Ecology and Conservation of River dolphins in Peru

Submitted by **Elizabeth Campbell**

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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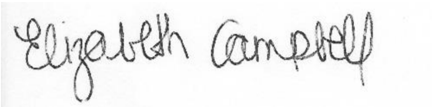

Elizabeth Campbell

Amazon River dolphin in the Pacaya Samiria National Reserve, Loreto Peru during the 2018 field season

Abstract

Freshwater cetaceans are seven highly threatened species with restricted ranges that inhabit rivers in close proximity to human populations. Over the past two decades, it has become increasingly clear that the limited resources to monitor population trends and existing knowledge gaps have hampered the design of effective conservation actions, with one species of river cetacean, the baiji (*Lipotes vexillifer*), being declared extinct. In this dissertation, I review the current state of knowledge on river cetaceans and provide new insights into the ecology and distribution of two South American freshwater dolphins, the boto or Amazon River dolphin (*Inia geoffrensis*) and the tucuxi (*Sotalia fluviatilis*). In **Chapter 1** I summarise what is currently known regarding their taxonomy, distribution, and ecology. **Chapter 2** reviews the current global conservation status of river cetaceans through a combination of expert elicitation and a synthesis of literature on threats and management. I also identify knowledge gaps and use this data to inform subsequent chapters. To improve the management of these species, I recommend future conservation efforts that build local capacity in each range country, strive for regional cooperation, and increase knowledge and public awareness. In **Chapter 3**, I interview fishers from the Peruvian Amazon to better understand their perceptions and interactions with the Amazon River dolphin and the tucuxi. I report perception of competition and negative perceptions, the use of Amazon River dolphins as bait for the piracatinga catfish fishery, and bycatch of both species in purse seines and gillnets. The results allow prioritisation of which ports should be monitored in order to reduce bycatch and direct take. In **Chapter 4**, I use satellite transmitters to identify overlap between monitored Amazon River dolphins and key threats in their range. All dolphin home ranges overlap with areas of small-scale fishery catch. Existing dams are relatively far away from dolphin populations, but proposed dams are less than 200 kilometres upstream. Monitored animals are close to a proposed hydroway, which will result in an increase in vessel traffic and recurrent dredging. In **Chapter 5**, I estimate the density of both species in a previously unexplored

area of the western Amazon of Peru while also testing the application of environmental-DNA (eDNA) for validating species presence. Sampling for eDNA is successful at detecting both species at 68% of the sampled locations. I discuss potential applications of this method for addressing knowledge gaps. In **Chapter 6**, I summarise the significance of the findings of my dissertation and suggest what should be done in the future to better conserve river dolphins. Using a variety of methods, including questionnaires, satellite transmitters, distance sampling, and eDNA, this dissertation provides baseline data for river dolphins in Peru. I propose that for the sustainability of their populations in Peru, research should concentrate on tracking population trends and estimating human-caused mortality. Participation of local communities in key conservation actions, such as the design and implementation of protected areas, research, and law enforcement, would increase the likelihood of conservation interventions being successful.

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Author's declaration

All chapters presented in this thesis were written by Elizabeth Campbell, under the supervision of Brendan J. Godley, Ruth H. Thurstan, Jeffrey C. Mangel, Joanna Alfaro-Shigueto, David March and Jose Luis Mena.

Fieldwork was carried out under the coordination of the Peruvian NGO ProDelphinus. Numerous staff of ProDelphinus contributed to the collection of data. Fieldwork was approved through the University of Exeter's ethics review board and the appropriate Peru government permit. All pictures presented were taken by Mariela Pajuelo and Sebastian Castaneda (Chapter 5).

Chapter 2: Challenges and priorities for river cetacean conservation (Published in *Endangered Species Research*)

Elizabeth Campbell, Joanna Alfaro-Shigueto, Enzo Aliaga-Rossel, Isabel Beasley, Yurasi Briceño, Susana Caballero, Vera M. F. da Silva, Cédric Gilleman, Waleska Gravena, Ellen Hines, Mohd Shahnawaz Khan, Uzma Khan, Danielle Kreb, Jeffrey C. Mangel, Miriam Marmontel, Zhigang Mei, Vanessa J. Mintzer, Federico Mosquera – Guerra, Marcelo Oliveira-da-Costa, Mariana Paschoalini, Shambhu Paudel, Ravindra Kumar Sinha, Brian D. Smith, Samuel T. Turvey, Victor Utreras, Paul André Van Damme, Ding Wang, Tara Sayuri Whitty, Ruth H. Thurstan, Brendan J. Godley

E.C., R.H.T., and B.J.G designed and led the study. E.C. led the literature review and questionnaire data analysis. All authors interpreted data and contributed to writing the manuscript and gave final approval for publication.

Chapter 3: Coexisting in the Peruvian Amazon: Interactions between fisheries and river dolphins (Published in *Journal for Nature Conservation*)

Elizabeth Campbell, Jeffrey C. Mangel, Joanna Alfaro-Shigueto, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley

E.C., J.C.M., and J.A.S. designed and performed the study. E.C. collated the data. All authors interpreted data and contributed to editing the manuscript and gave final approval for publication.

Chapter 4: Satellite-monitored movements of the Amazon River dolphin (Submitted to *Oryx*)

Elizabeth Campbell, Jeffrey C. Mangel, Joanna Alfaro-Shigueto, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley, David March

E.C. and D.M. designed and executed the analysis. E.C., J.C.M., J.L.M, J.A.S. deployed satellite transmitters. All authors interpreted data and contributed to writing the manuscript and gave final approval for publication.

