

Group Size, Habitat Use and Behavioral Ecology of Amazon River Dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in the Pacaya-Samiria National Reserve, Peru

Evan Hall  
April 2012

Submitted as partial fulfillment of the Queen's University School of Environmental Studies BSc (Honours) program

## Abstract

Two species of cetacean occur sympatrically in the Amazon River and its tributaries; botos (*Inia geoffrensis*) and tucuxis (*Sotalia fluviatilis*). Little information exists on the ecology of each species as well as any differences in their ecology. In this study, a generalized linear model was used to examine the habitat use and behavior of botos and tucuxis along a small river system in the Pacaya-Samiria National Reserve, Peru. Analysis of habitat use indicated that botos used confluences significantly more than any other river habitat and tucuxis used river centers significantly more than any other habitat along the Samiria River. Tucuxis used the river center significantly more than any other habitat type, followed by confluence and river-center habitat, whereas botos used the confluence significantly more than any other habitat type and showed no significant distinction between the other habitat types (except river center, which was least used). The differences in habitat use between the two study species may be indicative of how they avoid competing with each other and may be indicative of niche separation between the two species. Group size data was collected for both species during July and August 2011 and compared with group size data from published data from other regions and was also used to highlight differences between the respective biology of each species. Group size differed significantly between species, with tucuxis being observed in larger groups than botos, which may indicate tucuxis are more social than botos. Additionally, observed behavior differed between the two species, with tucuxis socializing significantly more than botos. These results may indicate that socializing is a more integral component in the biology of tucuxis than that of botos. The differences in sociobiology between each species will help provide information on the life history of each species in small rivers, which is not well documented. Furthermore, by examining the ecology of botos and tucuxis, inferences can be made about each species' ecological requirements of each species in small rivers, which can be used to help create more effective conservation strategies that adequately protect the needs of both species.

## **Acknowledgements**

Firstly, I would like to thank Operation Wallacea for providing me the opportunity to collect data in the Pacaya-Samira National Reserve, Peru. Secondly, I would like to thank Allistair Smith who helped me with my methodology and was excellent at fielding my various questions about research design in the field. Furthermore, I would like to thank the Peruvian guides, the OpWall research assistants as well as Beccy Patten and Gareth John. I would also like to thank Richard Bodmer and Amazon Eco specifically for providing their boats and resources during the expedition.

I would also like to thank my supervisor Ryan Danby for his help formulating specific research questions and hypotheses based on the data I collected as well as his advice and feedback in developing and formatting my proposal, poster and thesis paper. Finally I would like to thank Charles Molson of the Statistics department for his initial consultation involving my data analysis and Paul Martin from the Department of Biology for all his help developing, coding and answering countless questions involving the development of my data analysis.

## Table of Contents

<b>Abstract</b> .....	<b>2</b>
<b>Acknowledgements</b> .....	<b>3</b>
<b>Table of Contents</b> .....	<b>4</b>
<b>List of Figures</b> .....	<b>5</b>
<b>List of Tables</b> .....	<b>6</b>
<b>List of Common Abbreviations</b> .....	<b>7</b>
<b>Introduction and Literature Review</b> .....	<b>8</b>
<b>Hypotheses</b> .....	<b>14</b>
<b>Methods</b> .....	<b>15</b>
Data Collection .....	16
Data Analysis .....	<b>Error! Bookmark not defined.</b>
<b>Results</b> .....	<b>22</b>
<b>Discussion</b> .....	<b>30</b>
Conservation Implications and Future Applications.....	40
<b>Conclusion</b> .....	<b>41</b>
<b>Works Cited</b> .....	<b>43</b>
<b>Appendix</b> .....	<b>47</b>

## List of Figures

<b>Figure 1:</b> Location of the Pacaya-Samiria National Reserve, Peru	<b>15</b>
<b>Figure 2:</b> Histogram of boto group size observations	<b>23</b>
<b>Figure 3:</b> Histogram of tucuxi group size observations	<b>24</b>
<b>Figure 4:</b> Hierarchal organization of riverine habitat use for each study species	<b>28</b>
<b>Figure 5:</b> Hierarchal organization of the behaviors exhibited by each study species	<b>29</b>

## List of Tables

<b>Table 1:</b> Ethogram of dolphin behavior	<b>19</b>
<b>Table 2:</b> Riverine habitat classification	<b>19</b>
<b>Table 3:</b> Ranked generalized linear models for 'boto' count data	<b>25</b>
<b>Table 4:</b> Ranked generalized linear models for 'tucuxi' count data	<b>25</b>
<b>Table 5:</b> Ranked generalized linear models for tucuxi and boto combined data	<b>26</b>

## **List of Common Abbreviations**

**AIC**- Akaike's Information Criterion

**FWPA**- Fresh Water Protected Area

**GLM**- Generalized Linear Model

**IUCN**- International Union for Conservation of Nature

**IWC**- International Whaling Commission

## Introduction and Literature Review

Globally, river dolphins constitute a cetacean taxon that is at risk due to anthropogenic impacts (Vidal et al. 1997). This is a result of the close relationship between riverine and terrestrial habitats as well as the densely populated nature of the world's large rivers, which contain many species of small cetaceans. The current status of the Yangtze River dolphin (*Lipotes vexillifer*) presents the most dramatic example of how anthropogenic impacts can affect riverine cetacean species. This species is currently listed by the International Union for Conservation of Nature (IUCN) as 'Critically Endangered' and may possibly be extinct (Smith et al. 2008; Turvey et al. 2007) given a lack of recorded sightings during extensive surveys (the last confirmed sighting was in 2002). Human impact from habitat destruction (i.e. dam and port construction), pollution, and unsustainable by-catch are cited as the main reasons for the decline of the Yangtze River dolphin (Turvey et al. 2007). The negative impacts these threats pose are not limited to the Yangtze River but, in fact, threaten riverine cetaceans worldwide. The focus of this study was on the two species of 'river dolphin' that occur in South America, specifically in the Peruvian Amazon.

There are two species of river dolphin that occur sympatrically in the Amazon River basin; the Amazon River dolphin (or boto), *Inia geoffrensis* (de Blainville, 1817) and the tucuxi, *Sotalia fluviatilis* (Gervais & Deville, 1853). *Inia geoffrensis* is a true river dolphin of the Platanistoidea superfamily. There currently exists three subspecies of *I. geoffrensis*; *I. g. boliviensis* which are native to Bolivia, *I. g. humboldtiana* which is native to the Orinoco basin of Venezuela and Colombia and *I. g. geoffrensis*, or boto, which is found throughout the Amazon Basin of Brazil, Ecuador and Peru. Botos occur throughout the Amazon River (including the delta) except where impassable obstacles such as rapids, waterfalls, and low water levels prevent their movement (Best & da Silva 1989). Botos exhibit a tendency to migrate into flooded forested areas of the Amazon during high water season (Martin & da Silva 2004b), most likely to prey on fish that have migrated in to the flooded forests as well.



The other species of cetacean that occurs in the Amazon is the grey river dolphin (family; Delphinidae). Recently, two distinct species of *Sotalia* were recognized by genetic (Caballero et al. 2007) and morphological (Fettuccia et al. 2009) analysis. The two species now recognized are *S. fluviatilis*, or tucuxi, which inhabits the Amazon River, and *S. guianensis*, which inhabits estuarine and marine environments along the eastern waters of South and Central America. Tucuxis are found throughout the Amazon watershed including the upper reaches of the river as far inland as Peru and Ecuador. During the high water season, tucuxis may migrate into smaller tributaries of the Amazon. However, unlike botos, they do not appear to move into the flooded forested areas in search of food. Instead, they remain in the tributaries, lakes and channels of the Amazon (da Silva & Best 1996).

#### *Conservation Status of Botos and Tucuxis*

Both species are currently listed as 'Data Deficient' by the IUCN (Reeves, 2010 & Secchi, 2010), mainly due to insufficient data on threats, ecology and population trends. There is no formal abundance estimate for either species and currently no data on population trends relative to human impacts. However, while the magnitude and extent of human impact on either species is not well understood, there are several prevalent threats both species face throughout much of their distribution. In certain areas of the Amazon, both botos and tucuxis are afforded some level of informal protection from direct persecution due to their prevalence in local superstitions (Cravalho, 1999). However attitudes towards the dolphins (specifically botos, as they are regarded as more of a nuisance than tucuxis) may be changing as increasing population and fishing effort continues to push people and dolphins into competition for resources. Currently, both species are threatened either directly or indirectly by the presence and actions of fishermen. In many areas of the Amazon, both species are intentionally killed by fishermen, who view them either as competitors for fish, or as a nuisance (dolphins can cause considerable damage to fishing nets as well as equipment).

Aside from direct persecution related to fishing activity, further fishing-related mortalities of both species of dolphin can be attributed to incidental boat-

strikes and entanglement in fishing gear. Aliaga-Rossel (2002) found this to be the case in Bolivia, however little data exists on the quantity of dolphins that are accidentally killed in these manners throughout the South American distribution of both species, including the Amazon. Anecdotal evidence from various publications (i.e. McGuire, 2002; da Silva, 1996) as well as conversations with guides in the Pacaya-Samiria suggest that these sources of mortality are widespread throughout the Amazon, but there is currently insufficient information to quantify the significance of these sources of mortality (IWC, 2000).

Overfishing does not appear to be a direct threat to either species as much of their diet is of fish too small to be commercially valuable (da Silva and Best, 1996) and the threat of depleted fishing stocks is especially low in the Pacaya-Samiria where fisheries are well regulated within the reserve.

