaceans (Trujillo et al., 2010), and as they cover large areas of the Amazon, estimating have not been conducted across their whole distribution (Gomez-Salazar et al., 2012a). Studies agree that the abundance of boto is higher than tucuxi in the Amazon Basin (Campbell et al., 2017; Paschoalini et al., 2021; Vidal et al., 1997), which correlates to the number of individuals found of each species in this study.

Other dolphin surveys have been done with strip transects of 200m and cross transects at 45 degrees to cover the water in the river and to not miss individuals of dolphins (Gomez-Salazar et al., 2012a). Juruá is a tributary from the Amazon River and is small compared to earlier similar studies, and thus this method was not possible to conduct, therefore we did strip transects as mentioned in the methods. This study was constricted to surveys done only during the low-water season, and each transect was only surveyed once on a single day, without any temporal replication. This means that dolphins can move in this time span, and the chances of surveying the same individuals are greater as dolphins show residency in the same areas (Martin & da Silva, 2004a). Transects done upriver and downriver have a difference in velocity of speed as the boat moves faster downriver with the help of water discharge (Osborne, 2012b). Studies have shown that the speed of the boat is not significant for the ability to detect dolphins but only increases the chances of observing the same individuals multiple times or experiencing dolphins following the boat if the speed is too low (Aliaga-Rossel et al., 2006; Gomez-Salazar et al., 2012a; Martin et al., 2004).

4.1 Group sizes

Tucuxi have the higher mean group size and the group sizes of tucuxi are significantly larger than the group sizes for boto (Figure 2). Most of the dolphins observed of both species were either of a single individual or pairs. This is consistent with previous studies of these two species where they were also found to be solitary or in pairs (Gomez-Salazar et al., 2012a; Paschoalini et al., 2021; Trujillo et al., 2010; Vidal et al., 1997). Group sizes of 1-4 for boto and 1-6 for tucuxi observed here are also similar to those observed elsewhere (da Silva & Martin, 2018; Flores et al., 2018). This correlates to the findings in this thesis as tucuxi are known to be a more sociable species (Flores et al., 2018), and can cooperate across genders

and other groups. Although the largest group sizes registered in this study were rarely observed, larger groups have been observed with up to 15 individuals for boto and 26 for tucuxi registered elsewhere in Amazonia (Gomez-Salazar et al., 2012a).

Yet, it is notoriously difficult to estimate dolphin group sizes and comparing across studies is therefore difficult because different observers may perform or interpret observations differently. For example, it can be difficult to estimate group sizes as there is limited time to see an animal/group and characterize it (Vidal et al., 1997). In addition, dolphins often travel in incohesive groups where individuals can be found up to 50 meters apart. The group definition utilized in this study may therefore have underestimated group sizes. Other researchers have therefore used a different strategy for calculating group size, such as counting all individuals seen emerging from the water within a 1-minute timeframe (Gomez-Salazar et al., 2012a).

However, the size of the river may also influence group size. The Juruá river is smaller than those included in the study by Gomez-Salazar et al. (2012a) and the dramatic decrease in aquatic habitat during the low-water season may prove a bottleneck for larger group sizes in the region (Gomez-Salazar et al., 2012b; Mintzer et al., 2016). With smaller habitats and hunting grounds, it could be more beneficial to be a larger group to cooperate in finding food and fighting off competitors (Campagna, 2018). River dolphins have no natural predators in the Amazon basin and in the Juruá River (Cook et al., 2022), which mean they have no need for large groups to fight off these or protect their offspring. This may explain the small group sizes among Amazonian river dolphins compared to marine species (ref), as they experience the presence of larger marine predators. This means that there is no need for cooperation in large groups, and because there is plenty of food resources in the river, it is advantageous to stay in small groups.

Group sizes were not estimated for the lake surveys, but if this was done it could have provided a different pattern than for the river because tucuxi is known to have significantly larger groups in this type of habitat (Gomez-Salazar et al., 2012a; Gomez-Salazar et al., 2012b; Vidal et al., 1997).

