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Unveiling the Conservation Status of *Inia* and *Sotalia* in the Brazilian Northeastern Amazon

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Abstract

Very few freshwater ecosystems maintain river dolphin populations. Over the last century, much effort has been invested in assessing threats and impacts to river dolphin species in Asia. As a result, population sizes, distribution, and trends in populations of these species are well known. For many reasons, the situation in South America is quite different, and considerable knowledge gaps remain regarding the species in the region. Nevertheless, the Amazon region sustains the world's largest population of river dolphins, mostly in Brazil. The Brazilian Amazon encompasses nine states, and many of these territories lack credible information on river dolphin ecology, habitat use, population trends, genetics, and distribution. For instance, the International Union for Conservation of Nature's geographic range maps for *Inia geoffrensis* and *Sotalia fluviatilis* do not acknowledge their occurrence throughout Amapá in the northeastern Amazon. This study adopted a biogeographical rather than a hydrological approach to assess the distribution of river dolphin species in Amapá. The research compiled field data gathered from 2008 to 2020 and produced geographic range/distribution maps for *I. geoffrensis* and *Sotalia* spp. in Amapá. A literature review was coupled with field work and interviews with authorities and local researchers to assess distribution, and past and present evidence of anthropogenic disturbance of the species. Critical knowledge gaps were identified, and approaches to improve the protection of the species and their habitats in the region are recommended. We suggest that at least 4,224 and 2,596 km of rivers for *I. geoffrensis* and *Sotalia* spp., respectively, should be added to the IUCN's geographic range maps as well as the exclusion of 1,033 km of water courses erroneously indicated as an occurrence area of *I. geoffrensis*.

Key Words: distribution, Amazon River dolphin, tucuxi, Guiana dolphin, threats, habitat change, Amapá

Introduction

River dolphins are a particularly vulnerable group of freshwater cetaceans distributed in only 14 countries in Asia and South America. All species are threatened by human-induced habitat modification and ecological disruption of river basins (Smith & Reeves, 2012). The recent extinction of the baiji (*Lipotes vexillifer*), endemic to the Yangtze River, China, highlights the potential effect of such impacts (Turvey et al., 2007). In South America, species can be found in the Amazon biome and the Orinoco basin where the largest populations of river dolphins on Earth remain (Oliveira-da-Costa et al., 2019).

Throughout the Amazon (including inland and coastal waters), five species of dolphin (Cetartiodactyla) are recognized: the delphinid tucuxi (*Sotalia fluviatilis*; Gervais, 1853) and Guiana (*S. guianensis*; Van Bénéden, 1864) dolphins, and the iniid Amazon River dolphin (*Inia geoffrensis*; Blainville, 1817), the Bolivian boto (*I. boliviensis*; d'Orbigny, 1834), and the Araguaian boto (*I. araguaiaensis*; Hrbek, Farias, Dutra, & da Silva, 2014) (Ruiz-García & Shostell, 2010; Trujillo et al., 2010; Hrbek et al., 2014). In contrast, the Taxonomy Committee of the Society for Marine Mammalogy recognizes only one species of *Inia* (https://marinemammalscience.org/species-information/list-marine-mammal-species-subspecies). According to the International Union for Conservation of Nature and Natural Resources (IUCN), both tucuxi and Amazon River dolphins are in the category "Endangered" (da Silva et al., 2018, 2020), and the Guiana dolphin is considered "Near Threatened" (Secchi et al., 2018).

In the Amazon, dolphins are vulnerable to anthropogenic disturbance because they share the same habitats and use similar food resources as humans (Rocha-Campos et al., 2010; da Silva et al., 2018). These dolphins are among the least known cetaceans (Trujillo et al., 2010; da Silva et al., 2018). Population estimates, and ecological and genetic studies from several regions of the Amazon are essential tools for guiding conservation and management strategies (Primack & Rodrigues, 2001; Gómez-Salazar et al., 2012). However, the large size of Amazonia, the complex and expensive logistics required to study and survey dolphins, and the lack of funds limit access to critical samples (Oliveira-da-Costa et al., 2019). Knowledge of species' geographic distribution is critical for answering many ecological questions and underpins effective conservation management, yet information on distribution is usually limited in spatial resolution or reliability (Merow et al., 2017).

The IUCN's geographic range maps for tucuxi and Amazon River dolphin only include the Amazon basin and sub-basins (Castello et al., 2013) and do not include, for the most part, these dolphins' occurrence in the northeastern portion of the Brazilian Amazon, notably in parts of the State of Amapá which comprise other basins. However, geographic range and distribution maps can be greatly improved by taking a broader perspective and adopting the Pan-Amazon region as the geographic scope for these species. Furthermore, maps adopted by many authorities in Brazil, such as the National Hydrographic Division, the National Water Resources Council, and the National Water Agency, recognize Amapá as an integral part of the Amazon (Elesbon et al., 2011; Pfafstetter, unpub. data).

Amapá is one of the nine states comprising the Brazilian Amazon. Nearly 70% of its total area is designated as protected areas or indigenous territories. This area is unique because it provides the last tributaries that feed into the Amazon basin. It contains the northeastern most river in the country, which forms the eastern most limit in distribution of some of Brazil's most threatened aquatic mammals, such as giant otters (*Pteronura brasiliensis*), Amazonian and West Indian manatees (*Trichechus inunguis* and *T. manatus*), and the Amazon River dolphin. However, few papers have been published on the aquatic biodiversity in the region. Current knowledge about river dolphins in Amapá is too limited in accurate information on their distribution, ecological requirements, and anthropogenic impacts to them. The present study presents information from 12 years of field assessments conducted in Amapá. The findings show that the distribution maps for *I. geoffrensis* and *Sotalia* spp. need to be updated because current knowledge of the species' distributions is critical for developing sound management and conservation strategies. Documentation of previously unpublished information regarding potential threats to the species will help address the knowledge gaps in the literature, and suggestions for approaches to improve the conservation of these species in the Amazon are provided.

Methods

The present study adopted a biogeographical approach of the Pan-Amazon region. Between 2008 and 2020, records of *Inia* and *Sotalia* were collected on field trips and interviews from water courses throughout Amapá, a region located on the Brazilian border with French Guiana and Suriname. In Amapá, nearly 72% of the 142,814.5 km^2 of land is legally protected, and approximately one third is covered by wetlands (Santos, 2016). The region's terrestrial habitats are characterized by a mixture of lowland Amazon rainforest, savannahs, and white-water swamps (*várzea*) (Sá-Oliveira et al., 2015). Population estimation surveys were conducted in portions of the Jari, Vila Nova, Matapi, Amazon River–North Channel, Araguari, and Cassiporé Rivers; additional data were collected from platforms of opportunity.

To gather available information on the presence of dolphin species in the river systems of Amapá, we conducted a thorough online search and found approximately 50 published and unpublished documents from peer-reviewed journal articles and books, technical and government reports, academic works, and websites. All ~50 documents were considered to be accurate to the best of our knowledge and were incorporated into the current study. In addition, local inhabitants (n = 876), researchers (n = 12), park managers (n = 23), and state/federal officers (n = 17) were interviewed using a standardized protocol designed for this study. Because sympatry between tucuxi and Guiana dolphins in the Amazon Estuary is likely, and because it is not clear how far inland Guiana dolphins occur or how far out into the ocean tucuxis occur in Amapá, some publications did not clearly report to which species they referred. Hence, we chose to compile all *Sotalia* spp. information under one heading.