Chapter 5: Exploring the Potential Use of Environmental DNA (E-DNA) for Amazon Aquatic Mammals (Prepared for submission to *Perspectives in Ecology and Conservation*)

Elizabeth Campbell, Joanna Alfaro-Shigueto, Jeffrey C. Mangel, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley

All authors interpreted data and contributed to writing the manuscript and gave final approval for publication.

Chapter 1. General Introduction

1. Freshwater cetaceans of the world

Freshwater dolphins and porpoises are among the world's least known and most endangered cetaceans (Smith & Smith, 1998) although work on the group around the world has increased in recent years (Campbell et al., 2022, Chapter 2). Globally, it is considered that there are seven extant species of river dolphins. However, the number of recognised species and their taxonomic composition is continually under review (Society for Marine Mammalogy, 2021). Previously, all obligatory river dolphins (i.e., exclusive to freshwater habitats) were grouped into one Superfamily, the Platanistoidea, owing to their similar habitat and visual appearance. Since then, genetic investigations have conclusively demonstrated that each species belongs to their own family (Cassens et al., 2000). It is currently thought that multiple distinct marine cetacean ancestors colonised rivers at different times and in different places (Hamilton et al., 2001). Five of the river cetacean species occur in Asia. The other two species are found in the Amazon, Araguaia/Tocantins, and Orinoco River basins of South America.

1.1 Asian River Cetaceans

The Yangtze finless porpoise (*Neophocoena asiaeorientalis asiaeorientalis)* is the only freshwater porpoise and is endemic to the Yangtze River, Poyang and Dongting lakes in China (Wang et al., 2013). It shared a sympatric relationship with the Yangtze River dolphin, or baiji (*Lipotes vellixefer*), which was declared functionally extinct in 2007 (Turvey et al., 2007).

The Indus (*Platanista minor*) and Ganges River dolphins (*Platanista gangetica*) are two species that are distributed only in the freshwater systems of the Indian subcontinent (Braulik et al., 2021). The Ganges River dolphin can be found in India, Bangladesh and Nepal occurring in the Ganges, Brahmaputra and Karnaphuli-Sangu River systems (Bashir et al., 2012). The

Indus River dolphin has a more restricted range, occurring only in Pakistan and India's Indus River system (Braulik, 2006).

The Irrawaddy dolphin (*Orcaella brevirostris*) is a freshwater cetacean that lives in both fresh and marine environments. Freshwater subpopulations can be found in the Ayeyarwady River, Mahakam River and the Mekong River of Myanmar, Indonesia and Cambodia, as well as Songkhla Lake in Thailand and Chilka Lake in India (Smith et al., 2007).

1.2 South American river dolphins

The Iniidae family is composed of one genus; however, the number of species and subspecies is still under scientific debate (Society for Marine Mammalogy, 2021). These species are known as “bufeo colorado” in Colombia, Ecuador, and Peru; “toninha” in Venezuela and “boto” in Brazil. Their international common names are “boto” or Amazon River dolphin. Two subspecies are recognised by the Society of Marine Mammals: *I.geoffrensis geoffrensis, and I.geoffrensis bolivensis* (Society for Marine Mammalogy 2021). The latter has been suggested as a separate species but is not yet accepted, at least until more evidence is provided (Banguera-Hinestroza et al., 2002; Ruiz-Garcia et al., 2008). In 2015, another species was proposed, the Araguaian river dolphin (*Inia araguaiaensis)* (Hrbek et al., 2014) restricted to the Madeira rapids in Bolivia and Brazil (Paschoalini et al., 2020). However, due to the small number of samples and limited geographic range of these samples the scientific community has concerns over the species level designation.

The tucuxi is the second delphinid genus found in South America (*Sotalia fluviatilis*). The Guiana dolphin (*Sotalia guianensis*), a related dolphin found in coastal and estuarine environments, was previously grouped with the tucuxi but is now recognised as a distinct species (Caballero et al., 2007). Populations of the Guiana dolphin have recently been described and genetically confirmed in freshwater ecosystems of Venezuela's Lake Maracaibo and Orinoco rivers (Briceño et al., 2021; Caballero et al., 2017).

These populations are being closely monitored to identify possible hybridisation and adaptations to freshwater environments (Dos Santos et al., 2018).

1.2.1 Distribution

The Amazon River dolphin species have a wide geographic range and can be found along the entire Amazon River of Brazil, Peru, Colombia, Ecuador, and Bolivia, starting at the headwaters in the Ucayali and Marañon Rivers in Peru to the mouth near Belém, Brazil (Chapter 2, Fig.1; Gomez-Salazar, Trujillo, Portocarrero-Aya, et al., 2012). They are also present across the Orinoco River basin of Venezuela and Colombia, except for waters north of the Pará falls. These dolphins live in various aquatic habitats, such as major rivers, smaller tributaries, and lakes (Martin & da Silva, 2004). Abundance and density vary significantly by season and among rivers (Paschoalini et al., 2021). During the dry season, Amazon River dolphins are concentrated in the main channels of the rivers, whereas during the high-water season they disperse into the flooded forests and river floodplains (Martin et al., 2004).

The tucuxi also occurs in the main tributaries of the Amazon River of Brazil, Colombia, Ecuador, and Peru (Gomez-Salazar, Trujillo, Portocarrero-Aya, et al., 2012). It does not occur in Bolivia and its presence in the Orinoco River basin is controversial (Caballero et al., 2017; Gomez-Salazar et al., 2010). Seasonal river level fluctuations influence its distribution, with channels and lakes occupied during rising and high water but avoided during low water. Unlike Amazon River dolphins, tucuxis do not go into the flooded forests but they do share a preference for areas with reduced currents (Gomez-Salazar et al., 2010).