4.2 Dolphin encounter rate in the river

The results show that the closer a community is to the transect line, the higher the encounter rate for boto will be in each transect. It also shows that the encounter rate will be higher at each transect if a confluence is present (Figure 2A). For tucuxi, the only variable significant was confluence, which means that a confluence present at the transect will also increase the encounter rate for this species (Figure 2B). The confluence variable for both species had a high mean estimate of the effect it has on the encounter rate, but also a large confidence interval at 95% certainty. We can therefore say at confluence have a high effect on the encounter rates, but there is a great variance in this estimate, and it can vary from the actual effect.

Overall encounter rates observed for both river dolphin species in the current study are similar to earlier studies performed during the low season in Amazonian rivers and tributaries (Gomez-Salazar et al., 2012a; Vidal et al., 1997). Both species had significantly higher encounter rates at confluences, where smaller tributary streams enter the main river. These findings are also consistent with results from other studies that show that the highest dolphin density estimates are found in these areas (Aliaga-Rossel et al., 2006; Martin et al., 2004). These areas are known to contain a high abundance of fish and these areas are therefore also important fishing locations for the human population (Martin et al., 2004). The high encounter rates of both dolphin species would suggest competition and aggressive behavior. However, no obvious signs of this were seen during the surveys, whereas both dolphin species were seen feeding and socializing. Perhaps there is simply such an abundance of fish in these areas that competition is unnecessary, and cooperation is more useful.

None of the other variables tested for the tucuxi significantly influenced the encounter rate of this species, whereas boto was less frequently encountered close to local communities. A similar effect was found in the Bolivian Amazon (Aliaga-Rossel et al., 2006) where boto abundance was higher in areas of low human population and boat traffic. Boats can also interfere with the echolocation used by dolphins as they communicate and hunt (ref.), so as boat traffic significantly increases with increasing human populations this could complicate dolphin life. Indeed, this may be the reason for the negative impact of distance from communities encounter rates of *I. geoffrensis*. *S. fluviatilis* was also negatively influence by proximity to cities, though not significantly so. There is generally more noise pollution in areas with a lot of people (Gomez-Salazar et al., 2012a; Martin et al., 2004), often caused by motorized vessels.

Yet, it is evident that the dolphins are not shy of boat traffic as numerous individuals were observed close to the boat and were also regularly following the canoe during lake surveys. This could be due to the fact that dolphins have never been hunted in the study area (Cook et al., 2022), which means that the dolphins have no reason for avoiding boats as they can easily navigate around them. This could potentially prove problematic into the future if dolphin hunting becomes an activity (Loch et al., 2009) – particularly if pressure for resources increases as a result of climate change and population growth (Endo et al., 2016) that would lead to more intense competition between humans and dolphins.

However, for now the high abundance of resources mean that competition for resources between humans and dolphins will remain low. In the Juruá, fishing is mostly under local subsistence and under community-based management preventing excessive exploitation of the fish resources. This is probably why there was no effect of protection (i.e. transects located inside and outside the protected areas) on dolphin encounter rates and encounter rates of dolphins are high even outside the ResEx Médio Juruá and RDS Uacari. In addition, river dolphins form part of local folklore and are considered important. Fishermen therefore usually release dolphins quickly after noticing that they are entangled in fish nets (Cook et al., 2022).

4.3 Habitat use

Boto preferred swimming along the banks of the river whereas tucuxi was more readily observed in the middle (center) of the river – although these dolphins also showed a preference for river margins. Fish species that are important dietary items for both dolphin species form large schools that migrate near the riverbanks (Martin & da Silva, 2004b) This may explain why many dolphins were seen in this part of the river. In fact, 69% of all observed dolphins were found here. Both species were also frequently found along beaches, most likely for the same reason.

However, the tucuxi was more frequently observed in the center of the river. This is consistent with previous findings (Gomez-Salazar et al., 2012a). This may be due to physiological differences between the two species. Moving upstream against the river currents can be very energy costly, especially for a species such as boto with its large size and the slow pace of swimming (da Silva & Martin, 2018). In addition, boat traffic is higher in the center of the river during the low-water season to avoid fallen trees, sand banks and other obstacles. As the tucuxi

is a smaller and faster dolphin species than the boto, they can more easily withstand the current and avoid fast-moving traffic than their slower-moving counterparts (Flores et al., 2018). The boto is more threatened by fast-moving boats than other dolphin species (da Silva & Martin, 2018). Channels and backwaters were less frequently used by both species.