As both species occur throughout the Amazon and are frequently found in the same river sections (Martin and da Silva, 2004), human influences on the riverine ecosystems of the Amazon affect both species. The International Whaling Commission (IWC) (2000) has projected that construction of hydroelectric dams and irrigation for agriculture used to supply energy and food for increasing human populations in Columbia, Venezuela, Brazil and Peru may pose threats to river dolphins as sources of habitat loss. The creation of dams along the Amazon would likely pose barriers to river dolphins, preventing their movement and creating isolated populations. Tucuxis may be specifically vulnerable to damming as they feed on migratory fish species (da Silva and Best, 1994), which may also suffer from the obstruction of river flow caused by the creation of dams. Reduction in water level due to irrigation for agricultural purposes has also been attributed as a threat to river dolphins (da Silva and Best, 1989) as there have been reported incidences of botos becoming stranded due to water fluctuations associated with water diversion. Furthermore, conversion of forest to agricultural land as well as deforestation related to the timber industry have been outlined by the IWC (2000) as potential sources of habitat degradation mainly due to its implications on river productivity and prey abundance.

Both botos and tucuxis could also be threatened by the presence of pollutants in the food web of the Amazon and its tributaries. Little information exists on the prevalence and persistence of biologically persistent pollutants in the Amazon River's food web, but according to one study (Rosas and Lethi, 1996) conducted near Manaus, Brazil, mercury contamination in botos is low. However, expanding agriculture (and the associated increase in use of pesticides) along the Amazon as well as increasing mineral extraction throughout South America may increase the amount of pollutants entering the food web.

A crucial component of protecting river dolphins from human activity is by determining their habitat requirements and critical habitat throughout their distribution so that important areas can be protected. Determining critical habitat and habitat requirements of river dolphins in the Amazon are important components of an effective conservation strategy (Gomez et al. 2011). Designation of critical habitat is used to minimize the impacts of human activity, guide future development projects and provide information for effective management decisions designed to protect both species (i.e. formation of protected areas, areas with restrictions on fishing etc.). As little exists on the ecology of both species, it is currently unclear whether they share similar or different habitat requirements, although in large rivers they seem to frequent similar features (Martin and da Silva, 2004).

### *Habitat Use*

The distribution of a species is not uniform across its range. The abiotic and biotic factors that determine where a species can survive are not distributed evenly across the biosphere and these factors influence how a species uses available habitat. Habitat selection is the process or behavior that an animal uses to select or choose a habitat in which to live (McClary et al. 2010). It involves a hierarchical process of 'choices' an organism makes about what habitat it uses at different scales of the environment (Hutto, 1985). As this study was observational in nature, habitat use rather than habitat selection was the measure that was quantified for both species. Habitat use was the term used to describe where each species was

observed along the river, as 'habitat preference' is difficult to quantify between species as it requires studying the habitat use of each species where the other is absent (i.e. Piscart et al. 2010).

There are several ways that allow habitat use and habitat selection to be quantified. Traditional methodologies for quantifying habitat use consist of using Chi-square analyses (i.e. Neu, 1974; Byers, 1984; Wedekin, et al. 2010) or generalized linear models (GLMs) (Garaffo et al. 2010). Initial consideration was given to following a methodology similar that that outlined in Wedekin et al (2010), where the use of Bonferroni confidence intervals and a Chi-square goodness of fit analysis were used to determine habitat use as well as habitat preference and avoidance Guiana dolphins (*Sotalia guianensis*). The limitation of this methodology was that it did not allow the examination of the relationship between habitat use and the influence of habitat and behavior simultaneously. The use of a GLM to quantify habitat selection or for predictive habitat modeling is an effective and popular tool applied to terrestrial animals. However, the application of GLMs (either to quantify habitat use or to create predictive models) is still an emerging field in the study of marine ecology (Redfern et al. 2006) especially the ecology of cetaceans. In this study analysis using a GLM was chosen in order to compare and contrast habitat use of the two species of river dolphin found in the Amazon and because of the potential to incorporate a behavioral analysis into the model. Little information exists on the creation of habitat use/behavioral ecology models, especially within the framework of GLMs and so a component of this study was an exploration of using a GLM for habitat use and behavioral ecology models.

Several studies (i.e. Martin and da Silva, 2004c; McGuire and Winemiller, 1998) have used shoreline characteristics to examine habitat use and preferences of botos as well as tucuxis. This is likely because shoreline characteristics are inexpensive and non-time consuming to quantify as they can be determined via observation from a boat and require little to no formal sampling. They are also indicative of the hydrology of the immediate vicinity (current, river depth, slope of bank etc.) and so useful biological information can be inferred by using shoreline features. Previous research has shown both *Inia* and *Sotalia* appear to frequent similar physical

features proximal to the banks of 'large' water bodies (Martin and da Silva 2004c). But it is unclear how the two species of dolphin interact with these habitats in smaller river systems or how behavior varies in relation to these factors. According to Roughgarden (1976), different species that require similar resources will often segregate the use of these resources either spatially or temporally. Furthermore, according to Gause's law (1934), two species that occur sympatrically cannot occupy the same niche and so differences in habitat use and behavior may indicate how these two species avoid competing with each other. The objective of this research was to collect and analyze behavioral information as well as habitat associations to determine if habitat use differs between the two species in hopes of highlighting specific habitats each species requires in small rivers. Determining habitat use in small tributaries is important for the effective conservation of both species because determining where each species is likely to occur along a river can highlight areas where they may be most at risk from human activity. Secondly, determining if habitat use varies between the two species is also an important piece of information to ensure both species receive adequate and representative habitat protection.

In the last 15 years there has been an increase in research conducted on habitat use as well as abundance of *Inia* and *Sotalia* along the Amazon using increasingly standardized methodology (Vidal et al. 1997). However, much of this research has been conducted along the large channels and rivers of the Amazon (average river width greater than 400m). What remains unclear is the relative importance of small (<200m wide) river systems found within *Várzea* (flooded forest) of the upper Amazon. This study aims to examine river dolphin ecology in small rivers within the upper Amazon floodplain system, specifically within the Pacaya-Samiria National Reserve, Peru by comparing average group size of the two species as well as their habitat use and behavioral ecology with existing research. Collecting data on group size as well as habitat use of botos and tucuxis in the Pacaya-Samiria National Reserve will help provide valuable information that is critical to effectively manage and conserve the two species throughout their range in the Amazon basin.

## Hypotheses

Based on the above information, this study examines the following hypotheses:

- 1) Mean group size of *Inia* and *Sotalia* in small *Várzea* tributaries will differ from observations recorded on either species from previous research along larger sections of the Amazon River and other river systems. The difference in group size between regions may differ because of the extreme hydrological changes small tributaries undergo between high and low water seasons. During high water, group size may be relatively small due to the increased availability of habitat and river systems throughout the *Várzea* floodplain. Low water conversely, may result in a 'concentration' of the two species, where groups become larger because of decreasing habitat.
- 2) Habitat use, based on the availability of each habitat type, will not be evenly distributed. Previous research has indicated that certain riverine habitats are used disproportionately in comparison to their relative availability (Martin et al 2004c) in larger river systems along the Amazon. Because similar aquatic features and habitats (beaches, confluences etc.) can be found in both large and small tributaries, both species are likely to use them similarly regardless of the tributary's size.
- 3) Behavior will not be evenly distributed across each habitat type relative to habitat availability. For example Martin et al (2004c) noted that the main activity of river dolphins where confluences occur was feeding. Because of the high habitat heterogeneity of small tributaries, the two species will likely exploit certain habitats disproportionately in order to conserve energy. Furthermore behavior will differ between the two separate species. Because the two species occupy the same stretches along a river, they may be using different areas of the river for specific purposes (i.e. one area of river for socializing) to avoid competing for space.

## Methods

### Subjects and Study Site

This study was conducted in a portion of the Pacaya-Samiria National Reserve, the largest protected area in Peru. The reserve covers an area over 20,000 km<sup>2</sup> and is situated in the western Amazon basin. The reserve is comprised of what is referred to as *Várzea*, a type of forest that is seasonally inundated by floods of nutrient-rich, sediment-loaded 'whitewater' rivers in the Amazon (Prance, 1979). Two large tributaries of the Amazon River, the Ucayali and the Marañon, flow through the park. Their point of convergence marks the beginning of the reserve. The study sites were located along the Samiria River (a small tributary of the Marañon River) and an oxbow lake located within the Pacaya-Samiria National Reserve.



Figure 1: Location of the Pacaya-Samiria National Reserve, Peru. Small rectangle is location of the Pacaya-Samiria Reserve within Peru. Photo Credit: Google Maps

The focus of research was on the two species of cetaceans that are found in the Amazon basin; botos (*Inia geoffrensis*) and tucuxis (*Sotalia fluviatilis*). The two can be distinguished by several key physical characteristics. Firstly, botos are generally larger than tucuxis and have large, broad pectoral fins. Secondly, botos do not have a distinct dorsal fin, but instead have a long dorsal ridge whereas tucuxis have a distinct, falcate dorsal fin. Thirdly, while coloration of both species can vary through their life stages (i.e. changes with age), juvenile botos generally are dark grey and this color fades to a pinkish color as the dolphin ages. Tucuxis generally exhibit light-grey to bluish-grey coloration on their back and a pinkish to light grey color on their stomach.

## **Data Collection**

### *Transect Procedure*

Data for this research study were collected during surveys between the 24<sup>th</sup> of July and the 22<sup>nd</sup> of August of 2011. Data were collected along 5 km transects traversed in a motorized boat. Two different boats were used during the survey period, one with a large 'viewing' platform located at the bow of the boat roughly 2.5m above the water and the other with a small platform about 1m above the water. Transects were set along the center of the Samiria River 5km upstream and 5km downstream from 'base camp'. The boat did occasionally deviate from the center of the river in order to compensate for hydrological variables (i.e. strong currents or debris floating in the river). Each transect consisted of two separate sub-transects; the first 5km of the 'upstream' transect was travelled by using the motor of the boat. Once the boat travelled 5km upstream the motor was shut off and the boat traveled along the 'return' transect by drifting. A similar procedure was followed for the 'downstream' transect, except the boat first drifted (with the motor off) downstream 5km and the 'return' transect was travelled using the boat's motor. The average speed travelling downstream during transects was 4 km/h and the average speed travelling upstream was 12 km/h. Transects were monitored



from 7:00 to 18:00h (daylight hours) with one transect being completed in the morning and one in the afternoon.