A shapefile with the country boundaries was downloaded in 2011 from https://resources.arcgis.com/content/data-maps/10.0/world to show Latin America with its political division, including boundaries for Brazil. The shapefile was provided by DeLorme Publishing Company, Inc., with additional attributes from Environmental Systems Research Institute (ESRI), Inc.

The study area was subdivided into three sectors according to the characteristics of the Amapá

drainage network and its interconnections with bodies of water: (1) Atlantic, (2) Araguari River–Amazon River Mouth, and (3) Amazon River–North Channel (Figure 1). These sectors are part of the two great systems in the region: (1) the Amazon River Estuary, which has the longest tidally influenced area in the world (Nittrouer et al., 2021), and (2) the coastal rivers of the Guyana Shield watershed (Rosales, 2003). The Atlantic sector, which belongs to the system of the Guyanas coast, is located in the northern part of Amapá and comprises the coastal river systems that flow into the North Atlantic Ocean. The Araguari River–Amazon River Mouth, where the Bailique Archipelago is located, is the sector with the greatest coastal changes in the Amapá state (see "Waterscape Changes") and comprises a transition area between the Amazon River sector and the Atlantic sector. The Amazon River sector corresponds to the region between the Jari River and the southern portion of the Bailique Archipelago, with rivers flowing directly into the Amazon River and its North Channel. The entire region, in the coastal plain, is exposed to inundation resulting from inter-annual and seasonal climatic variability and from tidal processes (Santos, 2006).

The Atlantic sector (Figure 2) includes the Oiapoque River and its namesake bay; Cassiporé, Calçoene, Flexal, Macarri, and Sucuriju Rivers with their tributaries; Maruani Lake; Tijolos Creek; and the water bodies of the adjacent oceanic coast from Oiapoque Bay to the North Cape region, including the Igarapé do Inferno Creek and the Varador Channel. The sector is characterized by the presence of several estuaries with higher salinity values upstream during the dry period (September to November) than the rainy season (March to May) (Santos et al., 2018). Cabo Orange National Park, Maracá-Jipioca Ecological Station, Piratuba Lake Biological Reserve (northern portion), and the Uaçá and Juminá indigenous lands constitute the protected areas located in this sector.

The Araguari River–Amazon River Mouth sector (Figure 3) comprises the Araguari River, the Aporema River, the Tartarugal Grande River with its tributary Praxiuba Creek, and Comprido de Cima Lake. These lakes are interconnected with Tartarugal Grande and Araguari Rivers by several natural and artificial channels (*valas*), which, in turn, connect the North Cape area with the Amazon River mouth (Santos, 2006). The region has two main connections between the Araguari River and the Amazon River Mouth: (1) the Urucurituba Channel, which connects the old lower course of the Araguari River with the Gurijuba Channel (west of the Bailique Archipelago), created in 2014 when the Araguari River changed almost all its flow to the south, towards the Amazon River (this phenomenon resulted in the extinction of the tidal bore or *pororoca* inside the estuary [Santos et al., 2016b]); and (2) the Igarapé Novo do Gurijuba Channel,

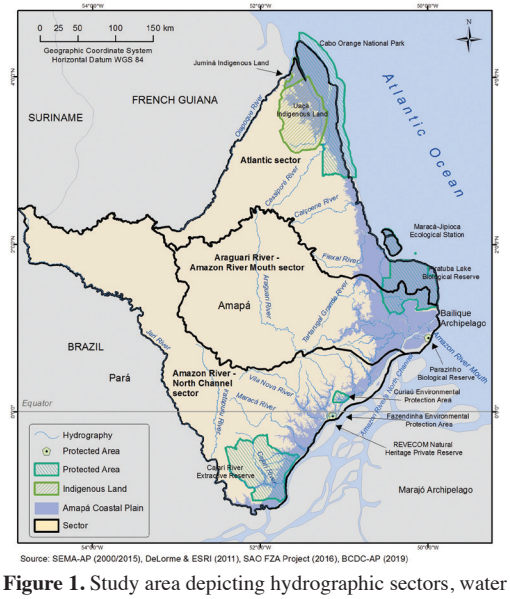

Figure 1. Study area depicting hydrographic sectors, water courses, protected areas, and indigenous territories

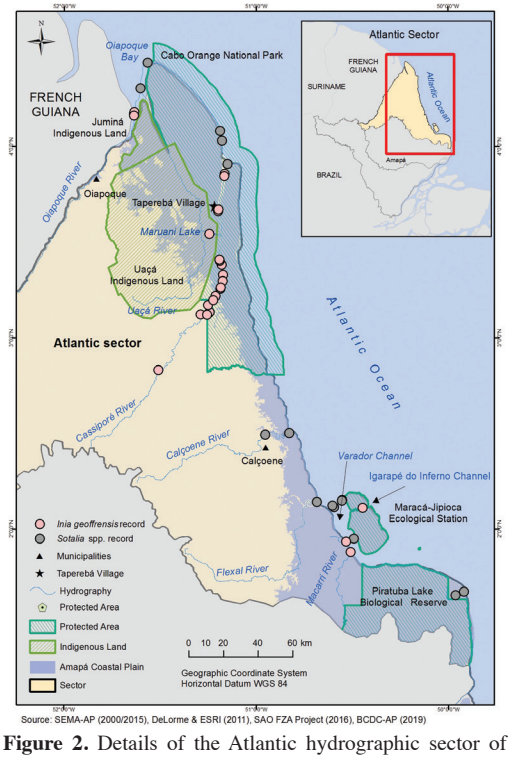

Figure 2. Details of the Atlantic hydrographic sector of Amapá, including dolphin records and protected areas

connecting the Araguari and Amazon Rivers by the Gurijuba River (Santana & Silveira, 2005; Santos, 2006). The Parazinho and the Piratuba Lake (southern portion) biological reserves are located in this sector. Three of the four dams in the state are located in the Araguari River.

The Jari, Cajari, Ajuruxi, Maracá, Vila Nova, Matapi Fortaleza, Curiaú, Pedreira, and Macacoari Rivers and their tributaries are located in the Amazon River sector (Figure 4). The Cajari River Extractive Reserve, Curiaú Environmental Protection Area, Fazendinha Environmental Protection Area, REVECOM Natural Heritage Private Reserve, and the Santo Antônio Hydroelectric Plant are located in this sector.

The geographical coordinates indicating the location of *Inia* and *Sotalia* were determined using primary sources (literature review, interviews, sightings, and sample material). For records with no geographic coordinates reported, we consulted vector files and printed maps of the Continuous Digital Cartographic Base of Amapá (Base Cartográfica Digital Contínua do Amapá [BCDC-AP]) (Vieira, 2015), the Atlas of Environmental Sensitivity to Oil of the Amazonas Mouth Maritime Basin (aka SAO Charts; Santos et al., 2016a), and the Nautical Charts of the Brazilian Navy (Diretoria de Hidrografia e Navegação [DHN], 2012, 2018, 2019, 2020a, 2020b). Because of recent changes in hydrography in Amapá, the vector file used in this study corresponded to the BCDC-AP file where the tributaries on the left bank of the Araguari River (Macarri and Tartarugal Rivers and their tributaries) were replaced by the digital files from SAO Charts. Maps were created using *ArcGIS Desktop*, Version 10.8.1 (ESRI, 2011).