1.2.2 Behaviour

Amazon River dolphins are generally solitary, cryptic animals that are usually seen as single animals or in groups of up to four individuals (Pavanato et al., 2019). Although the majority of groups of two are composed of mother-calf pairs, mixed groups and groups of males have also been observed (da Silva 2003). Large loose aggregations can be seen at confluences due to large concentrations of fish, or for resting and social purposes (Gomez-Salazar, Trujillo, & Whitehead, 2012).

Tucuxis, on the other hand, are more social and are more frequently observed in cohesive groups engaging in synchronised activities (Gomez-Salazar, Trujillo, & Whitehead, 2012). They perform full leaps, fluke-ups, spy-hopping, and surface rolling, among other aerial behaviours. These groups typically consist of one to six individuals, but larger groups of up to twenty individuals have been documented (Faustino & Silva, 2006).

1.2.3. Life history

Male Amazon River dolphins reach sexual maturity at about 200 cm in length. In females, sexual maturity occurs between 180–200 cm in length (Martin & da Silva, 2018). Age at first parturition is thought to be approximately nine years old. Reproductive events are seasonal, and the mating season coincides with low water levels, between September and November (da Silva, 2003; Martin & da Silva, 2018). Gestation time has been estimated at 11 months, and the calving season is long, with most births occurring at the peak of the river's flood level (Martin & da Silva, 2018). Calves are about 80 cm at birth. Lactation lasts for more than one year, possibly up to six years, and the birth interval is from 2 to 7 years (Martin & da Silva, 2018). Life spans are unknown, but females have been observed pregnant at 32 years old (Martin & da Silva, 2018).

Sexual maturity in the tucuxi dolphin is estimated to be at 140 cm in males and 132-137 cm in females (Rosas et al., 2010). Tucuxi calving occurs during low water season, after a gestation time of 11 months, with calves at birth measuring from 71 to 83 cm (da Silva & Best, 1996). The life span has been estimated as approximately 35 years for the tucuxi (da Silva, 2003).

1.3 Conservation Status

All river cetaceans are considered endangered by the IUCN and suffer similar anthropogenic pressures (Campbell et al., 2022, Chapter 2). Hydroelectric dams have caused changes to hydrological regimes, fish distributions to shift and created physical barriers to movement, thus degrading and fragmenting cetacean habitat (Araújo & Wang, 2015; Brownell Jr. et al., 2017; Choudhary et al., 2012). Other human activities, such as deforestation, mining, and population growth, have also had negative impacts on their habitats (A. M. Smith & Smith, 1998). Interaction with fisheries are resulting in population declines from targeted killing, especially of the Amazon River dolphin and the Ganges River dolphin, to be used as bait in fisheries (Brum et al., 2015; Kolipakam et al., 2020). Additionally, there are reports of bycatch in all species (Dewhurst-Richman et al., 2019; Marmontel et al., 2021). Although data on the impact of climate change on these species is limited, predictions show varying degrees of changes in water availability (e.g., more water extraction for human use, less precipitation), which could lead to profound hydrographic changes (Smith et al., 2009). Other threats include vessel strikes, ineffective tourism management, and traditional uses (Smith & Smith, 1998).

2. Thesis Overview

This thesis '***'River dolphin distribution, conservation, and fishery interactions in Peru'*** investigates the ecology and conservation of aquatic mammals of the Amazon. Through five chapters, written as independent units of study, I identify and assess the use of dolphins as bait in the Amazon, determine critical areas for conservation effort, assess their distribution and movement and demonstrate spatial overlap with key threats in non-protected and protected areas.

In **Chapter 2 '*Global review: Challenges and priorities for river cetacean conservation'*,** I provide a global summary on the conservation status of currently recognised river cetaceans; including a literature review and a synthesis of expert opinions from researchers and conservation practitioners worldwide. Even though threats to different species have been described, no recent global analyses have been conducted to identify common problems and solutions. I summarise the existing literature on the effect of dams, climate change, fishery interactions and secondary threats such as poorly managed tourism, and traditional use. Surveyed experts were also asked to consider what knowledge gaps and challenges impede conservation efforts and what could be done to aid them. We found that river cetaceans are mainly impacted by dams and interactions with fisheries. Conservation efforts globally are hampered by inconsistent government cooperation, insufficient funds, competition among researchers, and limited personnel. To improve the effectiveness of conservation efforts, experts agreed that implemented projects should be inclusive with communities, that there should be continued efforts to build local capacity at different levels (i.e., rangers, conservation practitioners, researchers) and that cetacean experts should work at a local and regional scale.

In **Chapter 3 '*Coexisting in the Peruvian Amazon: Interactions between fisheries and river dolphins*'**, by using rapid assessment questionnaires, I identified threats to river dolphins in Peru and prioritised areas for further research and conservation. Fishers reported bycatch in all ports surveyed (Campbell et al., 2020). Furthermore, the use of river dolphins as bait has been occurring since at least 2010 and is more common in rural ports. This chapter ties into the previous chapter's identification of fisheries interactions as a priority threat, as well as mapping and quantifying human-induced mortality as one of the priority knowledge gaps. Similar future surveys could be used to monitor river dolphin population status in priority areas, improve the estimation of bycatch and monitor the trajectory of direct take of dolphins in the Peruvian Amazon.

As identified in the Chapter 2, limited ecological knowledge currently precludes effective conservation measures; therefore, I focus on the Amazon River dolphin and tucuxi to fill this knowledge gap. In **Chapter 4 '*Satellite-***

***monitored movements of the Amazon River dolphin*,'** I describe the tracking of river dolphins in protected and non-protected areas. I found that movement patterns of dolphins were quite variable, with activity areas of 20 km^2 up to 106 km^2. Even in protected areas, I found that all dolphins overlapped with fishery efforts, and were close to areas assigned as having high fishery efforts. I measured their overlap with other key threats like dredging sites and proposed dams and found that all monitored dolphins were in close proximity to proposed areas for future infrastructure.