### *Observational Data*

Observation effort consisted of three spotters who rotated in shifts (allowing one spotter to rest per transect while two spotters were actively searching for dolphins), a Peruvian guide who drove the boat, and usually one or two research assistants who aided in recording data. One spotter had formal training spotting dolphins during transect surveys and the other two were students collecting dolphin data for their dissertations as well. The two spotters at the bow of the boat surveyed the front 180° and any dolphins that were missed or overtook the boat from behind were seen by guides/research assistants. Any dolphins seen coming to the surface were recorded and special care was taken to not double count any sightings. Data collection consisted of; species, behavior, riverine habitat type, age structure (when it was able to be determined), group size, weather conditions as well as the start and finish times of each transect

### *Group Size Data*

For this study a 'group' was considered to be any number of dolphins that displayed association and social cohesion with each other. The criteria used to determine association were largely based on criteria used by Vidal et al (1997). Association and social cohesion was determined if any number of dolphins were seen moving together in close proximity (often less than a meter apart) to one another and usually (not always) engaging in the same behavior for a sustained period of time and/or during multiple surfacings. Each individual group was considered one unique 'observation' for the group size analysis as well as the count data for analysis of habitat use and behavioral ecology.

### *Behavior*

When either species were sighted, the initial behavior exhibited was recorded based on predefined behavioral categories (Table 1). If the initial behavior was not immediately obvious (i.e. the dolphin swam out of sight, or was

exhibiting erratic surfacing behavior/intervals), the boat was slowed so the dolphins 'general' behavior could be determined. General behavior was categorized as what was determined to be the main behavior the dolphin (or group) exhibited. When general dolphin behavior was being determined, or if there was a discrepancy between the observer's behavior classifications, a consensus between observers as well as guides was reached as to what behavior the dolphin was exhibiting, before the behavior was recorded.

### *Habitat*

Habitat in which dolphins were initially seen was also recorded. Habitat types were adapted from previous research along the Amazon to incorporate site-specific habitats (Table 2). The criterion used to determine which habitat type a sighting occurred in were as follows:

Presence in a 'shoreline' habitat (bank, beach and flooded vegetation) was recorded if the initial sighting was within approximately 15m from the shore. Presence within the 'confluence' was recorded if a dolphin was sighted anywhere in the main river for 200m on either side of where the smaller tributary met the main channel. Floating vegetation was only encountered on 4 transects and dolphins were not seen interacting with the sparsely distributed floating mats of vegetation, so the floating vegetation habitat type was not used in the analysis. The river center was generally considered to be the center 75% of the river (except at the confluence where the entire river section was deemed confluence).

Recording dolphin sightings and determining the ecological and behavioral parameters of interest were often difficult. Behavior and habitat classification were largely based on the surfacing behavior/location of the initial sighting of an individual or group of dolphins. When there were uncertainties about habitat classification, behavior, or numbers of dolphins, verbal consensus among observers was reached as to the most accurate estimate of habitat, behavior and number of dolphins present. This was done by determining the 'general' behavior the dolphin(s) exhibited and the 'general' area of the river within which the dolphin(s) carried out this behavior. Consensus was reached among observers as well as

guides with the aid of research assistants to ensure that groups or individuals were not double counted and that the most accurate ecological data was recorded.

**Table 1:** Ethogram of dolphin behavior (adapted from Neumann, 2001; Stockin *et al*, 2009).

<b>Behavior</b>	<b>Code</b>	<b>Description</b>
Feeding	FE	Dolphins seen pursuing, capturing or eating prey or engaging in activities that would indicate feeding behavior such as diving, rapid turning etc.
Resting	RT	Dolphins remain close to the surface, are seen surfacing at regular, coordinated intervals and are either swimming very slowly, or not at all.
Socializing	SO	Dolphins seen physically interacting with one another (i.e. mating, chasing) or displaying aerial behaviors such as breaching, tail slapping, spy hopping etc.
Travelling	TR	Dolphins are seen swimming or porpoising at a sustained speed maintaining a specific heading or direction.
Milling/Other	MI	Dolphins are seen swimming, but frequently changing direction, making no noticeable headway in a specific direction.

**Table 2:** Riverine microhabitat classification (adapted from Martin *et al*, 2004).

<b>Habitat</b>	<b>Code</b>	<b>Description</b>
Flooded Vegetation	FLD	Areas of forest that are flooded. Where forest fringes the river and allows direct aquatic access from the river. River sections that border <i>Várzea</i> will also be classified under this category.
Floating Vegetation	FLT	Where the large areas of river are encroached by large ‘tangled’ mats of vegetation that are either anchored to the river margin or are attached to other large ‘mats’ of vegetation that are floating in the river.
Bank	BNK	Steep (gradient considered greater than 45°) mud/sand banks that are generally bordered by ‘ <i>terra firme</i> ’ (land higher than maximum high water levels) or that are exposed during low water. Generally occur along the outer bend of rivers where current is stronger.
Confluence	CON	Mouth of a channel joining the main river originating from any water source (other streams, lakes, rivers etc.).
River Centre	CTR	This habitat included the main channel of the river as well as areas that were not bordered (within 15 metres) by any other riverine habitat.
Beach	BCH	Where shallow (gradient considered less than 45°) sandbanks or sandbars are exposed along the river. Also, low current areas where flooded vegetation previously occurred and where water receded sufficiently exposing ‘beaches’. Generally occur on the inside of river bends where current is slower.

### *Relative Habitat Size*

In order to accurately determine habitat use, the relative availability of each habitat needed to be determined (Neu, 1974 and Wedekin, 2010). This was done by calculating the total area of each habitat along each of the two transects during three separate surveys (July 20<sup>th</sup>, August 5<sup>th</sup> and August 13<sup>th</sup>). A Global Positioning System (GPS) was used to record 'shore length' of each shoreline habitat as well as the section of river that was a 'confluence'. Then a total shoreline length of each habitat type was calculated for each transect of river surveyed (both 5km transects) by multiplying each shoreline habitat length by 15m (the distance from shore that was considered to be hydrologically influenced most by shoreline habitat). The area of the confluence was calculated in a similar fashion by multiplying the shoreline extent (determined by hydrological indicators such as mixing of currents, eddies etc.) by the river width. The area of river center was calculated by subtracting the total calculated areas of shoreline habitats as well as the confluence from the total area of each 5km river section (total river area surveyed in each transect was roughly 5,000m x 120m).

A substantial change in the water level occurred along the Samiria River during the field season and so a methodology was needed to account for the change in relative habitat size (specifically the change in area of shoreline habitats). The water level dropped 5.8m during the 5 weeks of data collection and as the water dropped, changes in the relative availability of some habitat types changed (i.e. beach habitat replacing flooded vegetation). As habitat area was not calculated for every survey day, a *post hoc* analysis was performed to determine the area of each habitat type for each survey day (Appendix). The area of riverbank, river center and confluence habitats changed very little over the survey period and so the area was calculated as an average over the study period. Area of beach and flooded vegetation however, changed substantially as water level decreased. To determine the area of both these habitats for each day surveyed, both habitats were plotted separately as scatterplots and their respective 'lines of best fit' were used to model the increase in beach area and decrease in flooded vegetation area for each day surveyed.

### *Data Analysis: Group Size*

Group size data was recorded for both species and the mean, standard deviation and standard error were calculated for each species individually. Primary datasets from previous research were unable to be obtained in order to statistically test whether group size differed significantly in the Pacaya-Samiria relative to other areas where group size has been estimated. However, the mean group size estimates as well as standard deviation and standard errors from two previous studies (one in the Amazon and one from Bolivia) were compared with mean group sizes estimated in the Pacaya-Samiria.

### *Data Analysis: Behavior and Habitat Use*

The interaction between species, habitat and behavior was analyzed by creating a generalized linear model (GLM) using the statistical package 'R'. The analysis consisted of two stages; firstly, models were developed for each species separately to determine which factors influenced the presence of each species individually along the river and to examine the interaction between habitat and behavior individually. The second part of the analysis pooled the data collected on both species in order to examine habitat use as well as behavioral interactions with habitat between species using a GLM. In order to perform both these analyses, the transect data was compiled into a 'presence/absence' spreadsheet format with each transect representing one 'sample' and presence in a specific habitat type being determined if a sighting occurred in that habitat during that transect. Presence-absence was treated as the response variable; and habitat, behavior, species and area were used as the explanatory variables. Interaction terms of species, habitat and behavior were also incorporated into the model to further examine behavioral and ecological relationships. Area was log-transformed due to the large variation in the area of specific habitat types as well as the lack of 'intermediate' sized habitats (most habitat types had relatively small areas compared to the area comprising the river center). Exploratory analysis on the data revealed that collinearity between habitat type and habitat area might have been a source of error, however there was no clear solution to this problem and so

the analysis was carried out with the understanding that some restraint must be used in interpretation of the results. The distribution specified to fit the GLM to the data was changed to a binomial distribution (to help reduce the influence of zeros in the presence-absence data), which did result in an increase in the adequacy of the models.

An information-theoretic approach was used during model validation. The procedure followed to carry out model selection was taken from Zuur et al (2009), 'Mixed Effects Models and Extensions in Ecology with R' (pp. 253), using the 'drop1' command. The best model was determined by comparing Akaike's Information Criterion (AIC) values and the model with the lowest AIC (Anderson et al, 1998) value being chosen in each successive step of model validation. In the first stage of the analysis, habitat use was quantified for each species separately using a GLM and explanatory variables that were removed during model validation were deemed as insignificant factors that did not contribute to the performance of the model. The second analysis examined the behavior of each species individually using the GLM. The third component of the analysis consisted of combining boto and tucuxi sighting data and applying a GLM in order to compare habitat and behavioral differences in more detail.