To assess the IUCN's geographic range of *Inia* and *Sotalia* dolphins in Amapá, spatial data in ESRI shapefile format were downloaded from www.iucnredlist.org. Vector data representing the geographic range of each species were overlayed with the hydrological data (line format) to identify the riverine and coastal extent of Amapá. To generate geographic range/distribution maps for *Inia* and *Sotalia*, the rivers were divided into two parts: (1) *confirmed presence* extended from the mouth of the river to the farthest sighting uprivers; and (2) *probable presence* extended from the furthest upriver confirmed record to the headwaters of the river. In the Jari and Araguari Rivers, only the confirmed presence was considered because there are geographic barriers (hydroelectric dams) that prevent the movements of river dolphins upriver from the dams.

The geographic ranges of *Sotalia* and *Inia* delineated by the IUCN in the State of Amapá go beyond the limits of the water bodies because in the IUCN assessment, they buffered the shoreline between 5 to 25 km in width for each river bank and used that buffered area to calculate the hydrological area of a river. The IUCN uses vector files in polygon format to represent the dolphins' distribution; we chose to present the distribution through a vector file in line format (UTM projection horizontal datum WGS 84), representing rivers, channels, and creeks. This allowed us to calculate the extension of each river—from its mouth to the furthest observation/record upriver. A vector file in line format, representing the coastal limits of Amapá, was used to calculate the extension of the distribution of species in the North Channel of the Amazon and in the Atlantic coast of the state. Despite using a format different from IUCN (i.e., line × polygon), it was possible to identify stretches of IUCN files that indicate the presence of dolphins in sites where dolphins effectively do not occur. Based on the information generated here, the IUCN may update its vector files of species occurrence.

Information obtained on distribution and location of potential threats was used to produce thematic maps, to illustrate the distribution of target species in protected areas, and to identify anthropogenic infrastructure such as hydroelectric plants, oil and natural gas operations, and mining operations. For information on mining activities, we used shapefiles from the Amapá Environment Secretary (Secretaria de Meio Ambiente do Amapá [SEMA-AP]), BCDC-AP (Rede Amazónica de Información Socioambiental Georreferenciada [RAISG], 2020), and information obtained during flight surveys in the study area; however, this does not represent an exhaustive mapping for mining.

Results

The information collected generated a georeferenced database with 148 records of *I. geoffrensis* and 71 records of *Sotalia* spp., which were used to define the distribution and geographic range of the dolphin species in Amapá (Figure 5).

Occurrence of Inia *and* Sotalia *in Amapá*

Inia *dolphins*—Amazon River dolphins have been recorded using estuarine and coastal habitats in the Atlantic, Araguari River–Amazon River Mouth, and Amazon River–North Channel sectors:

- *Atlantic Sector (Figure 2)* – The first record of an Amazon River dolphin in the Cassiporé River was reported by Siciliano et al. (2008). In 2009, we confirmed the presence of the species in the area through interviews and sightings, as well as during our field trips in 2010, 2013, and 2014 (Figure 6). The presence of Amazon River

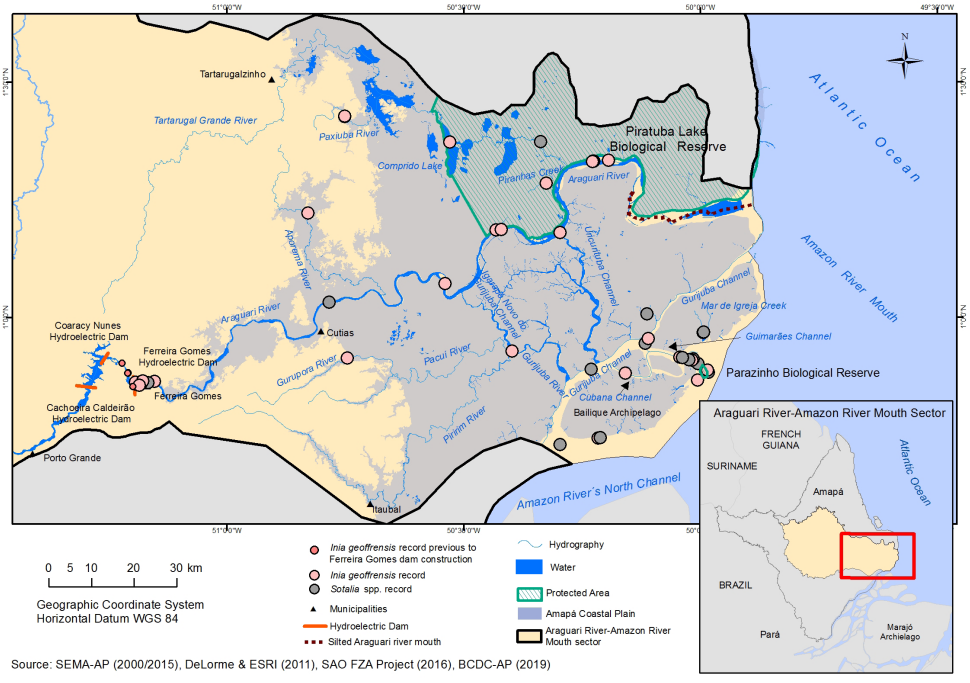

Figure 3. Details of the Araguari River–Amazon River Mouth hydrographic sector of Amapá, including dolphin records, protected areas, and hydroelectric dam locations

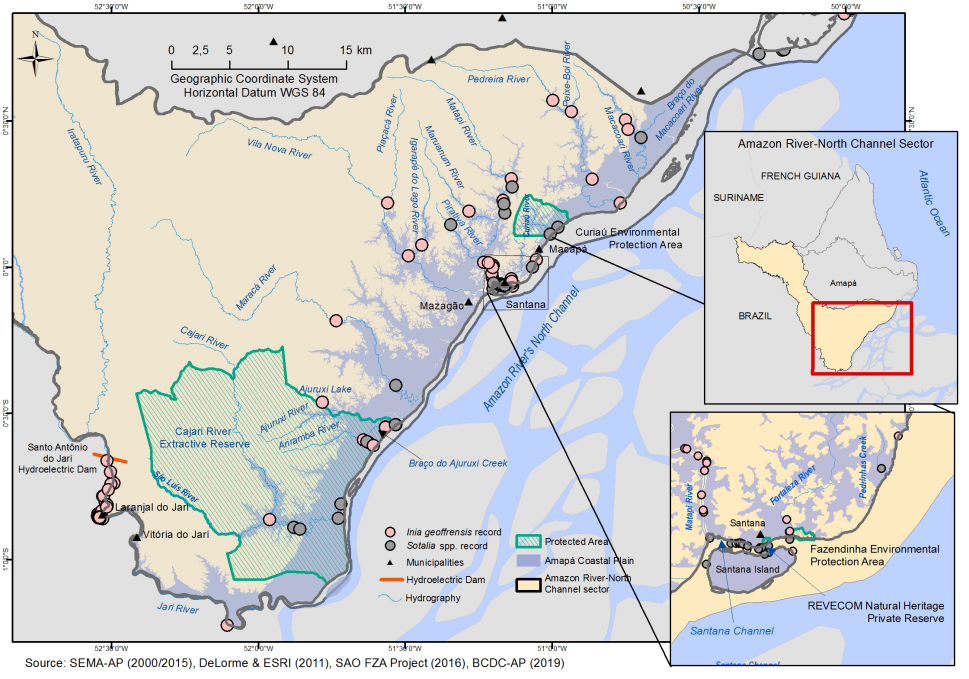

Figure 4. Details of the Amazon River–North Channel hydrographic sector of Amapá, including dolphin records, protected areas, and Santo Antônio do Jari Hydroelectric Dam location