To further investigate the distribution of river dolphins I use environmental DNA (eDNA), which allows presence to be assessed through the detection of DNA produced by shed skin, defecation, and other biological processes. In **Chapter 5 '*Exploring the potential of eDNA to assess distribution of Amazon River Dolphins'***

I determine areas where river dolphin species have been identified with eDNA and compare those to the distance sampling density estimates. I estimated dolphin density in two previously unexplored areas, in the Huallaga and Maranon rivers. I found that this area has low densities for both species, with less than 1 individual per km for both species. Furthermore, eDNA was successfully discovered throughout the area, with 91% of sites demonstrating positive detections for the Amazon River dolphin and 58% of sites for tucuxi. In addition to this, the Amazon manatee (*Trichechus inunguis)* and the Neotropical otter (*Lontra longicaudis*) were detected. I will discuss future uses of eDNA with regard to knowledge gaps for these species, specifically their distribution, and how this may aid conservation efforts.

Finally, in **Chapter 6**, I synthesise and discuss my major findings, emphasising the value of combining complementary methodologies in order to gain a better understanding of river dolphin distribution and movement patterns. I propose how my findings can be applied to policy and discuss future directions for river dolphin research in South America, as well as how these can benefit future conservation planning.

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Chapter 2: Challenges and priorities for river cetacean conservation

Elizabeth Campbell, Joanna Alfaro-Shigueto, Enzo Aliaga-Rossel, Isabel Beasley, Yurasi Briceño, Susana Caballero, Vera M. F. da Silva, Cédric Gilleman, Waleska Gravena, Ellen Hines, Mohd Shahnawaz Khan, Uzma Khan, Danielle Kreb, Jeffrey C. Mangel, Miriam Marmontel, Zhigang Mei, Vanessa J. Mintzer, Federico Mosquera – Guerra, Marcelo Oliveira-da-Costa, Mariana Paschoalini Frias, Shambhu Paudel, Ravindra Kumar Sinha, Brian D. Smith, Samuel T. Turvey, Victor Utreras, Paul André Van Damme, Ding Wang, Tara Sayuri Whitty, Ruth H. Thurstan, Brendan J. Godley

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Abstract

River cetaceans are particularly vulnerable to anthropogenic impacts due to their constrained ranges in freshwater systems of China, South Asia, and South America. We undertook an exhaustive review of 280 peer-reviewed papers and grey literature reports (1998-2020) to examine the current status of knowledge regarding these cetaceans and their conservation. We aimed to better understand the scale of threats they face, and to identify and propose priority future efforts to better conserve these species. We found that the species have been studied with varying frequency and that most of the research on threats has focused on habitat degradation and fragmentation (43%, mainly driven by dams and extractive activities such as sand mining and deforestation) and fishery interactions (39%, in the form of bycatch and direct take). These threats occur across all species, but more information is needed, primarily on quantifying the population impacts as a basis for designing mitigation measures. Other threats identified include pollution, vessel collisions, traditional use, and poorly managed tourism. Emerging methods such as environmental DNA, and unmanned aerial vehicles are described for studying these species. Promising conservation interventions include cetacean-specific protected areas, natural *ex-situ* protection, community-led conservation, and education programmes. However, transnational political will is required for a step-change towards broad-scale protection in freshwater environments. In addition, we propose increasing capacity building, developing management plans, working closely with fishing communities, enhancing public awareness, expanding regional collaborations, and diversifying funding.

1. Introduction

River cetaceans are a polyphyletic group, with similar habitats and shared sensory and morphological characteristics (Fig. 1 and Table 1). They live exclusively in freshwater habitats in Asia and South America. The group includes the extinct baiji (*Lipotes vexillifer)* (Turvey et al. 2007, Smith et al. 2017), the Yangtze finless porpoise (*Neophocoena asiaeorientalis asiaeorientalis)*, the Irrawaddy dolphin (*Orcaella brevirostris)*, the Ganges River dolphin (*Platanista gangetica),* the Indus River dolphin (*Platanista minor)* (Braulik et al. 2021), the tucuxi (*Sotalia fluviatilis)* (Caballero et al. 2007), the Amazon River dolphin (*Inia geoffrensis geoffrensis)* and the Bolivian river dolphin (*I. g. boliviensis)* (Ruiz -Garcia et al 2008). Population numbers for the Asian species are in the low thousands (See Table 1 for details) and no accurate estimates are available for South America river cetaceans.

River cetaceans are among the world's most threatened aquatic mammal groups. Their restricted ranges, which overlap with increasing human population needs, make them particularly vulnerable to anthropogenic threats (Reeves & Martin 2009, Raby et al. 2011, Braulik et al. 2015, Brum et al. 2021). River cetaceans depend on waterways often located within intensively human-modified landscapes (Castello et al. 2013, Albert et al. 2020). These waterways are used to extract resources for food, irrigation, construction, and industrial activities; modified to generate energy, reduce flood risk, and improve navigation; and contaminated with discharge from agriculture, industry, mining, and human habitations. These activities result in habitat loss and degradation that effectively reduce distribution ranges for river cetacean species and increase human-dolphin interactions (Braulik et al. 2014, da Silva et al. 2018, 2020, Aliaga-Rossel & Escobar-WW 2020).