## **Results**

### *Group Size*

In total, 486 sightings of botos were recorded (Figure 2). The majority (56.6%) of sightings consisted of individual animals and 34.2% of sightings consisted of a pair of botos. The largest group of botos observed consisted of 4 individuals but only comprised 1.03% of total sightings for that species. The average group size for boto observations was 1.56 (SE= 0.033).

There were a total of 197 sightings of tucuxis during the survey period (Figure 2). Ninety-nine % of tucuxi groups were of 1-7 individuals with pairs being the most common group size (39.6% of sightings) followed by individuals (20.8%) and groups of three (16.8%). The mean group size of tucuxis was 2.66 (SE = 0.11)

and the largest group of tucuxis observed was composed of 11 individual animals. The mean group size of each species was compared using a t-test in order to see if group size differed significantly between species. Mean group size of botos and tucuxis were found to be significantly different ( $p < 0.01$ ) with tucuxis being observed in larger groups than botos.

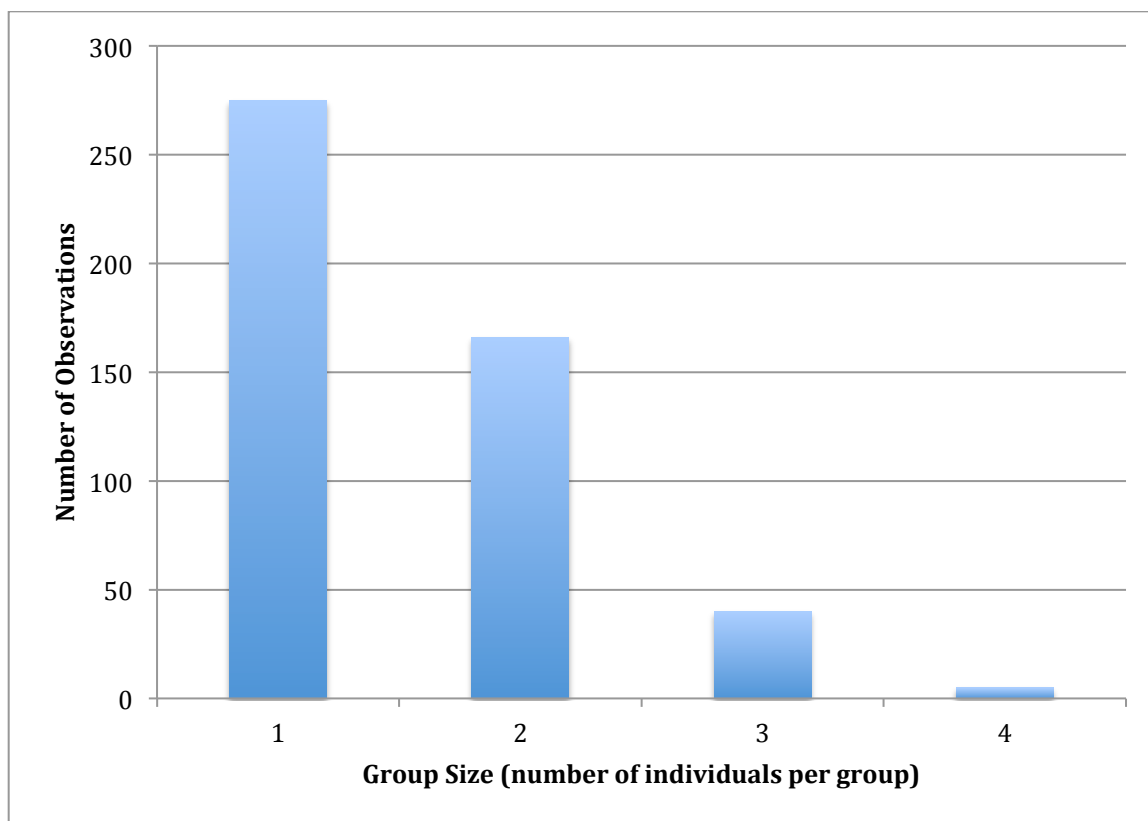


Figure 2: Histogram of boto group size observations (n=486).

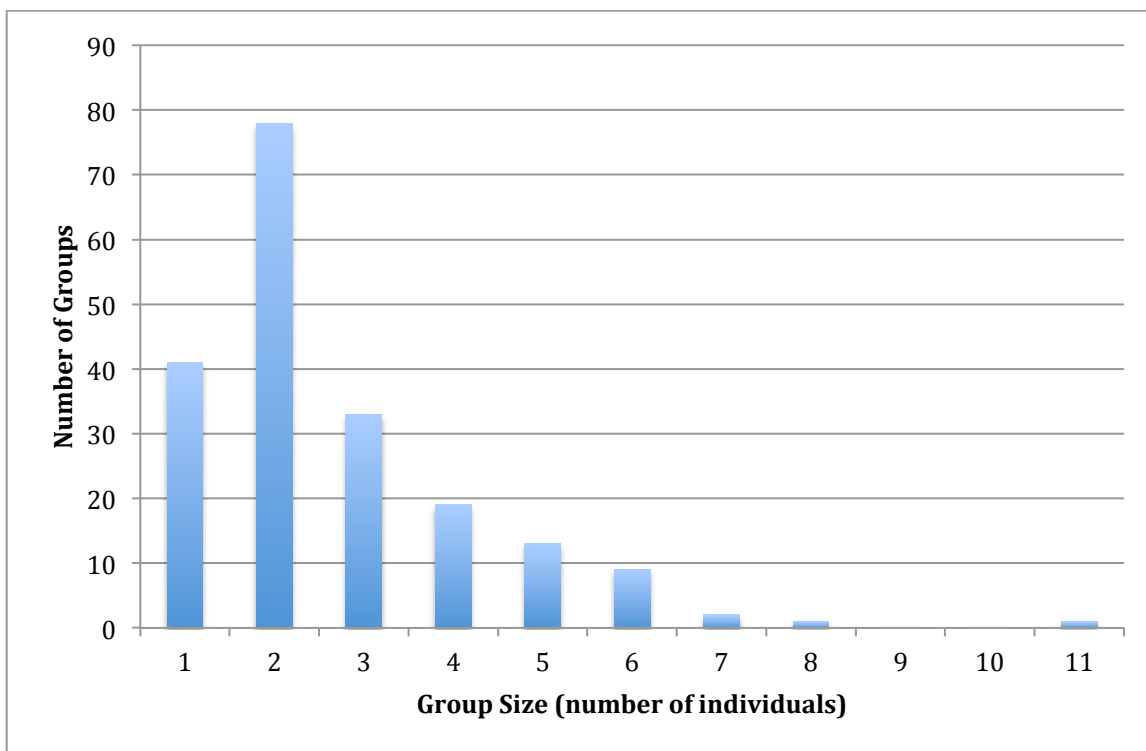


Figure 3: Histogram of tucuxi group size observations (n=197).

### *Model Selection and Validation*

Table 3 and Table 4 show the model iterations of explanatory variables used to examine each species (botos and tucuxis, respectively) separately, with the ‘best’ model by parsimony (lowest  $\Delta AIC$  values) shown in bold. The model containing all variables (saturated model) is shown in italics. The model selected for botos included the factors of behavior, habitat and the Log of area. The model selection for tucuxis included the factors of behavior and habitat. A further analysis was conducted during model selection by using an ANOVA to determine which models differed significantly from the saturated model. This analysis indicated that habitat area is an important explanatory variable in modeling habitat use for botos, but not for tucuxis.



Table 3: Ranked generalized linear models for ‘boto’ count data. Model selection was based on lowest  $\Delta$ AIC value (shown in bold). The model containing all variables (saturated model) is shown in italics.

Model Name	Explanatory Variables	$\Delta$ AIC
<b>inia1</b>	<b>behavior+habitat+log(area)</b>	<b>0</b>
<i>Inia</i>	<i>behavior+habitat+log(area)+habitat:behavior</i>	2.5
inia2	behavior+habitat	12.1
inia8	behavior+habitat+habitat:behavior	14.9
inia7	behavior+log(area)	28.5
inia3	behavior	131.1
inia6	habitat+log(area)	239.3
inia4	habitat	249.7
inia5	log(area)	261.1

Table 4: Ranked generalized linear models for ‘tucuxi’ count data. Model selection was based on lowest  $\Delta$ AIC value (shown in bold). The model containing all variables (saturated model) is shown in italics.

Model Name	Explanatory Variables	$\Delta$ AIC
<b>sotalia2</b>	<b>behavior+habitat</b>	<b>0</b>
sotalia1	behavior+habitat+log(area)	1.1
sotalia8	behavior+habitat+habitat:behavior	7.9
<i>sotalia</i>	<i>behavior+habitat+log(area)+habitat:behavior</i>	9.0
sotalia7	behavior+log(area)	26.1
sotalia4	habitat	78.5
sotalia6	habitat+log(area)	79.6
sotalia3	behavior	91.7
sotalia5	log(area)	103.5

**Table 5:** Ranked generalized linear models for tucuxi and boto combined data. Model selection was based on lowest  $\Delta$ AIC value (shown in bold). The model containing all variables (saturated model) is shown in italics.

Model Name	Explanatory Variables	$\Delta$ AIC
<i>dolphin</i>	<i>species+behavior+habitat+log(area)+species:habitat+species:behavior+habitat:behavior</i>	<b>0</b>
dolphin1	species+behavior+habitat+species:habitat+species:behavior+habitat:behavior	12.7
dolphin2	species+behavior+habitat+log(area)+species:behavior+habitat:behavior	13.2
dolphin4	species+behavior+habitat+log(area)+species:habitat+species:behavior	16.8
dolphin3	species+behavior+habitat+log(area)+species:habitat+habitat:behavior	14.1

### *Habitat Use*

The GLM output for each species (Figure 3) indicated that botos were found in the confluence significantly more than any other habitat type ( $p=0.0229$ ) and tucuxis were found in the river center significantly more than any other habitat type ( $p=0.0327$ ). The second most used habitat type for botos was flooded vegetation, followed by beaches, riverbanks and the river center. Although botos used these habitat types disproportionately, their use was not significantly different from one another (at the 95% confidence level). Tucuxis exhibited relatively more stratification in terms of which habitats they used. The confluence as well as riverbanks were used significantly more than beaches ( $p<0.01$ ). There were no recorded sightings of tucuxis interacting with flooded vegetation, which resulted in a very high standard error ( $SE= 578.6$  with a sample size of 197) in the model. Although use of flooded vegetation was not reported as significant (due to high standard error), it can likely be assumed that tucuxis use flooded vegetation significantly less than any other habitat type.