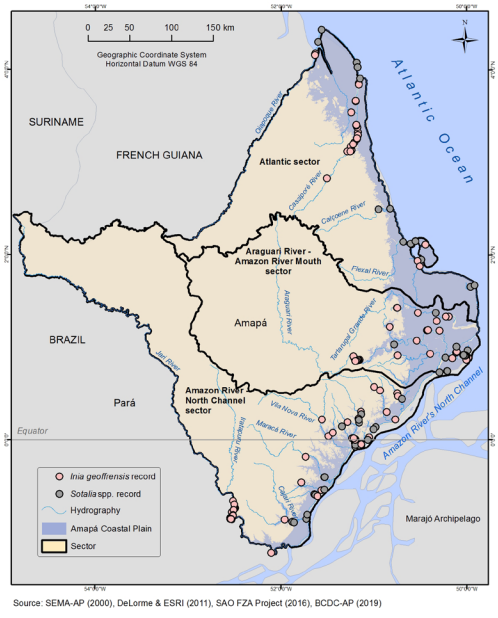

Figure 5. *Inia geoffrensis* and *Sotalia* spp. records in Amapá, northeastern Brazilian Amazon, based on field efforts (2008 to 2020)

Figure 6. *Inia geoffrensis* specimens sighted in Cassiporé River, September 2014: (A) adult specimen sighted against a backdrop of mangroves, and (B) pair of *I. geoffrensis* (likely adult female and calf). (*Photo credits:* A. B. Silva)

dolphins in the Cassiporé area varies daily due to tide and throughout the year. During the rainy season, Amazon River dolphins follow shoals of marine fish, such as the cocosoda catfish (*Pseudauchenipterus nodosus*), that enter the Cassiporé River to spawn in the flooded areas during spring tides (high tides above average). In the dry season, dolphins have been reported foraging near the mouths of streams during flood tides, full and ebb. In the dry season, the saltwater reaches the Taperebá village (03° 40' 27.24" N, 51° 12' 5.86" W), approximately 22 km inland, and the animals move upstream, remaining between the brackish water and the rapids in deeper channels in the inland zone, mainly in the Nazaré pool (Retiro Nova Esperança community). As the freshwater level rises during the rainy season, the animals distribute more widely. In May 2018, we obtained additional sightings of Amazon River dolphins in the Cassiporé River, which justified an attempt to capture animals to deploy satellite transmitters and follow their movements during the second half of 2018. However, adverse environmental conditions (e.g., tidal dynamics, influence of the *pororoca*, riverbed with rocks) precluded the effort. Research efforts are needed to learn more about dolphins in the Cassiporé River area, especially because this Amazon River dolphin population is apparently isolated from other populations in the Amazon basin. Reliable sources reported few but regular *Inia* sightings in French Guiana in the Approuague River during the wet season (May-June) only (Benoit de Thoisy, pers. comm., 14 December 2020) and in the Ouanary River. These might represent lost, transient, or exploratory animals, or new small populations as yet unrecorded.

- *Araguari River–Amazon River Mouth Sector (Figure 3)* – In part of the Piratuba Lake Biological Reserve, the Amazon River dolphin was recorded in Tabaco and Piranhas Creek (Araguari River) and Retiro Boa Esperança, Primavera, Tapado, Tracajá Gordo, and Andiroba villages (Flexal River) (Melo, 2006). During additional expeditions, we confirmed the presence of the species in the Rititi Creek, Comprido Lake, São Benedito, Princesa, and Rego Comprido. Lima et al. (2010a) documented the presence of Amazon River dolphins in the Araguari River from the rapids downstream from the Coaracy Nunes Hydroelectric Dam to its mouth in the Atlantic Ocean prior to the building of the Ferreira Gomes Hydroelectric Dam. No dolphins became entrapped in the stretch of the Araguari River between the hydroelectric dams, and the Ferreira Gomes Dam is the current

observed limit of occurrence of dolphins in that river. Local inhabitants from the vicinity of the Parazinho Biological Reserve in the Bailique Archipelago reported the regular presence of Amazon River dolphins in that area (Barbosa et al., 2010a).

- *Amazon River–North Channel Sector (Figure 4)* – Residents of the Curiaú River Environmental Protection Area reported Amazon River dolphin sightings in sympatry with tucuxis in the Curiaú, Pescada, and Pirativa Rivers. Amazon River dolphins use stretches of the Matapi, Vila Nova, and Amazon Rivers near Santana Island (Lima et al., 2010b). *I. geoffrensis* occurs in Poço dos Botos in Itaubal do Piririm as well as in the Maracá River in the vicinity of the Mazagão municipality (Siciliano et al., 2008). Drummond et al. (2008) reported the occurrence of Amazon River dolphins in the Cajari River Extractive Reserve where park managers recorded individuals of this species in the mid and lower Cajari Basin, especially in the Muriacá and Ariramba Rivers (R. Nonato, pers. comm., 11 June 2018). In the Jari River, during the first year of monitoring prior to the construction of the Santo Antônio do Jari Hydroelectric Dam, records of the species were obtained downstream from the Santo Antônio Falls (Sete Soluções e Tecnologia Ambiental, unpub. data). During the monitoring at the pre- and post-filling phases of the reservoir, between 2012 and 2018, Amazon River dolphins occurred regularly in the area. In our field trips upstream from the dam, in Jari and Iratapuru Rivers (the latter flows into the Jari), the presence of dolphins was not confirmed; therefore, the Santo Antônio do Jari Dam is considered the current observed distributional limit.

  I. geoffrensis was the only species of the genus previously considered to be present in Amapá (da Silva et al., 2018). Analysis of the cytochrome b of an Amazon River dolphin carcass found floating on the Araguari River confirmed that it belonged to a specimen of *I. geoffrensis* (F. R. Santos, pers. comm., May 2019). Although this finding might be expected, additional samples are needed to elucidate whether this specimen represents a recent migrant or an isolated population, and it is important to know whether the species' movement into the Araguari River occurred at the mouth of this river or through the channels carved by buffaloes (see "Waterscape Changes" below).

Sotalia *Dolphins*—Similar to *I. geoffrensis*, *Sotalia* spp. have been recorded in Atlantic, Araguari River–Amazon River Mouth, and Amazon River–North Channel sectors:

- *Atlantic Sector (Figure 2)* – In the northern part of Amapá, residents interviewed reported the presence of Guiana dolphins in the coastal–estuarine region near the Oiapoque, Cassiporé, and Calçoene Rivers. The presence of Guiana dolphins in the vicinity of the Maracá–Jipioca Ecological Station and in the marine portion of the Piratuba Lake Biological Reserve, near the Sucuriju community, was verified through interviews with local citizens and from a skull sample (Siciliano et al., 2008; Barbosa et al., 2010b).