4.4 Dolphin presence in lakes

None of the tested variables can explain why there are dolphins in the lakes, but the model selection process showed that there was a likelihood that distance from city and community, and area of lake could affect the presence of dolphins. However, further investigation is needed to understand the relationship between these variables and the presence of dolphins. Dolphins were observed in approximately half of the lakes surveyed, but boto was observed in many more lakes than the tucuxi. This is perhaps not surprising since tucuxi seldom uses flooded forests and rarely visits lakes and channels during the low-water season (Flores et al., 2018; Martin & da Silva, 2004a; Silva, 1994). Yet, other studies (Gomez-Salazar et al., 2012a; Paschoalini et al., 2021; Trujillo et al., 2010; Vidal et al., 1997)- have found tucuxi at higher density in lakes than boto, but encounter rates were not estimated for the lakes in this study, so a comparison of results are not possible. The results presented here suggests that boto is better adapted to these lake systems at low water and that they are better adapted to utilize the várzea forest when it is flooded. During the high-water season, the várzea forest is flooded and becomes accessible to a large suite of aquatic species, but the flooded forest remains relatively hard to navigate for larger species and requires high mobility to move through the vegetation and to avoid getting stuck in shallow pools (Osborne, 2012c).

The boto clearly possess physiological characteristics that enables them to navigate these floodplain forests and utilize lake habitats during low-water, whereas tucuxi can risk death by moving into these habitats (da Silva & Martin, 2018; Flores et al., 2018). Indeed, research shows that although *I. geoffrensis* are separated from other species of *Inia*, there is gene flow for example from the lower Madeira river to the upper Madeira river despite the presence of significant rapids separating these regions (Gravena et al., 2014). Even though they are mostly a slow-swimming species, they can produce short bursts of speed to move up rapids (Gravena et al., 2014). The boto can thus move great distances, even up rapids, and appears to have few barriers to what habitats they can utilize year-round (Mintzer et al., 2016). The above attributes

may explain why there are boto individuals in lakes even though they have no connection to the river. They do not choose habitats solely for the fact that they have a rich food supply for the entire season but are not fearful of getting stuck in pools because they can easily migrate if needed. In fact, the boto can easily swim in waters as shallow as 1.5 meters (Martin & da Silva, 2004a; Martin & da Silva, 2004b; Mintzer et al., 2016). In addition, the use of lakes limits competition with tucuxi, and food supply in the lakes is highly concentrated and abundant during the low-water season. However, the apparent reliance on floodplain forests and lakes by the boto in the Juruá may be perilous as climate change progresses and produces more extreme drought events that may render lakes inaccessible.

The tucuxi was only present in 3 of the 24 lakes that were surveyed, which means that most of them do not risk leaving the main river. However, some individuals appear to have learned that there are enough resources to survive the low-water season in some lakes even though are completely cut off from the main river. The tucuxi is known to use the same area over several years, showing seasonal residency in these areas (Flores et al., 2018). This could explain why some tucuxi individuals occur in the lakes during the low water season. In fact, the three lakes where tucuxi was found had a similar size and depth, suggesting that they may have been carefully selected. The lakes were large, measuring between 1,91 km² and 3,28 km², making them all among the top 8 biggest lakes that were observed and were under pirarucu management. However, it may also be possible that these tucuxi individuals were involuntarily trapped in these lakes but may not be in immediate danger as the lakes are abundant in resources.

6 Conclusion

To conclude, group sizes and encounter rates of both river dolphin species observed in the Juruá river were similar to those observed in previous studies. The current study also underlined their fondness for confluences where resource abundance usually is high. However, the two species also clearly differ in that the boto more often utilizes floodplain lakes whereas the tucuxi generally avoided these. Future research should expand the dolphin surveys to include more lakes across the Juruá floodplain and include the high-water season to assess any potential between-season differences in habitat preference and encounter rates. In addition, it may be useful to improve estimates of dolphin abundance and distribution in the Juruá by performing a mark-recapture study and utilizing new technology by putting GPS trackers on individuals of

each species to assess seasonal habitat use. This may be important as the Amazon basin river dolphins are facing threats, such as climate change, hydropower development and competition for resources from growing human populations, that can severely impact their way of life. A more holistic understanding of river dolphin abundance, group sizes, and distribution and what affects these, is therefore vital for the future conservation of these species.

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