### *Behavior*

The observed behavior of each species was examined using the GLMs for each respective species. Both species were observed feeding significantly more than any other behavior (boto;  $p < 0.01$ , tucuxi;  $p = 0.0162$ ). Botos also spent significantly more time travelling and resting than they did milling or socializing ( $p < 0.01$ ), which were the two least observed behaviors for that species. Tucuxis were observed exhibiting similar behavioral tendencies with traveling being observed significantly more than resting and socializing ( $p < 0.01$ ) as well as milling ( $p = 0.021$ ), which was the least observed behavior for that species.

### *Behavioral Ecology*

The ranking of several iterations of the 'combined model' that was used in order to statistically examine differences in habitat use and behavior between the two species of river dolphin (Table 5). The hope was that this model would also yield information on what behaviors each species exhibited in the different habitat types, however this analysis was beyond the capacity of the model that was used. The 'best' model selected by the lowest AIC value was the saturated model and is highlighted in bold. This stage of analysis indicated that riverbanks were used significantly more by tucuxis than by botos ( $p = 0.013$ ) and that tucuxis were observed socializing significantly more than botos ( $p < 0.01$ ).

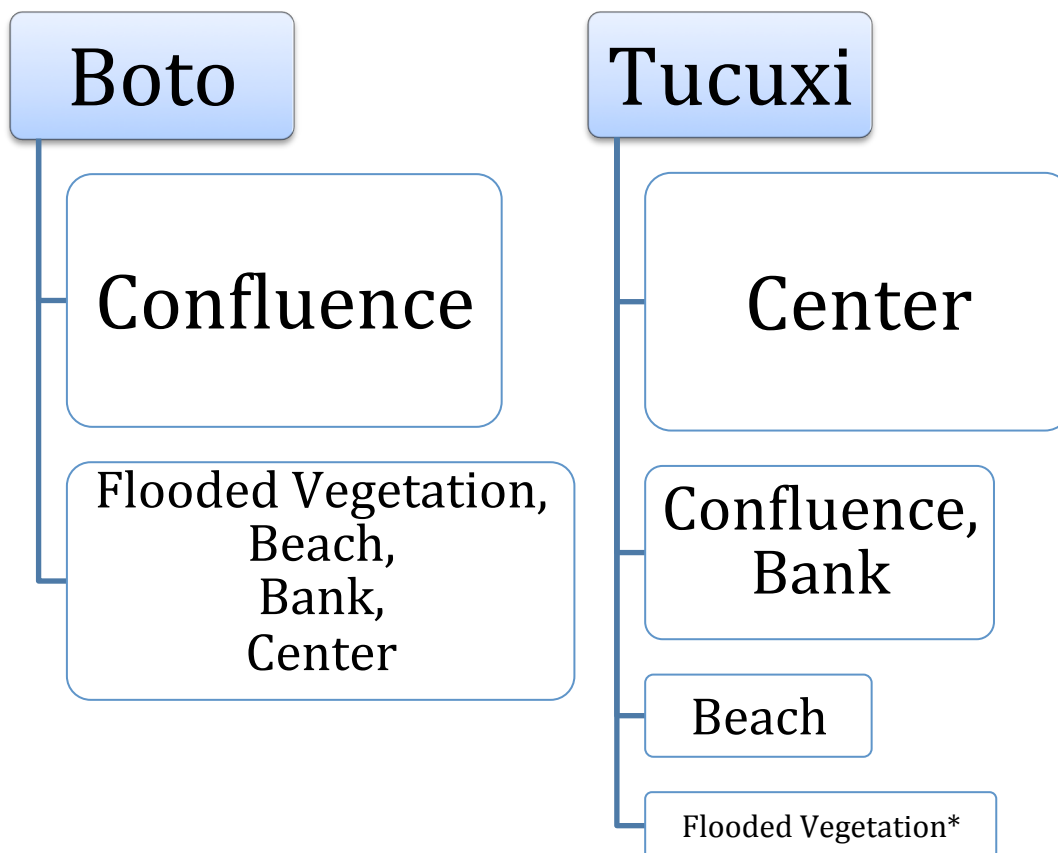


Figure 4: Hierarchical organization of riverine habitat use for each study species. The habitat types are ranked for each individual species, with the most used habitat type in larger boxes at the top and the less used habitat types in smaller boxes, descending towards the bottom. Each discrete box represents statistical significance at the 95% confidence level and should be interpreted to mean that habitats in higher boxes are selected significantly more than habitats in lower boxes.

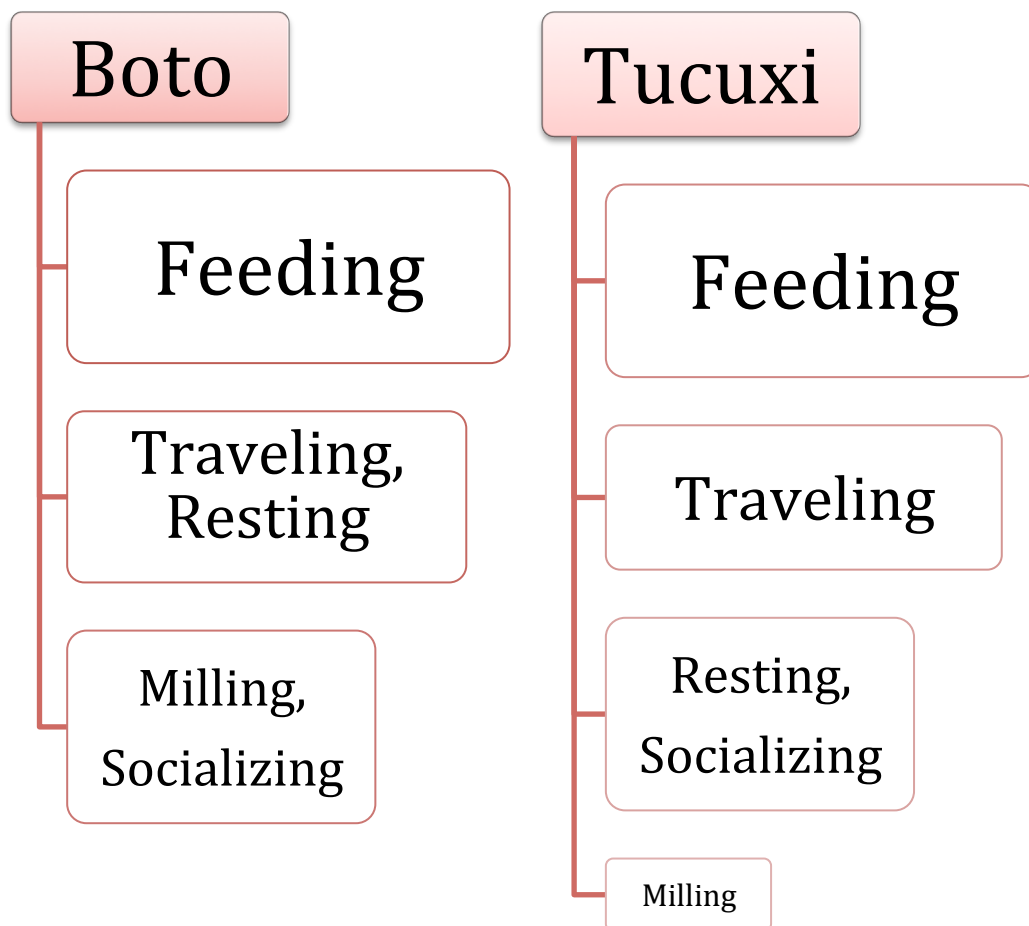


Figure 5: Hierarchical organization of the behaviors exhibited for each study species. Behaviors are ranked for each individual species, with the most common behavior in larger boxes at the top and less common behavior in smaller boxes, descending towards the bottom. Each discrete box represents statistical significance at the 95% confidence level and should be interpreted to mean that higher boxes represent behaviors observed significantly more than behaviors in lower boxes.

## Discussion

### *Group Size*

This study set out to examine differences of group size between the two species as well as variation of group size throughout their distributions in South America. Determining variation of group sizes throughout each species' distribution was unable to be done with a statistical analysis because of difficulty in obtaining raw data from published research on river dolphin group sizes throughout both their ranges. Furthermore, many studies considered 'loose associations' (i.e. dolphins within a certain area of survey) in determining group size, which this study did not do. The criteria used to determine group size in this study followed methods outlined by Vidal et al (1997), where groups were determined to be animals appearing to have social cohesion. River dolphins are frequently concentrated in areas (i.e. confluences) along rivers and these 'loose associations' (potentially being over 20 individuals in a 60mx100m area, as was seen during this study) are not indicative of each species' respective social relationships.

A comparative analysis of group size was conducted by comparing the standard deviation and standard error calculated for mean group size from published research in other areas of each species' distribution. Along the Samiria river, average boto group size was 1.56 (SD=0.729, SE= 0.033, mode=1) and 2.66 (SD=1.58, SE = 0.11, mode=2) for tucuxis. A study by Martin et al (2004) conducted along the Japurá River, Brazil found that average group size for botos was 1.42 (SE=0.036, mode=1) and 2.24 (SE=0.065, mode=2) for tucuxis. These findings seem similar to what was observed along the Samiria River in this study. Aliaga-Rossel et al (2006) calculated mean group size for *I. g. boliviensis* along two rivers in Bolivia and found mean group size to be 3.3 (SD=2.96) along the Tijamuchi River and 1.8 (SD=0.75) along the Yacuma River. These group sizes are slightly larger than group size calculated for botos along the Samiria River, but with a large variation around the mean, it is difficult to determine if group size in Bolivia is significantly higher than Peru.