- *Araguari River–Amazon River Mouth Sector (Figure 3)* – In the Araguari River basin, tucuxis were sighted at the rapids located across the Ferreira Gomes municipality up to the mouth of that river system (Lima et al., 2010a). The Ferreira Gomes Hydroelectric Dam was installed in October 2014 with no record of entrapment of dolphins upstream from the dam. The occurrence of tucuxis in the Piratuba Lake Biological Reserve (Tabaco in the Araguari River; and Retiro Boa Esperança, Primavera, Tapado, Tracajá Gordo, and Andiroba in the Flexal River) was reported by Melo (2006) during a study on the mammalian fauna of that protected area. People interviewed near the Bailique Archipelago claimed that tucuxi occur regularly in the area surrounding the Parazinho Biological Reserve (Barbosa et al., 2010a).

- *Amazon River–North Channel Sector (Figure 4)* – In the Pirativa River, in the Curiaú River Environmental Protection Area, tucuxi were recorded exhibiting universally aggressive behavior toward an Amazonian manatee calf (Vergara-Parente et al., 2004). Ferreira et al. (2009) also reported the presence of the species during a mammal inventory of that area. Later, we confirmed tucuxi presence in the Curiaú, Pescada, and Pirativa Rivers by interviewing residents in those locations. In a compilation of the presence of aquatic mammals on the north coast of Brazil, Siciliano et al. (2008) reported sightings of *Sotalia* spp. in the Amazon River–North Channel sector in the municipality of Santana. In that same stretch, Miranda (2009) documented regular occurrence of tucuxi adults and calves. Interviews conducted by the same author with the residents around the port area of Santana revealed frequent sightings of groups larger than six tucuxi. Barroso et al. (2014, 2015) reported site fidelity of tucuxis near the "Açaí Port" based on 6 months of monitoring in 2013. Lima et al. (2010b) compiled an inventory of aquatic mammals in this region and sighted

tucuxi around the Santana Island. The presence of tucuxis is reported as recurrent in the Ariri community on the Matapi River (Oliveira et al., 2010; Santos et al., 2015). Siciliano et al. (2008) reported sightings of tucuxis in the Maracá River (Mazagão municipality) and in the lower Cajari River, specifically in a stretch from Porto do Braço up to the mouth of the Amazon River. The presence of tucuxi at the mouths of the Cajari and Ajuruxi Rivers was also reported by park managers from the Cajari River Ecological Station (R. Nonato, pers. comm., 6 November 2018) and by researchers who worked previously in the region (D. Ferreira, pers. comm., May 2012). The occurrence of tucuxis in the Jari River basin was suggested in the region's hydroelectric mammal survey (Empresa de Pesquisa Energética [EPE], unpub. data). Tucuxi were recorded during the Environmental Impact Assessment (EIA) of the Santo Antônio do Jari Hydroelectric Dam (Ecology Consultoria Ambiental, unpub. data) but only downstream from the Santo Antônio Falls. However, we did not confirm the presence of the species downstream from those falls during our surveys between 2012 and 2018.

Range Extension of Dolphins in Amapá

Using the georeferenced database, the presence of dolphins was documented in rivers and their respective tributaries that flow into the Atlantic, Araguari River–Amazon River Mouth, and Amazon River–North Channel sectors where 10 protected areas provide habitat for the conservation of the species (Figure 1). Most of the records are located in the lower course of the rivers in the coastal plain.

IUCN's *I. geoffrensis* geographic range map contains 1,304 km of habitat (all of the Jari and Iratapuru Rivers and part of the Amazon River–North Channel sector). Nevertheless, because *Inia* does not occur in the Iratapuru or the Jari Rivers upriver from the dam (1,033 km), we subtracted that amount from the IUCN's geographic range estimate. The overlapping range area between IUCN's and our updated range map is 271 km; our range contains 4,495 km more than that of the IUCN map. Therefore, the total updated geographic range map for *I. geoffrensis* in Amapá (discounting the overlapped area of the IUCN's) is 4,334 km distributed across the Atlantic, Araguari River–Amazon River Mouth, and Amazon River–North Channel sectors (Figure 7), approximately 16 times larger than IUCN's.

The IUCN's range map for *S. guianensis* covers the entire coast of Amapá (807 km), thereby encompassing our data. IUCN's *S. fluviatilis* range distribution (along the southern, estuarine coast of Amapá) covers 230 km. However, there is a 123 km overlap between both species of *Sotalia* in the IUCN's map, resulting in a total range distribution for *Sotalia* spp. of 913 km. The IUCN's geographic range map for *S. fluviatilis* did not consider inland rivers in Amapá; therefore, most of the range documented herein is new, although we are unsure how many of the new records were of *S. guianensis* entering some freshwater systems. The current inland geographic range for the genus *Sotalia* (regardless of species) in Amapá documented in this article is 2,596 km (Figure 8), an increase of almost 200% compared to IUCN's estimate.

Knowledge of Threats to Inia *and* Sotalia *in Amapá*

Effect of Dams on River Dolphin Distribution—Currently, four hydropower dams are operating in the state (Figure 9). Three are located in the Araguari River basin where the Coaracy Nunes (78 MW), Ferreira Gomes (252 MW), and Cachoeira Caldeirão (219 MW) hydroelectric plants have been in operation since 1975, 2014, and 2016, respectively. Those dams were established as multiple serial dams with interconnected reservoirs in the Araguari River between Porto Grande and

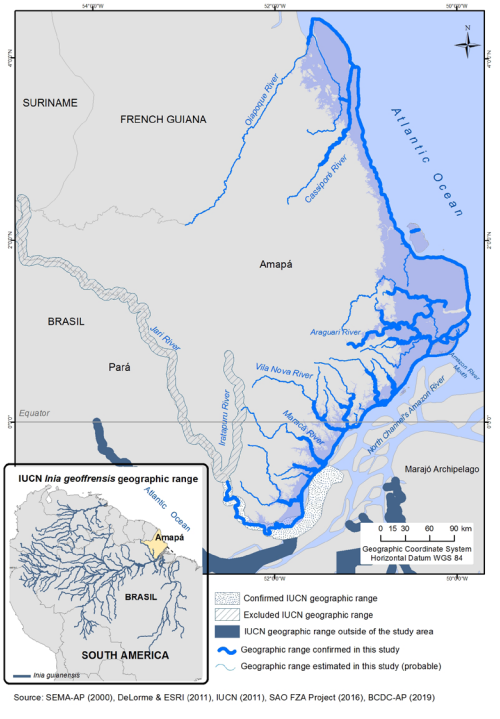

Figure 7. *Inia geoffrensis* range distribution in Amapá, northeastern Brazilian Amazon, based on IUCN's and this study, including confirmed and estimated (probable) range