River cetaceans hold ecological, cultural, and economic value in the systems they inhabit. Ecologically, they play a vital role at the top of freshwater food chains (Behera 1995) and have been used to indicate the status of other threatened sympatric species (Turvey et al. 2012) and overall habitat health (Smith & Reeves 2012, Gomez-Salazar et al. 2012c). Culturally, they are often central to local myths and legends (Cravalho 1999, Schelle 2010, da Silva et al. 2017). Furthermore, they can provide livelihoods and economic value as tourist attractions (Romagnoli 2009, Beasley et al. 2010), and serve as flagship species for promoting the conservation of rivers (Burgener et al. 2012).

Most reviews on river cetaceans have focused on a single species (Smith et al. 2001, Wang 2009, Waqas et al. 2012, Sinha & Kannan 2014, Braulik et al. 2015) or on a specific geographic area (Zhao et al. 2011, Brum et al. 2021). The most recent overarching review, including species from Asia and South America, was completed over 20 years ago (Smith & Smith 1998). Although there are differences in the resources, cultures, and politics among countries where river cetaceans occur, a comprehensive approach can identify broad trends and compare threats and potential solutions. Therefore, this review aims to 1) provide an updated overview of current threats to all river cetaceans, 2) identify research gaps, novel methodologies, and conservation strategies, and 3) recommend potential measures for improved conservation.

2. Methods

2.1 Literature search

To compile documentation of threats and management of river cetaceans, we conducted an exhaustive literature search using the online search engines Google Scholar and Web of Science core collection. Keywords included the common and species-level scientific names of all the focal species (according to the Society for Marine Mammalogy's Committee on Taxonomy,2020), and 'threat', 'conservation', or 'management'. For example, we searched for "Inia geoffrensis AND threat", and for "Amazon River dolphin AND threat". We searched each species with 'conservation' and with 'management', so each species had a total of 6 keyword combinations. We consulted material published between January 1, 1998, and December 31, 2020 (extracted March 3, 2019, and updated March 16, 2021), reading in full all 626 Web of Science results and the first 500 publications listed in Google Scholar. We included scientific articles, published books, and available "grey" literature that directly mentioned threats, conservation, or management, or that proposed future conservation efforts (n =240, Table S1). These publications were supplemented by an additional 40 publications identified by co-authors (Table S2). The literature gathered through the search and co-author contributions included sources in English, Spanish, and Portuguese.

From the 280 identified source materials, the following information was compiled: (1) the country (ies) where the research took place, (2) the year the study was published, (3) the species under threat, (4) the type of threat, (5) the aims of the research, (6) the methods used, and (7) key findings. We categorised threats (Table 2) and assigned relevant publications to at least one threat category. We created an additional category for research that tested new methods applied to conservation efforts.

2.2 Expert elicitation

A total of 41 experts were invited to participate in this review, and 29 accepted (Affiliations: 6 Academia and NGO-Private, 11 NGO-Private only, 9 Academia only, and 4 Government). Because we aimed to include at least two authors per country per species with diversity in nationality, gender, and seniority, we determined whom to contact by their research location and their recent publications. We asked correspondents who agreed to participate to provide additional, relevant literature we had not identified, and to complete a questionnaire about the river cetacean species in their region(s) of work. The questionnaire included four sections: (1) most significant threats, (2) information gaps, (3) challenges, and (4) opportunities for conservation. Correspondents were allowed to list, in order of importance, a maximum of five themes per section. To assess how threats were ranked, we calculated descriptive statistics for broad threats (e.g., fisheries) and sub-threats (secondary, more specific threats, e.g., bycatch). For the other sections (knowledge gaps, challenges, and opportunities), we scaled ranks from 100 (highest priority) to 20 (lowest priority) and calculated averages to synthesise expert opinion across the whole species group and by species. For ties, a median value of two ranks was used.

2.3 Presentation of results

The following two sections of the review highlight the major results of the literature search (Overview of Threats and Moving Conservation Forward), and the succeeding three sections compile the primary themes that emerged from the expert elicitation (Knowledge Gaps, Primary Challenges, and Primary Opportunities for Conservation). Finally, we present our conclusions and recommendations garnered from the combined approach.

3.Overview of threats

Published research on river cetacean conservation has increased over the past decade, with an average of six papers per year from 1998-2008 and then an average of sixteen per year from 2009-2020 (Fig. 2a). By country, work in China has resulted in the most publications (n= 79), followed by Brazil (n=54) and India (n=41) (Fig. 2b). Species have been studied to varying degrees, with the most sources focused on Yangtze finless porpoise (n=60, 21% of reviewed items) and the fewest on the Indus River dolphin (n=16, 6%) (Fig. 2c).

The frequency with which a threat appears in the literature may not be the same as the importance of the threat and their impact on extinction risk, but a cross comparison with expert opinion allows us to prioritise those threats that require urgent attention. Habitat degradation was the most frequently mentioned threat in publications (n=112, 43%) followed by fisheries interactions (n=102, 39%) (Figure 3a). Sources mentioned pollution (n=24, 10%) and other human interactions (n=21, 8%) less frequently. Expert responses from the questionnaire similarly recognised habitat degradation and fisheries interactions as the most significant threats (Fig. 3b, Fig. 4 and Fig. S1). Fisheries were ranked as the primary threat most frequently (63% ranked it first, 34% ranked it second), followed by habitat degradation and loss (37% ranked it first and 46% ranked it second).

3.1 Fishery interactions

Fishery interactions are a well-recognised threat to small cetaceans worldwide (e.g., Read 2008, Brownell Jr. et al. 2019, Nelms et al. 2021), and a primary cause of river cetacean mortality (e.g., Turvey et al. 2007, Zhao et al. 2008, Kelkar & Dey 2020). Identified threats from fisheries include bycatch, targeted catch, overfishing, and electrofishing. Although we discuss these threats separately, several authors observe that they are intertwined and often indistinguishable.