There is evidence from published data that group sizes of *Inia spp* and tucuxis do vary regionally, and even seasonally, although boto and tucuxi group size seem to be constant in the Pacaya-Samiria Reserve (McGuire, 2002). Other publications (summarized in McGuire, 2002) indicate average group sizes ranging from 1.2-6.1 animals for *Inia spp* and 2.0-6.0 animals for tucuxis at various locations throughout their South American distributions. These ranges suggest that boto and tucuxi group sizes may be relatively small in the Samiria River. However with the little information that exists on group size throughout both species' distribution and limited access to raw data sets, it is difficult to draw any meaningful inferences based on the comparison of group sizes throughout the Amazon.

The term 'river dolphin' is a bit of a misnomer, as botos and tucuxis are not closely related (Hamilton, 2001). The majority of boto sightings were individual adult animals and tucuxis were most often sighted in pairs of adult animals. These findings suggest differences in the sociobiology of each species. Botos seem to be solitary animals occurring mostly as individuals or pairs. Although tucuxis were encountered as individuals, the majority of sightings were groups of two or more animals. Tucuxis were also found in significantly larger groups and this may be indicative tucuxis being more social than botos.

### *Behavior*

The similarities observed in the behavior of each species make intuitive sense based on the similarities within general activity budgets of animals, with feeding followed by travelling (likely travel to and from feeding areas) and resting being the most important components of day-to-day animal life. However there does exist some distinction in observed behavior between botos and tucuxis. Tucuxis did not exhibit a significant difference between the amount of observed resting and the amount of observed socializing. This emphasizes an important inference that was put forth earlier in the discussion with regards to tucuxis being found mostly in groups of two or more. Since tucuxis were observed in significantly larger groups and socializing behavior appears to be important, it may be that

socializing is an important component of daily life for tucuxis but not botos. This can likely be attributed to the differences in each species' respective life histories. Tucuxis are true dolphins and found most frequently in groups, which would require them to spend time with group members socializing. Botos are mostly solitary individuals and so socializing may not as important among botos. The use of a GLM is not a conventional method used to quantify behavior, but was tried for this research study and results of the GLM seem to support observations in the field. A comparative analysis between conventional behavioral analysis methods and GLMs would likely provide further insight into the possible limitations of using a GLM in a behavioral analysis.

#### *Habitat Use and Potential Niche Separation Between Species*

The results from this study indicate confluences are important features in small river systems. Botos were observed in highest numbers within the confluence and this observation seems to mirror previous research (i.e. Martin and da Silva, 2004 and Gomez-Salazar, 2011) conducted on larger river sections. It seems that the ecological importance of confluences for the life history of botos is independent of scale (confluences are likely productive features at large as well as small scale). The confluence was the tucuxis second most-used riverine habitat and so is likely important to their survival as well (research from larger rivers indicates that tucuxis frequent confluences as well). The second and third most used habitat types for botos were flooded vegetation and beach habitats. Although they were not used significantly more than banks or the center, these habitat types may be important. As water levels dropped, exposed beaches replaced the areas that were flooded vegetation at the onset of the study. Botos may have a preference for these shallow water, low gradient habitats. Tucuxis used beaches and flooded vegetation significantly less than any other habitat type (no tucuxis were spotted interacting with flooded vegetation), which highlights another difference in habitat use between the two species where botos may use shallow water habitats and tucuxis may use deeper areas of the river (such as riverbanks and the river center). An interesting difference between habitat use of botos and tucuxis was that tucuxis



used the river center significantly more than any other habitat type. Previous research (i.e. Martin and da Silva, 2004 and Gomez-Salazar, 2011) has indicated that in larger river systems, river centers do not support high numbers of river dolphins and so this result not only highlights differences in each species' respective habitat use, but potentially a difference in how tucuxis use habitats in small vs. large river systems.

### *Niche Separation*

Sympatry among different species is common in marine environments and likely riverine environments as there are more constraints to mobility due to the confines of riverbanks. When two species occur sympatrically and are using the same resources, co-existence of the two species may lead to temporal or spatial segregation of resource use in order to reduce competition (Roughgarden, 1976). Many marine cetacean species occur sympatrically and separation of ecological niches is primarily based on differences in habitat use as well as diet (Bearzi, 2005). Many co-occurring cetacean species often exhibit slight differences in the temporal and spatial use of their ranges (i.e. Whitehead and Shannon, 1995; Garafo et al, 2011; Parra, 2006). The differences in habitat use observed between botos and tucuxis could highlight how these two species spatially partition resource use in small river systems in order to avoid competing where space and resources are limited. Results from this study suggest that in small rivers, botos accomplish this by using shallow water habitats and tucuxis use habitats that occur in deeper river sections and confluences are where the two species overlap likely due to confluences being highly productive features.

As this study only took place over a five-week period, temporal segregation of each species could not be examined but could potentially be incorporated in future studies to examine how habitat use changes throughout the high and low water seasons. There does seem to be adequate literature on how each species' habitat use changes with water level (i.e. Martin, 2004; McGuire, 2002) and it seems botos enter flooded forests and tucuxis remain in river channels during high water.

Ecological niche separation can also be attributed to differences in diet between two sympatric species. There is evidence that diet varies between botos and tucuxis, with botos possibly consuming a more diverse range of prey than tucuxis (Best and da Silva, 1989). Further study of the dietary constituents of each species may provide further insight into the mechanisms the two species use avoid competing with one another (i.e. each species may show preference for a few specific species or families of fish).

### *Habitat Use*

The results of the GLM indicate tucuxis use the river center significantly more than any other available habitat type in small rivers. I will put forth four hypotheses that may explain why tucuxis may be using the river center more in smaller river systems:

Firstly, model selection for tucuxis indicated that area was not an important factor in the presence of tucuxis along the river. As the river center was the largest habitat by area, a large percent of sightings occurred in this habitat type. However the analysis was designed with this in mind and the GLM was used to examine disproportionate use of habitat (i.e. using a habitat more than would be expected based on its size). Table 4 shows that habitat area was not incorporated into the selected tucuxi model but an ANOVA was run and the model that was chosen (without area) did not differ significantly from the model that included area and so area alone is likely not the reason for tucuxis using this habitat significantly more than others.

The second hypothesis is that the hydrological characteristics of the river center in smaller river systems are not as extreme as in larger river sections. The river width along the Samiria River is on average 120m and so there is likely not as much contrast from the productive shoreline habitats as there is along the larger sections of Amazon where river width is frequently over 1000m wide. The relative homogeneity of small rivers may result in fish being relatively more evenly distributed throughout the river, which allows tucuxis to forage for prey throughout the river. Furthermore, the depth of smaller river sections is likely not

as deep as larger river sections and would allow tucuxis to pursue prey throughout the water column in small rivers, whereas fish may escape in the deeper channels of large rivers due to the difficulties associated with hunting fish in open water.

The third hypothesis is that tucuxis may prefer the river center in smaller river sections, possibly due to abundance of preferred prey species in these sections, or the absence of obstructions such as fallen trees or submerged vegetation. When tucuxis were observed travelling, it was often with substantial speed. Travelling along the river center would allow them to move more freely than traveling along the banks, or beaches or to pursue prey at greater speed than is possible in flooded vegetation. Tucuxi preference for the center of small rivers may be indicative of the manner in which botos and tucuxis segregate from each other spatially to avoid competition in small rivers where space is limited.

Finally, botos may be outcompeting tucuxis and excluding them from their preferred habitat type (i.e. the confluence, which was the second most used habitat type for tucuxis) in smaller rivers. Botos are larger and predominantly found in confluences, which may indicate that they are dominating that habitat type in small rivers. A potential reason why competition for resources in smaller rivers may exist is due to the fact there is less physical space than larger rivers and potentially less resources available for both species resulting in one species excluding the other. Exclusion is documented among cetacean species but is more pronounced than what was observed during this study. For example Whitehead et al (1992) found that sperm whales were located about 10km away from bottlenose whales in feeding areas, which may have been indicative of one species excluding the other. However this extreme form of exclusion is likely not the case with botos and tucuxis as both species can be observed feeding in the same areas with little to no observable interactions.

This last hypothesis brings up further interesting discussion. In cetacean literature, habitat used by dolphins and whales is often referred to as 'habitat preference' (i.e. Wedekin, 2010) and data collected on the spatial distribution of cetaceans is used to make inferences on habitat preference. The term 'habitat preference' assumes that cetaceans are actively selecting for habitats they are

commonly observed in. However, what this inference does not take into consideration is the influence cetacean species exert on one another's distributions and that without the presence of the other (potentially 'dominant') species, habitat use may change in response to the available resources. There is the possibility that tucuxis would 'prefer' to use confluences, but possibly find it too 'busy' if large numbers of the larger botos are feeding in these habitats and so use other available habitats (i.e. the center of small rivers) in order to avoid competing for space. This is a plausible hypothesis that might explain why results from this study differ from what has been documented in larger rivers. Less space is available in small rivers and so confluences may be dominated by botos because there is not enough space for both species to co-occur. This hypothesis would be difficult to test, as it would require the removal of botos (which is not feasible) from an area in order to examine if tucuxis changed the amount they used different habitats such as confluences. This distinction should be addressed in further studies of cetaceans so that accurate ecological data is obtained especially in the context of determining niche separation.