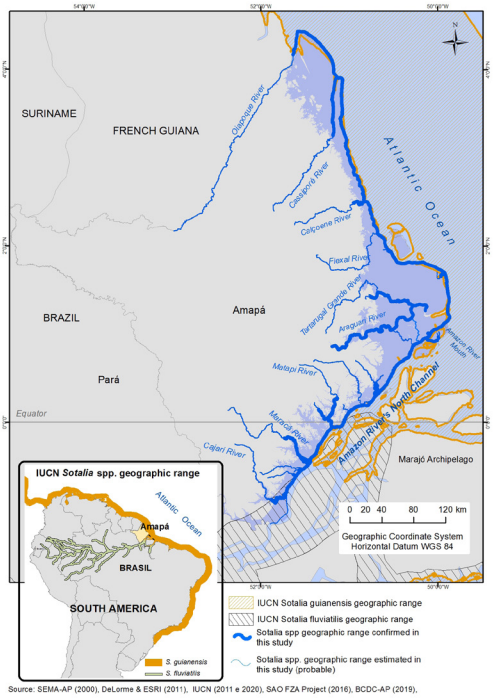

Figure 8. *Sotalia* spp. range distribution in Amapá, northeastern Brazilian Amazon, based on IUCN's and this study, including confirmed and estimated (probable) range

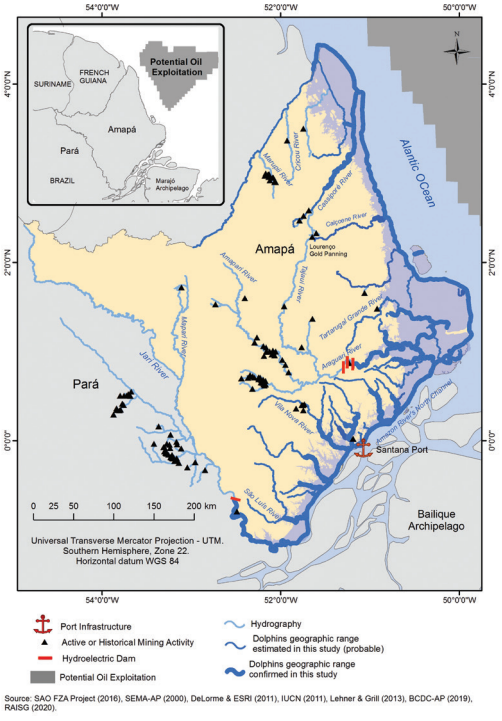

Figure 9. Representation of anthropogenic threats to river dolphins in Amapá state

Ferreira Gomes with an average inter-dam distance of 10 km. The fourth is the Santo Antônio do Jari Hydroelectric Dam, installed in the Jari River in the vicinity of the Laranjal do Jari (Amapá State) and Monte Dourado (Pará State) municipalities (http://www2.aneel.gov.br/scg/Consulta_Empreendimento.asp).

Information on the presence of river dolphins in areas influenced by hydroelectric projects in Amapá was obtained from the EIAs and/or reports from the environmental monitoring programs of the Ferreira Gomes (Ecotumucumaque Assessoria Ambiental, unpub. data, re. 2009) and Santo Antônio do Jari (Ecology Consultoria Ambiental, unpub. data, re. 2011) hydroelectric dams. Tucuxis and Amazon River dolphins were not observed in the region of the Santo Antônio do Jari Hydroelectric Dam during the inventories of the Basic Environmental Project in 1987 or in the studies carried out in the Jari Florestal e Agropecuária reserves (Ecology Consultoria Ambiental, unpub. data). Only the presence of tucuxis was confirmed during the EIA activities of the Santo Antônio do Jari (Ecology Consultoria Ambiental, unpub. data), and Amazon River dolphins were reported only downstream from the Santo Antônio Falls prior to the implementation of the dam (Sete Soluções e Tecnologia Ambiental, unpub. data). The Santo Antônio Falls act as a natural barrier for the dolphin population in the Jari River (Ecology Consultoria Ambiental, unpub. data).

No biological inventories and/or EIAs were conducted during the planning/construction of the Coaracy Nunes Dam (Bárbara, 2006). This site acted as a natural barrier for dolphins in the Araguari River, explaining the absence of records upstream from the dam. There are no records of dolphins in the area influenced by the Cachoeira Caldeirão Dam (Ecotumucumaque Assessoria Ambiental, unpub. data). Prior to the building of the Ferreira Gomes Dam, Lima et al. (2010b) documented Amazon River dolphins from the rapids downstream of the Coaracy Nunes Dam to the mouth of the Araguari River in the Atlantic Ocean. During the building phase, distribution of both species of dolphins remained similar in the region: Amazon River dolphins were recorded throughout the area, and tucuxis were upriver from the site selected for installation of the dam (Florestas Gestão Sócio Ambiental, unpub. data). From 2014, the year of establishment of the Ferreira Gomes Dam (downriver from Caldeirão

Falls), to 2017, there have been no sightings or reports of *Inia* in the area monitored (Consultoria Planejamento e Estudos Ambientais [CPEA], unpub. data); and during the same period (2014 to 2017), only tucuxis were observed downstream from the dam (CPEA, unpub. data). In addition, there has been no record of dolphins between Coaracy Nunes and Ferreira Gomes Dams, indicating that no animals were entrapped in this section of the Araguari River (CPEA, unpub. data).

Tucuxis were reported only downstream of the preexisting rapids in the Ferreira Gomes Dam (Lima et al., 2010a; Ecotumucumaque Assessoria Ambiental, unpub. data). After the installation of this dam, the distribution of tucuxis became restricted to the free-flowing stretch of the Araguari River. Between September 2015 and July 2017, during the operational phase of the plant, tucuxis were only documented downstream from the Ferreira Gomes Dam (CPEA, unpub. data; Figure 9). Between 2012 and 2018 (reservoir pre- and post-filling phases), the presence of Amazon River dolphins was regular in the Santo Antônio do Jari project's area of influence. However, tucuxis were no longer observed in the same area (about 60 km in the Jari River from the Laranjal do Jari municipality to the dam).

Contamination by Heavy Metals—High levels of mercury have been detected in the Cassiporé, Araguari, Jari, Oiapoque, Amapá Grande, and Amapari Rivers (Lima et al., 2015; Venturieri et al., 2017; Hacon et al., 2020) where mining operations occur (Figure 9). Mercury levels above the safe limit set by the World Health Organization for human consumption have been confirmed by analysis of tissue samples of fish collected in the region. *Inia* and *Sotalia* dolphins are present in the Cassiporé, Araguari, Jari, and Oiapoque Rivers. Because these species are at the top of the food chain and are primarily piscivorous, it is likely that the cetacean populations in these rivers also contain some level of contamination (Mosquera-Guerra et al., 2019).

Fisheries and Intentional Killing of Dolphins—Human–wildlife conflicts, including incidental and intentional catch of dolphins by fishing vessels, occur in the coastal–estuarine region near the Oiapoque, Cassiporé, and Calçoene Rivers in northern Amapá. The incidental catch of Guiana dolphins along the state's coast was first documented by Beltrán-Pedreros (1998), who reported the capture of 613 individuals in Amapá's Ponta Grossa-Cabo Orange area by the Pará and Amapá fishing fleets. Bycatches in purse seine nets on the coast of Amapá between August 2006 and May 2007 may have been the result of fishing efforts from boats from the Pará's artisanal fleet (Emin-Lima et al., 2008). In 2007, the national press reported the capture of Guiana dolphins off the coast of Amapá using a net that was 6,500 m long by 7 m high. Eighty-three animals were caught by a single vessel and were later marketed as shark bait (G1, 2007; Pacheco, 2010). According to a local inhabitant from Calçoene, sightings of "black dolphins" (probably *S. guianensis*) in the region are decreasing; this is attributed to the high number of fishing vessels from several states that engage in fishing activities in Calçoene's coastal–estuarine region in Amapá.