3.1.1 Bycatch

Bycatch was mentioned as a threat to all river cetacean species (58 papers, 73% of authors listed bycatch in the questionnaire) (Smith & Hobbs 2002, Mansur et al. 2008, Trujillo et al. 2010, Raby et al. 2011, Iriarte & Marmontel 2014), and they were a principal reason behind the extinction of the baiji (Turvey et al. 2007). Gillnets was the métiers that appeared most frequently in the literature, involving all species (Baird & Beasley 2005, Kreb & Budiono 2005, Mintzer et al. 2015, Khanal et al. 2016, Brownell Jr. et al. 2019, Kelkar & Dey 2020). Set bagnets and seine nets were also identified as risks (Karnaphuli-Sangu River: Dewhurst-Richman et al. 2019, Amazon and Ucayali Rivers: Campbell et al. 2020). On the Yangtze River, illegal rolling hooks was also a common cause of mortality, accounting for close to almost half of the deaths of finless porpoises from 2008 to 2013 (Mei et al. 2019; Turvey et al 2013) and of baijis in the 1980s to late 1990s (Zhou et al. 1998, Turvey et al. 2007).

Most of the surveyed papers identified bycatch as a significant, observed threat in their research areas, but few contained quantitative data. Those that did, used interviews to estimate bycatch rates for the Yangtze finless porpoise (Turvey et al. 2013), Irrawaddy dolphins in the Mahakam River (Kreb et al. 2010, Whitty 2014), and Ganges River dolphin population in Karnaphuli-Sangu River complex of Bangladesh (Dewhurst-Richman et al. 2019). The latter estimated annual mortality rates and found that sustainable removal limits were exceeded 3.5-fold (Dewhurst-Richman et al. 2019). In an interview survey in the Brazilian Amazon, 43% of fishermen reported entanglement of Amazon River dolphins in their nets. Seventy-four percent of these fishermen that reported entanglements used gillnets (Mintzer et al. 2015). In Peru, interviews helped identify high-risk areas for further investigation (Campbell et al. 2020). Strandings also provided data for bycatch estimations. There were 13 deaths from entanglement in fishing gear, two deaths from vessel collision, two deaths from direct killing, and nine deaths from unknown reasons between 2007 and 2013 (Mansur et al. 2014b).

Research focusing on bycatch management measures is relatively scant. Technical regulations have involved measures such as time/area closures, gear modifications/bans, and seasonal to year-round fishing bans. These measures have only been partially effective, as they depend on fisher compliance, and rigorous enforcement (Whitty 2014, Mei et al. 2019). The efficacy of bycatch reduction devices such as pingers requires investigation, as does their long-term effect on dolphin behaviour (Campbell et al. 2020). Preliminary reports are encouraging. One test in the Peruvian Pacaya-Samiria Reserve found reduced dolphin detections at the pinger site than at the control site (Campbell 2020). A test of the effects of pingers on Ganges River dolphins indicated subtle displacement in terms of the mean surfacing distance from the pinger but not in the minimum distance of approach (Smith 2013). Additionally, in the Mahakam River, fine-tuned pingers for Irrawaddy dolphins showed dolphins actively avoiding nets with pingers (Kreb et al. 2021).

3.1.2. Targeted killing

Targeted illegal catch of river cetaceans (mentioned in 37 publications and by 48% of the co-authors) is mostly driven by the demand for meat to use as bait in small-scale fisheries (Mintzer et al. 2018). Dolphin oil and body parts of the Ganges River dolphin are used in India and Bangladesh to attract two catfish species (*Clupisoma garua* and *Eutropiichthys vacha*) (Sinha 2002, Wakid 2009, Bashir 2010, Reece et al. 2013, Kolipakam et al. 2020). In South America, the use of Amazon River dolphin and tucuxi as bait for piracatinga catfish (*Calophysus macropterus*) is an ongoing threat (Estupiñan et al. 2003, Mintzer et al. 2018) and demand remains high (Salinas et al. 2014, Perez 2018). The use of Amazonian dolphins as bait was first recorded in Brazil in the early 2000s (Silveira & Viana 2003, Loch et al. 2009, Mintzer et al. 2013, Brum et al. 2015), and the practise has since extended to Bolivia, Colombia, Ecuador, Peru, and Venezuela (Mosquera-Guerra & Trujillo 2015, Guizada & Aliaga-Rossel 2016, Fruet et al. 2018, Escobar-WW et al. 2020, Trujillo et al. 2020b, Campbell et al. 2020). Such illegal take for use as bait was the primary cause of the halving of both South American river dolphin populations in the Mamirauá Sustainable Development Reserve (Brazil) over a period of two decades (da Silva et al. 2018a).

Legal strategies have been put in place with the aim of reducing the targeted catch of dolphins. For example, the Indian Wildlife (Protection) Act (1972) protects the Ganges River dolphin from any use without government authorisation. However, this act has been largely ineffective since *in lieu* of harpooning, fishers position nets in places where dolphins are likely to be captured, a practise referred to as "assisted incidental capture" (Sinha 2002). Temporary and permanent moratoriums on trade in piracatinga products were imposed by Brazil and Colombia (Instrução (Portaria SAP/MAPA nº 271, of 1º July 17, 2021 (Brazil), Resolución 01710 (Colombia)). However, the surveillance of large river basins is complex, especially for border areas with limited monitoring of fish commerce and transportation (Trujillo et al. 2020b). Piracatinga products are sold disguised as other species (Salinas et al. 2014, Cunha et al. 2015, da Silva et al. 2018b).