#### *Habitat Classifications*

The use of shoreline and river features as discrete habitat types was a simple way to quantify habitat use of botos and tucuxis and it is apparent that both species do frequent particular habitats within the river. As predictive distribution modeling becomes more widely used in the ecology of cetaceans, relevant environmental variables can be used to gather ecological information at a more precise resolution. However, the local scale biotic and abiotic variables that influence their distributions (water temperature, abundance of prey, current etc.) are not well known and should be included in further research. Discrete habitats were used instead of measuring continuous environmental variables mainly because the materials required to take measurements of these variables were unavailable at the research station and most habitat-related studies of botos and tucuxis have used shoreline characteristics in their analysis (i.e. Martin and da Silva, 2004; Gomez-Salazar, 2011). Although useful ecological information can be

inferred by using riverine habitats (for example the confluence being a key area for fish and thus a key area for the dolphins who prey on these fish), it seems that the current use of shoreline characteristics as discrete habitats may not be the most accurate method of quantifying and highlighting requirements and differences between the spatial distributions of botos and tucuxis at a fine scale. For example Garafo et al, (2011) used a GLM to determine what environmental variables were important for two co-occurring dolphin species that occur sympatrically off the coast of Argentina. This method found that differences in environmental variables (sea surface temperature, chlorophyll, depth, etc.) significantly explained the distribution of each species and may indicate niche separation between the two species. Direct measurements of environmental variables throughout the Amazon within the framework of a GLM analysis could yield precise information on what biotic and abiotic factors influence the spatial distribution of botos and tucuxis at a local scale and provide further insight into the specific ecological requirements of each species.

The use of discrete riverine habitats may still be the most practical method for predicting the distribution of botos and tucuxis at a broad scale. According to Davis et al (1998), the following five factors are considered broad-scale factors that influence cetacean distribution: physical – chemical (e.g. surface water temperature and salinity), climatological (e.g. frontal systems and wind), geomorphological (e.g. depth and slope of bathymetry), biotic (e.g. presence of predators or prey) and anthropogenic (e.g. presence of boats and human-made noise). Using these factors in a broad scale analysis of the Amazon may help create accurate models that explain and predict the distribution of Amazon River dolphins. However, as the size and hydrological heterogeneity of the large South American watersheds (ie the Amazon and Orinoco) is immense, measuring these variables accurately is not currently feasible. Instead, identification of important landscape features (river habitats) such as confluences and lakes may be the most effective (and practical) means to predict the distribution of either species as well as determine areas important for their survival at a broad or regional scale.

### *Use of GLM*

The decision to use a GLM to examine habitat use and behavior was made for several reasons. Firstly, GLMs are capable of describing behavioral and ecological interactions with a high level of precision. Secondly, the use of a GLM was also chosen because behavioral data could be compared with habitat data in a single model instead of several models that would have been time consuming and not easy to compare between two species. Thirdly, there are few studies that attempt to compare habitat use and behavior using a GLM. Finally, little exists in the literature on whether a GLM is an appropriate methodology to examine if behavior is influenced by habitat type or if differences exist between the behavioral ecology of two separate species.

The method of data collection used in this study (transect surveys) may have created some sources of error with the analysis using GLMs. Only two separate transects were sampled over the study period and were only located about 5km from one another. Furthermore, each transect was often sampled twice a day (usually immediately following the first transect) This may have led to pseudoreplication affecting the results as well as inherent limitations to the general applicability of extrapolating a small sampling size of riverine habitats to a broader scale.

Collinearity also existed between habitat area and habitat type likely due to the uneven distribution of areas of specific habitat types (flooded vegetation, beaches and the confluence only constituted a small area whereas riverbanks and the river center were relatively large). However, a solution to this problem was not apparent. The difficulty in dealing with collinearity may have derived from the manner in which data was collected as well as a result of limitations in my proficiency with the statistical package 'R'. Zuur et al (2009) page 475, chapter 21 (and references within) suggested three approaches to dealing with collinearity among explanatory variables; i) removing variables so that remaining variables are not highly correlated, ii) using linear combinations variables and iii) using biased estimation procedures such as principal components analysis. None of these

methods were deemed appropriate in order to deal with the relationship between habitat and area, which was likely due to an issue with how the explanatory variables were classified and recorded. Removing either variable would have defeated the purpose of carrying out the analysis as habitat use based on availability was at the core of this study. Furthermore, using principal components analysis or linear combinations of habitat and area would likely have made results difficult to interpret and, furthermore, are not possible with discrete data. More robust methods of data collection, would likely have been effective at reducing the sources of error in the GLM.

The 'combined' GLM used to examine the behavioral ecology of the two species was unable to examine what behaviors were most prevalent in specific habitat types. Determining behavioral ecology may be outside the realm of what is capable with GLMs, but other methods do exist to examine these relationships in marine ecology (i.e. Parra, 2006). Furthermore there was a substantial amount of error in this model, which limits the applicability of the conclusions and inferences drawn from the output of the model.

As GLMs become more widely applied in marine ecology, and the ecology of cetaceans specifically, the ability to establish relevant environmental variables and data collection methods *a priori* will allow accurate ecological information to be collected. The use of a GLM in this study performed well as a descriptive model for examining differences in behavior as well as habitat use between the two study species and meaningful biological and ecological information was highlighted from the analysis.

Although the statistical strength due to flaws in methodological design (such as the small sample size of habitat features) as well as inherent limitations with the output from the models may prohibit broad scale applications of the findings of this study, it seems that at a fine scale, habitat use in small rivers differs among the two study species. What remains to be seen is; 1) what environmental variables influence the spatial distribution of botos and tucuxis and how do they differ, 2) are the observed differences in habitat use between botos and tucuxis widespread throughout their range in smaller river sections, and 3) whether the observed

differences in habitat use between botos and tucuxis is a result of preference for those habitats, interspecies interactions, or a combination of both.

## **Conservation Implications and Future Applications**

Gomez-Salazar, (2011) proposed delineating the area within 200m from shoreline, confluences, and lakes in large rivers as critical habitat to ensure the protection of river dolphins in South America. The results from this study seem to support the approach of using discrete habitat classifications (as used in this study and other studies in various regions) as an effective way to delineate important river features as both species may frequent confluences in small river systems as well. A predictive habitat approach could potentially yield an effective means to create Fresh Water Protected Areas (FWPAs) as well as identifying areas that river dolphin populations might be under threat from human impact (either from existing or proposed development). Identification of important landscape features (river habitats) such as confluences and lakes in large and small river systems may be the most effective (and practical) means to predict the distribution of either species as well as determine the locations and sizes when planning for FWPAs at broad, regional and local scales.

Because the Pacaya-Samiria is considered a pristine, well-managed FWPA, studying biological and ecological information as well as differences in habitat use within the reserve could be used as a baseline to determine how various intensities of human impacts in other areas of the Amazon affect the distribution, habitat selection and behavior of the two species. Furthermore, ecological data could be collected in the Pacaya-Samiria with minimal bias related to human presence and could be used to compare how the ecology and behavior of the two species changes in the presence of various intensities of human impact.

The Pacaya-Samiria has one of the highest river dolphin (and cetacean) encounter-rates in the world (Gomez-Salazar, 2011). The reason for this high abundance of top predators is largely due to how fisheries and land use are



managed within the park. Three key components of the management framework in the Pacaya-Samiria that directly benefit dolphins and should be applied in future conservation efforts in other areas are: i) limits imposed on gillnet mesh size used to minimize dolphin entanglement in fishing gear, ii) maintaining healthy fish populations throughout the reserve through integrated fishing regulations balancing human need with ecological sustainability and, iii) limiting development and land use within the reserve.

## **Conclusion**

Little information exists on the ecological differences of the two species of cetacean found sympatrically throughout the Amazon River. This study was the first attempt to describe differences in sociobiology and ecology between two co-occurring cetacean species by focusing exclusively on a small river system in the Pacaya-Samiria National Reserve, Peru. By using a GLM to compare and contrast behavior and habitat use between botos and tucuxis, the following ecological and biological inferences can be made: Botos used confluences significantly more than other habitats and tucuxis used river centers significantly more than any other habitat along the Samiria River. Tucuxis showed more variation in habitat use than botos, with the confluence as well as riverbanks being used significantly more than the other habitats (except the river center). These differences in habitat use may be indicative of niche separation between the two species, with botos using habitats in shallow water and tucuxis using habitats in deeper water within small rivers. Group size differed significantly between species, with tucuxis being observed in larger groups than botos and observed behavior differed between the two species, with tucuxis socializing significantly more than botos. These results may indicate that socializing is a more integral component of the biology of tucuxis than that of botos. These differences in sociobiology between each species will help provide information on the life history of each species in small rivers, which is not well documented. This study suggests group size, behavior and habitat use differ between botos and tucuxis in a small river in the Pacaya-Samiria National Reserve,

Peru and these differences may be indicative of ecological niche separation as well as differences in the sociobiology of two species. Although the findings of this study may have limited applicability to broad scale conservation efforts, it seems that differing habitat requirements must be taken into consideration when planning protected areas that include small river sections.