Fishermen in the Amapá municipality reported Guiana dolphin carcasses in the vicinity of the Maracá–Jipioca Ecological Station (Barbosa et al., 2010b), which were believed to be associated with incidental entanglement of animals in purse seine and trawl nets from boats displaying Amapá and Pará flags. The carcasses were used as bait for gurijuba fish (*Arius* sp.), and the fat was marketed. Lima et al. (2012) reported that 21 Guiana dolphins were captured incidentally or intentionally near the Maracá–Jipioca Ecological Station and used as shark bait. Interviewees in the Parazinho Biological Reserve (in the Bailique Archipelago) and Amapá and Santana municipalities stated that cetaceans are used by *geleiros* (Amapá commercial fishing freezing boats) as bait for sharks and other commercial fish (Barbosa et al., 2010a). Incidental and intentional catches of *Sotalia* spp. occur frequently in the area surrounding the Parazinho Biological Reserve (Barbosa et al., 2010a, 2012; Lima et al., 2012). Amazon River dolphins have a habit of removing fish trapped in fishing nets and, therefore, are often in conflict with local fishermen. Thus, some fishermen in the area around the Parazinho Biological Reserve and the Cassiporé River shoot at dolphins to frighten them away and keep them from damaging their nets. Intentional and accidental catches of Amazon River dolphins have occurred in the region of the Matapi, Vila Nova, and Amazon Rivers around Santana Island (Lima et al., 2012). The accidental capture of Amazon River dolphins was also documented in Barão de Piaçacá, a rural area of Santana, and in the Cassiporé River.

Exploitation of Byproducts—Guiana dolphins are used as shark bait, and their eyes, genitalia, and oil are traded in the Ver-O-Peso market in Belém (R. F. C. Souza, unpub. data). Dias et al. (2014) documented seizures of 135 specimens of mammals in Amapá between 2005 and 2009, 9% ($n = 12$) of which were the teeth and reproductive organs of *Sotalia* spp. (Dias, 2010). Intentional catches of *Inia* and *Sotalia* spp., and the marketing of byproducts (e.g., fat, genitalia, and eyes), were also documented in the Macapá and Santana port regions (Lima et al., 2012). Amazon River dolphin fat is used as a medicine for the treatment

of inflammation and swelling in places like Retiro Boa Esperança (Cassiporé River) and in the regions of the Matapi, Vila Nova, and Amazon Rivers around Santana Island where amulets from the slaughter of individuals of the species are also sold (Lima et al., 2012).

Waterscape Changes—The Amazon coast in the Amapá state is remarkable for the fast and continuous changes of its morphology and drainage network in the coastal plain. Several natural and anthropogenic factors are responsible for these changes and for the current geomorphological configuration in the region which includes changes in the ground level conditioned by sea-level changes and tectonic processes (Silveira, 1998), interannual and seasonal climatic variability which influences river floodings (Santos, 2006), tides and tidal bore (Santos et al., 2005), and cattle activities (Santos & Figueiredo, 2003). In the Araguari River–Amazon River Mouth sector, several changes have been reported related to channel siltation and changes in the drainage courses, the opening of new water courses, and the creation and closing of lakes (Silveira et al., 2002; Santana & Silveira, 2005; Santos, 2006; Santos et al., 2016b; Jardim et al., 2018).

Currently, the most striking changes are related to the closing of the Araguari River mouth (Santos et al., 2016b), a process documented since the 1980s (Santos, 2006). Extensive land use for cattle-raising activities has increased in the last 30 years in this area, resulting in several artificial channels being opened by local farmers or created by water buffaloes (Santos et al., 2003). The Araguari River mouth is completely blocked today and has been colonized by vegetation (VFS, pers. obs.). Since the establishment of this new connection between the Araguari and Amazon Rivers by the Urucurituba Channel, the width of the latter has increased (Rosario et al., 2017); and in June 2014, the depth was 34 m in some stretches (Santos, 2017). Because of these changes, the upstream waters of the Araguari River are more influenced by the white waters of the Amazon River (Rosario et al., 2017) than in the past. All these changes in the landscape, and consequently in the hydrographic network, affect dolphin distribution.

Discussion

The information compiled herein has significantly expanded what is known about the distribution of Amazonian river dolphins of the genera *Inia* and *Sotalia* in the State of Amapá. It has raised questions regarding the impact of anthropogenic development on the river dolphin populations in the northern part of their distribution. It has also opened up opportunities for collaboration between local researchers, private energy companies, and protected area managers to conduct further research to learn more about the fine-scale distribution of each of these dolphin species.

Amapá is considered the new economic frontier of the Amazon, notably owing this moniker to agricultural expansion, installation of dams, and the potential extraction of oil and natural gas. These and other activities, such as extensive buffalo ranching and gold mining, which have been occurring since the 19th century in the state, negatively affect the environment and impair aquatic habitats essential to aquatic mammals (Lima et al., 2015).

The growing investment in hydroelectric projects in the Amazon is one of the greatest threats to aquatic mammal species such as river dolphins (Reeves & Leatherwood, 1994; Gujja & Hunziker, 2000; Instituto Brasileiro do Meio Ambiente [IBAMA], 2001; Paschoalini et al., 2020). These structures could degrade or even eliminate specific habitats such as oxbow lakes, quantitatively and qualitatively modify food resources, restrict daily and seasonal movements, fragment populations, and consequently lead to genetic isolation (Reeves & Leatherwood, 1994; Smith & Reeves, 2000; Reeves et al., 2003; McAllister et al., unpub. data). Although the records indicate that the establishment of the Ferreira Gomes Dam may have influenced habitat use by dolphins in the region, that project does not seem to have caused isolation or fragmentation of populations. Similarly, the Santo Antônio do Jari Dam may not have caused isolation/fragmentation of river dolphin populations. Because our quarterly sampling efforts over 6 years (2012 to 2018) of monitoring in the Santo Antônio do Jari area returned no tucuxi sightings, it is possible that a previous record was a misidentification (Amazon River dolphin juveniles are similar in size and coloration to tucuxis) by less experienced observers. However, because the species occurs in the lower Jari, and no physical barrier exists between that river's mouth in the Amazon River to the Santo Antônio Falls, sporadic incursions of tucuxis in this part of the river would not be impossible.