Alternative bait, another strategy to reduce the use of dolphin bait, was trialled in the Ganges (Sinha 2002) and in the Amazon (Franco et al. 2016, Beltrão et al. 2017). Unfortunately, it has not proven effective. Such programmes should be paired with long-term efforts to teach fishermen how and why to use alternative bait (Sinha 2002, Beltrão et al. 2017, Mintzer et al. 2018).

Targeted catch also includes the killing of dolphins by fishers who see them as competitors for fish resources. This almost certainly occurs with all river cetacean species to varying degrees but has been reported specifically as a threat for the Ganges (Behera et al. 2013, Dewhurst-Richman et al. 2019), Amazon, and the Bolivian River dolphins (Aliaga-Rossel 2002, Alves et al.

2009, McGuire 2010, Brum et al. 2015, Mintzer et al. 2015, Guizada & Aliaga-Rossel 2016, Campbell et al. 2020).

3.1.3. Overfishing

The potential depletion of dolphin prey due to increasing fisheries is of concern (mentioned in 12 publications and by 53% of the co-authors; Smith & Smith 1998, Wang et al. 2006, Raby et al. 2011). This threat is rarely studied by itself; rather, it is mentioned as a common consequence of the growing presence of commercial fishers using non-selective gear, and it may be a relatively minor threat when compared to directed and incidental capture.

More data are required to understand how competition with fisheries affects cetaceans, at the population level. Studies focused on resource competition estimated high levels of spatial overlap in the species and size of fish targeted by fishers and the Ganges River dolphin (Kelkar et al. 2010, Paudel et al. 2020a) but knowledge gaps remain elsewhere.

3.1.4. Electrofishing

Electrofishing occurs widely in rivers in Asia. A recent review of the impacts of the practise on freshwater cetaceans concluded that contact with an electrical current can kill or injure freshwater dolphins and porpoises (Thomas et al. 2019). However, questions remain about the exact nature and scale of the impacts. Thomas et al. (2019) mentioned that previous reports attributing mortality of baijis and finless porpoises to electrofishing are ambiguous (e.g., Zhang et al. 2003, Mei et al. 2019), since death from electrofishing is often inferred when proof of other causes (i.e., propeller wounds, external net marks) is not found.

3.2 Habitat degradation

Habitat degradation and loss in freshwater ecosystems result mainly from water infrastructure development (especially dams), climate change, and deforestation.

3.2.1. Water infrastructure projects

River cetaceans require sufficient water flow to allow movement between deep pools and refuge from high velocity currents (Smith & Reeves 2000a). Development projects have wide- ranging impacts on freshwater flow and to different degrees affect all river systems inhabited by cetaceans. These projects include dams, barrages (low gated dams that divert water), embankments, and river dredging (mentioned in 58 publications and by 80% of co-authors; Reeves et al. 2000).

Large upstream dams especially threaten the Yangtze finless porpoise, as their habitat is modified by the Three Gorges and Gezhouba dams as well as other smaller dams, regulators, and embankments in tributaries and appended lakes (López-Pujol & Ren 2009, Zhao et al. 2011, Fang et al. 2014). Although the Three Gorges Dam, completed in 2010, is upstream of the current distribution of this porpoise and to the historical distribution of the baiji, it has altered flow regimes and reduced fish spawning (Zhao et al. 2008, Wang 2009, Fang et al. 2014, Chen et al. 2017).

The Indus and Ganges River dolphins are both affected by extensive irrigation systems with at least 20 dams and 50 barrages that have reduced freshwater flow and fragmented habitats (Smith et al. 2000, Braulik et al. 2014, Sonkar & Gaurav 2020). These dams have reduced sediment transport and the availability of preferred habitats in bars, islands, counter-currents, and deep pools (Reeves et al. 1991, Smith & Reeves 2000a, Paudel et al. 2015, Karim & Bindra 2016). Barrages have been identified as the principal factor in the 80% habitat reduction observed in Indus River dolphins range (Braulik et al. 2014). Dams can also cause local extinctions. For example, the upstream disappearance of the Ganges River dolphin occurred within 6-7 years of the construction of Kaptai dam in the Karnaphuli River in Bangladesh (Smith et al. 2001), and within 12 years of the construction of Madhya Ganga Barrage (Bijnor, Uttar Pradesh, India) (Sinha et al. 2010).

Limited water means less physical habitat and warmer and slower rivers (Braulik et al. 2015), particularly during the low-water season (Smith et al. 2009a, 2010, Braulik et al. 2012, Choudhary et al. 2012, Paudel et al. 2015). In some cases, dolphins also enter irrigation canals and become isolated and trapped (Waqas et al. 2012, Aliaga-Rossel & Escobar-WW 2020). From 1992 to January 2021, 194 Indus dolphins were reported trapped in canals, 163 were successfully rescued and returned, while the remainder died (Sindh Wildlife Department & WWF-Pakistan unpublished data). Studies have identified the minimum water flow thresholds to maintain Ganges River dolphin populations and in-stream habitat availability that assists their longitudinal distribution (Paudel et al. 2020b) thus supporting water use planning and conservation.

Water infrastructure development affects Irrawaddy dolphins to a lesser degree. However, there is a strong potential for projects in the planning phase to severely impact all populations of the species (Minton et al. 2017). Dams in China's Taping River have modified the downstream water flow of the Ayeyarwady River and reduced habitat at the confluence (Smith et al. 2007). The construction of the Don Sahong Hydropower Project (International Rivers 2013), a large run-of-the-river dam, has already affected a small group of dolphins inhabiting the Lao/Cambodia transborder deep pool habitat at the far upstream extent of the Mekong River dolphin population, leading to their likely extirpation (Beasley et al. 2013, Krützen et al. 2018). The Sambor and Stung Treng dams proposed for construction across the mainstream of the Mekong River are also of significant concern (Smith et al. 2007, Brownell Jr. et al. 2017). However, plans for these dams have been temporarily suspended (Khan & Willems 2021).