## Works Cited

- Aliaga-Rossel E. 2002. Distribution and abundance of the river dolphin (*Inia geoffrensis*) in the Tijamuchi River, Beni, Bolivia. *Aquatic Mammals* 28:312-323.
- Aliaga-Rossel E., T. McGuire, and H. Hamilton. 2006. Distribution and encounter rates of the river dolphin (*Inia geoffrensis boliviensis*) in the central Bolivian Amazon. *Cetacean Research Management* 8:87-92.
- Anderson D., K. Burnham, and G. White. 1998. Comparison of akaike information criterion and consistent akaike information criterion for model selection and statistical inference from capture-recapture studies. *Journal of Applied Statistics* 25:263-282.
- Bearzi M. 2005. Dolphin sympatric ecology. *Marine Biology Research* 1:165-175.
- Best R., and da Silva, V. 1989. Amazon River dolphin, boto *Inia geoffrensis* (de Blainville, 1817). Pp. 1-24 in S. Ridgway and H. Harrison, eds. *Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales*. Academic Press,
- 1989. Biology, status and conservation of *Inia geoffrensis* in the Amazon and Orinoco river basins. In: W. F. Perrin, R. L. Brownell, K. Zhou and Lu Jiankang, eds. *Biology and conservation of the river dolphins*. pp. 23-34. IUCN Species Survival Commission.
- 1996. *Sotalia fluviatilis*. *Mammalian Species*. 527:1-7.
- **1996. Freshwater dolphin/fisheries interaction in the Central Amazon (Brazil). Amazon. Limnol. Oecol. Reg. Syst. Fluminis Amazon. 14:165-175.**
- Byers C. R., R. K. Steinhorst, and P. R. Krausman. 1984. Clarification of a Technique for Analysis of Utilization-Availability Data. *The Journal of Wildlife Management* 48:1050-1053.
- Caballero S., F. Trujillo, J. A. Vianna, H. Barrios-Garrido, M. G. Montiel, S. Beltrán-Pedrerros, M. Marmontel, M. C. Santos, M. Rossi-Santos, F. R. Santos, and C. S. Baker. 2007. Taxonomic Status of the Genus *Sotalia*: Species Level Ranking for “tucuxi” (*Sotalia fluviatilis*) and “costero” (*Sotalia Guianensis*) Dolphins. *Marine Mammal Science*. 23:358-386.
- Cravalho M. A. 1999. Shameless Creatures: An Ethnozoology of the Amazon River Dolphin. *Ethnology* 38:pp. 47-58.
- da Silva V. 1994. Aspects of the biology of the Amazonian dolphins Genus *Inia* and *Sotalia fluviatilis*. University of Cambridge.
- Fettuccia D., V. da Silva, and P. Simões-Lopes. 2009. Non-metric characters in two species of *Sotalia* (Gray, 1866) (Cetacea, Delphinidae). *Brazilian Journal of Biology* 69:907-917.
- Garaffo G. V., S. L. Dans, E. A. Crespo, M. Degradi, P. Giudici, and D. A. Gagliardini. 2010. Dusky dolphin: modeling habitat selection. *J. Mammal.* 91:54-65.

- Garaffo G. V., S. L. Dans, S. Pedraza, M. Degradi, A. Schiavini, R. Gonzalez, and E. A. Crespo. 2011. Modeling habitat use for dusky dolphin and Commerson's dolphin in Patagonia. *Marine Ecology* 421:217-227.
- Gaus G. F. 1934. *Struggle for existence*. Williams & Wilkins company, Baltimore.
- Gomez-Salazar C., F. Trujillo, M. Portocarrero-Aya, and H. Whitehead. 2012. Population, density estimates, and conservation of river dolphins (*Inia* and *Sotalia*) in the Amazon and Orinoco river basins. *Marine Mammal Science*. 28:124-153.
- Hamilton H., Caballero S., Collins A. G. 2001. Evolution of River Dolphins. *Proceedings: Biological Sciences* 268:549-556.
- Hutto R. 1985. Habitat selection by nonbreeding migratory land birds. pp. 455-476. *Habitat Selection In Birds*. Academic Press, Orlando, Florida.
- IWC Scientific Committee (2000) Report of the Scientific Sub-Committee on Small Cetaceans, 2000. IWC, Cambridge, UK
- Martin A., and V. da Silva. 2004c. Riverine habitat preferences of botos (*Inia geoffrensis*) and tucuxis (*Sotalia fluviatilis*) in the central Amazon. *Marine Mammal Science* 20:189-200.
- 2004b. River dolphins and flooded forest: seasonal habitat use and sexual segregation of botos (*Inia geoffrensis*) in an extreme cetacean environment. *The Zoological Society of London* 263:295-305.
- 2004a. Number, seasonal movements, and residency characteristics of river dolphins in an Amazonian floodplain lake system. *Can. J. Zool.* 82:1307-1315.
- McGuire T. L., and K. O. Winemiller. 1998. Occurrence Patterns, Habitat Associations, and Potential Prey of the River Dolphin, *Inia geoffrensis*, in the Cinaruco River, Venezuela. *Biotropica*. 30:625-638.
- McGuire T. 2002. Distribution and abundance of river dolphins in the Peruvian Amazon. Texas A&M University, College Station, Texas.
- Neu C. W., C. R. Byers, and J. M. Peek. 1974. A Technique for Analysis of Utilization-Availability Data. *The Journal of Wildlife Management* 38:541-545.
- Neumann D. 2001. The activity budget of free-ranging common dolphins (*Delphinus delphis*) in the northwestern Bay of Plenty. *Aquatic Mammals* 27:121-136.
- Parra G. J. 2006. Resource Partitioning in Sympatric Delphinids: Space Use and Habitat Preferences of Australian Snubfin and Indo-Pacific Humpback Dolphins. *Journal of Animal Ecology* 75:862-874.
- Piscart C., J. Roussel, J. Dick, G. Gosbois, and P. Marmonier. 2011. Effects of coexistence on habitat use and trophic ecology of interacting native and invasive amphipods. *Freshwater Biology* 56:325-334.
- Prance G. T. 1979. Notes on the Vegetation of Amazonia III. The Terminology of Amazonian Forest Types Subject to Inundation. *Brittonia* 31:26-38.

- Redfern J., M. Ferguson, E. Becker, K. Hyrenbach, C. Good, and J. Barlow. 2006. Techniques for cetacean-habitat modeling. *Marine Ecology Progress Series* 310:271-295.
- Reeves R., T. McGuire, and E. Zuniga. 1999. Ecology and conservation of river dolphins in the Peruvian Amazon. *IBI Reports* 9:21-32.
- Reeves, R. R., Jefferson, T. A., Karczmarski, L., et al. 2008. *Inia geoffrensis*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 10 April 2011
- Rosas F. C. W., and K. K. Lehti. 1996. Nutritional and Mercury Content of Milk of the Amazon River Dolphin, *Inia geoffrensis*. *Comparative Biochemistry and Physiology -- Part A: Physiology* 115:117-119.
- Roughgarden J. 1976. Resource partitioning among competing species—A coevolutionary approach. *Theoretical Population Biology*. 9:388-424.
- Secchi, E. 2010. *Sotalia fluviatilis*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 10 April 2011.
- Shannon G., and H. Whitehead. 1995. Distribution and habitat partitioning by small odontocetes in the Gully, a submarine canyon on the Scotian Shelf. *Canadian Journal of Zoology* 73:1599-1608.
- Smith, B.D., Zhou, K., Wang, D., Reeves, R.R., Barlow, J., Taylor, B.L. & Pitman, R. 2008. *Lipotes vexillifer*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 16 October 2011
- Stockin K. A., V. Binedell, N. Wiseman, D. H. Brunton, and M. B. Orams. 2009. Behavior of free-ranging common dolphins ( *Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Mammal Science*. 25:283-301.
- Turvey S., R. Pitman, and B. Taylor. 2007. First human-caused extinction of a cetacean species? *Biology Letters* 3:537-540.
- Vidal O., J. Barlow, and L. Hurtado. 1997. Distribution and abundance of the Amazon river dolphin (*Inia geoffrensis*) and the Tucuxi (*Sotalia fluviatilis*) in the Upper Amazon river. *Marine Mammal Science* 13:427-445.
- Vidal O., J. Barlow, L. A. Hurtado, J. Torre, P. Cendon, and Z. Ojeda. 1997. Distribution and abundance of the Amazon river dolphin (*Inia geoffrensis*) and the Tucuxi (*Sotalia fluviatilis*) in the Upper Amazon river. *Marine Mammal Science*. 13:427-445.
- Wedekin L. L., F. G. Daura-Jorge, and P. C. Simões-Lopes. 2010. Habitat preferences of Guiana dolphins, *Sotalia guianensis* (Cetacea: Delphinidae), in Norte Bay, southern Brazil. *Journal of Marine Biology Assessment*. 90:1561-1570.
- Whitehead H., and S. Brennan. 1992. Distribution and behaviour of male sperm whales on the Scotian Shelf. *Canadian Journal of Zoology* 70:918.
- Zuur F., E. Ieno, N. Walker, A. Saveliev, and G. Smith. 2009. GLM and GAM for Absence-Presence and Proportional Data. Pp. 245-259. *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, USA.



## Appendix

Calculated habitat area for each transect (see methods):

Date (from July 24th):	Transect:									
	Upstream					Downstream				
	Area(m2) Flooded Vegetation	Beach	Center	Bank	Confluence	Area(m2) Flooded Vegetation	Beach	Center	Bank	Confluence
July 24	55800	0	416450	82600	45400	80961	0	450000	112600	0
25	51150	2350	416450	82600	45400	76685	377.1	450000	112600	0
26	46500	4700	416450	82600	45400	72409	2427.8	450000	112600	0
27	41850	7050	416450	82600	45400	68133	4478.5	450000	112600	0
28	37200	9400	416450	82600	45400	63857	6529.2	450000	112600	0
29	32550	11750	416450	82600	45400	59581	8579.9	450000	112600	0
30	27900	14100	416450	82600	45400	55305	10630.6	450000	112600	0
31	23250	16450	416450	82600	45400	51029	12681.3	450000	112600	0
August 1	18600	18800	416450	82600	45400	46753	14732	450000	112600	0
2	13950	21150	416450	82600	45400	42477	16782.7	450000	112600	0
3	9300	23500	416450	82600	45400	38201	18833.4	450000	112600	0
4	4650	25850	416450	82600	45400	33925	20884.1	450000	112600	0
5	0	28200	416450	82600	45400	29649	22934.8	450000	112600	0
6	0	28200	416450	82600	45400	25373	24985.5	450000	112600	0
7	0	28200	416450	82600	45400	21097	27036.2	450000	112600	0
8	0	28200	416450	82600	45400	16821	29086.9	450000	112600	0
9	0	28200	416450	82600	45400	12545	31137.6	450000	112600	0
10	0	28200	416450	82600	45400	8269	33188.3	450000	112600	0
11	0	28200	416450	82600	45400	3993	35239	450000	112600	0
12	0	28200	416450	82600	45400	0	37289.7	450000	112600	0
13	0	28200	416450	82600	45400	0	39340.4	450000	112600	0
14	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
15	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
16	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
17	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
18	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
19	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
20	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
21	0	28200	416450	82600	45400	0	41391.1	450000	112600	0
22	0	28200	416450	82600	45400	0	41391.1	450000	112600	0