The discovery of gold in the last quarter of the 19th century promoted the settlement of Amapá and has continued as an important activity in this region (Goix et al., 2019). Lourenço's is the oldest gold panning site with uninterrupted operation (Chagas, 2019). Waste from the extraction of this ore is the main cause of water and aquatic biota contamination in the Amazon (Lima et al., 2000, 2015; Nevado et al., 2010; Venturieri et al., 2017) because high concentrations of mercury are used in the gold separation process. Aquatic carnivorous mammals (i.e., river dolphins and otters) are

directly affected by the accumulation of large concentrations of pollutants because they occupy the highest level of the food web (Siciliano et al., 2005; Bossart, 2006). Mercury can affect the health of aquatic mammals by triggering neurological disorders, endocrine changes, decreased reproductive rate, neoplasms, developmental disorders, immunosuppression, and even death (O'Hara & O'Shea, 2001; Das et al., 2003).

Considering that the river basins inventoried by Lima et al. (2015) and Venturieri et al. (2017) are the most relevant to the fishery sector in Amapá, and considering the level of mercury contamination, especially of the ichthyofauna, the conservation of river dolphins in Amapá is of great concern. The high degree of contamination in the Cassiporé River basin could explain the low density of dolphins in the region because heavy metals tend to negatively influence reproductive rate (Hacon et al., 2020). To confirm this hypothesis, research at the subcellular level needs to be conducted to document impacts of heavy metals on river dolphins in this region. It is suggested that the Amazon River dolphins in the Cassiporé River occur in low density and that they may be isolated from other *Inia* populations in Amapá. This becomes even more concerning considering the high levels of metals (such as cadmium, chromium, copper, lead, zinc, and mercury) in fish and in the river water itself (Lima et al., 2015).

Bycatch by fishermen is responsible for the current decline of populations of various species of aquatic mammals (Read et al., 2006; Reeves et al., 2013; Food and Agriculture Organization of the United Nations [FAO], 2021), especially in coastal habitats such as those in Amapá. Negative interactions between cetaceans and fishing activities are frequent along the Brazilian coast and river systems (Secchi, 2012; da Silva et al., 2018; Secchi et al., 2018), including the northern coast of Brazil, but the magnitude of the impact of these interactions remains unknown. Information from Amapá suggests that bycatch occurs in the region and has the potential to negatively impact populations of *Sotalia* and *Inia*. The World Wildlife Fund (WWF) is currently conducting a Brazilian Amazon-wide survey on bycatch of river dolphins, which should be expanded to the whole regional range of the species. There is a need for a government-monitoring program for fishing, and for surveillance and law enforcement efforts towards fishing-related mortality of dolphins. Any intentional harassment to cetaceans is forbidden by Law Nbr 7.643 of 18 December 1987; however, there is no specific regulation against bycatch. These actions have been highlighted in the Brazilian National Action Plan for Amazonian Aquatic Mammals (Instituto Chico Mendes de Conservação da Biodiversidade [ICMBio], 2019), the South American River Dolphin Initiative 2020-2030 (WWF, 2020), and the CMP Nomination Template of a Conservation Management Plan for Amazon, Orinoco, and Tocantins–Araguaia river dolphins (*I. geoffrensis*, *I. boliviensis*, *I. araguaiaensis*, and *S. fluviatilis*) (The Governments of Colombia, Brazil, Ecuador, and Peru, 2020).

Four protected areas (Cabo Orange National Park, Piratuba Lake Biological Reserve, Maracá-Jipioca Ecological Station, and Parazinho Biological Reserve) in Amapá comprise 75% of the state's coastline where the fishing ban extends up to 10 km offshore (Silva & Dias, 2010). However, there are numerous examples of incidental or intentional death of cetaceans in this region because of fishing interactions. Because of a video by Globo Television Network showing incidental captures of Guiana dolphins on the coast of Amapá, the Prosecutor's Office stipulated a deadline for the Ministry of the Environment, IBAMA, and ICMBio to regulate the activity. The Gillnet Technical Working Group suggested exclusion areas for fishing in the North Cape and at the mouth of the Amazon River, but all discussions stalled when the management of fishery resources was transferred to the Ministry of Fisheries and Aquaculture. Therefore, conservation of both Guiana dolphins and fish stocks is still a concern for Amapá because of the lack of gillnet fishing management in the region (Souza, 2012).

Changes to the Amapá coastal plain have resulted from both natural and anthropogenic factors. Natural factors include those related to the Amazon River dispersal system, climate, and tides. Anthropogenic factors include extensive livestock farming, which has had one of the greatest impacts because of the physical modification of landscapes in areas such as the Amapá coastal plain (Santos & Figueiredo, 2002). To the best of our knowledge, no dolphins were entrapped with the closing of the old mouth of the Araguari River because of the depth of the new stretch of the river mouth. The opening of the new drainage canal allowed the connectivity of the Araguari basin (previously draining directly into the Atlantic Ocean) with the Amazon basin, and, consequently, the free transit between two previously and potentially isolated populations of dolphins.

The influence of the Amazon River extends far beyond the river's mouth, affecting the atmospheric, oceanographic, and geomorphological dynamics of the continental shelf, coastal zone, and mangrove ecosystems (Artigas et al., 2003; Coles et al., 2013). It also promotes connectivity between organisms in different basins (Vilaça et al., 2019). From February to May, the discharge of the Amazon forms a plume of low salinity water that extends offshore and northwesterly because of the Northern

Brazil Current (Müller-Karger et al., 1988) along the Brazilian northern continental shelf from 1° S to 5° N. This plume functions as a large ecological continuum of estuarine habitat, extending from the mouth of the Amazon River to beyond the Guianas (Vilaça et al., 2019). The presence of an Amazonian manatee specimen in the French Guiana coastal freshwater system was an extraordinary finding, which hints at the possible role the Amazon plume plays in connecting habitats (Vilaça et al., 2019) and supports the idea of a marine connection of hundreds of kilometers between the Cassiporé River system and the Amazon River and a possible explanation for the extension of *Inia* distribution. Thus, the Amazon River dolphin population in the Cassiporé River could represent a population isolated from others found in the Amazon basin. In the future, this population may be considered a distinct group (Funk et al., 2012), requiring further studies. This supports the importance of intensifying studies in the Cassiporé region to understand how this population adapts to variations in salinity and elucidating its ecological–genetic–evolutionary relationships. New capture efforts should be carried out to obtain biological and genetic data from individuals of that population.

Conservation of aquatic mammals is especially important in Amapá since it is considered a conservation priority area by the Brazilian Ministry of Environment (IBAMA, 2001; Ministério do Meio Ambiente [Ministry of the Environment; MMA], 2002). The vast area assigned protected status in Amapá as indigenous lands (Silva, 2007) and conservation units further increases the possibility of biodiversity conservation. This situation is favorable to the maintenance of healthy dolphin populations at the limit of their distribution in the northeastern Amazon.

We have documented a geographic range expansion of *Inia* into the Amazon River North Channel, the mouth of the Amazon, and other basins that currently flow or did flow into the North Atlantic Ocean, and possible expansion along the Guianas coast. The information presented herein suggests that the currently accepted distribution/geographic range of *Inia* and *Sotalia* in Brazil should be updated to be more expansive, and it highlights the potential of Amapá as an important area for new research and conservation efforts for Amazonian river dolphins. It is paramount to determine and classify the species of *Inia* that occur in the Cassiporé River basin potentially isolated from Amazonian populations and to clarify the range of both species of *Sotalia* in Amapá. The current and pressing threats of incidental and intentional mortality related to fishing activities and expansion of hydroelectric projects demand urgent research and conservation initiatives.

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