Dams in South America are also fragmenting and isolating dolphin populations. To date, 175 dams are operating or under construction in the Andean-Amazon basin; at least 428 more dams are planned over the next 30 years (Forsberg et al. 2017, Latrubesse et al. 2017, Anderson et al. 2018, Almeida et al. 2020). These are likely to negatively affect the long-term viability of Amazon River dolphins and tucuxi across their range (Araújo & Wang 2015). Dams impact the Araguaia–Tocantins Basin that supports an endemic population of Amazon River dolphin (Araújo & Wang 2015) proposed as a separate species (*Inia araguaiaensis)* by Hrbek et al., (2018). Dolphin densities were 68% lower downstream of the Tucuruí dam than upstream, and dolphins shifted their habitat use when comparing subregions - downstream, reservoir, and upstream (Paschoalini et al. 2020).

3.2.2. Climate change

The impact of climate change on river cetaceans has not yet received much research attention (5 publications) and was not highly ranked in the expert questionnaires (23% of authors, Fig 3). The ecological requirements of river cetaceans are, however, linked to the entire water cycle in all its complexity, from glacial melt and rainfall patterns to sea level rise and its effects on salinity and sedimentation (Smith & Reeves 2000a). Climate change will exacerbate other ongoing threats, particularly habitat degradation associated with water infrastructure development. A warmer climate is projected to affect all cetaceans through habitat loss, a shift in prey availability, and competition with other displaced species (Simmonds & Isaac 2007, Kaschner et al. 2011). Forecast change (e.g., precipitation, Alter et al. 2010) is expected to lead to increased construction of flood control structures. Local community pressure on fisheries could also grow, perhaps potentially leading to an increase in bycatch and prey depletion (Alter et al. 2010).

Although some models predict potential increases in overall water discharge of 17% in the Ganges-Brahmaputra and 44% in the Indus River by 2050 (Palmer et al. 2008), seasonal flow regimes are also projected to change with potential increases occurring during the high-water season and declines during the dry season, which could result in the loss of river dolphin habitat (Krishnaswamy et al. 2018). This could be exacerbated by dams and, in the Ganges and Brahmaputra, by plans for major inter-basin water transfer and inland water transport projects (Kelkar 2016). Precipitation in the Mekong River catchment is expected to increase during the monsoon seasons, causing more extreme floods, and a decrease during most of the remaining part of the year (Nijssen et al. 2001) but how these changes could affect the Mekong Irrawaddy dolphin population is unknown. Overall, water availability is expected to decrease in the Amazon-Orinoco basin by 18% (Palmer et al. 2008), with the magnitude of potential impacts on river dolphins depending as much on the seasonal timing of the decline as the overall reduction in availability (Mendez et al. 2017, Mosquera-Guerra et al. 2019a). Indeed, severe seasons of drought in the Peruvian Amazon have already been related to a decrease in dolphin numbers in locations where they were previously abundant (Bodmer et al. 2018). While it is not currently a problem in the Amazon, as the region grows drier, there may be more interest in water extraction (IPCC 2007, Alter et al. 2010).

Other aspects to consider in climate change models are rising water temperature and sea-level rise. Nijssen et al. (2001) predicted that water temperature in tropical river basins, such as the Amazon and Mekong, would rise evenly throughout the year, with different models showing an increase of 1 to 4°C by 2045. The Indus River dolphin already handles an annual 30°C temperature fluctuation in its environment, possibly making it more resilient to temperature variations in climate change scenarios (Braulik et al. 2015). However, more studies are needed to understand how temperature changes will affect river cetacean populations as well as the distribution of the prey they depend on. In addition, sea-level rise will likely affect the salinity of freshwater systems (Smith et al. 2009a). This could reduce available downstream habitat for species that already have restricted ranges. It is likely that obligate river cetaceans will be more vulnerable, as facultative species can adapt to a wider range of salinity.

3.3 Pollution

Due to confined habitats, riverine cetaceans are at a higher risk from pollution than similar marine species (Reeves et al. 2000). Numerous pollutants, from noise to bioaccumulated toxins may have damaging long-term consequences for this group (Senthilkumar et al. 1999, Kershaw & Hall 2019). However, research on their impacts is limited and long-term effects remain understudied.

3.3.1. Noise

Underwater noise from vessel traffic has been shown to affect river cetaceans (mentioned in 11 publications, and by 47% of co- authors). One primary effect is masking (when noise has similar frequencies to signals of biological interest; Southall 2005), which can reduce the effectiveness of communications, possibly impact foraging and breeding, hazard avoidance (e.g., failing to detect an incoming vessel), and cause long-term physiological damage (e.g., premature ageing) (Wright et al. 2007). Li et al. (2008) found the Yangtze finless porpoise avoided boats and had higher cortisol levels in noisier areas while Ganges River dolphins doubled their acoustic activity and metabolic rate to compensate for the masking effects of high ambient noise (Dey et al. 2019).

3.3.2. PCBs, DDTs and other chemical contaminants

Chemicals can pollute rivers through direct discharge from agriculture, industry, and shipping (7 publications, 50% co-authors, Braulik et al. 2015, Zhang et al. 2020). Chemical pollutants have been identified in the tissue of stranded or bycaught individual Yangtze finless porpoises (Zhang et al. 2020), Ganges and Irrawaddy dolphins (Senthilkumar et al. 1999, Kannan et al. 2005, Yang et al. 2008) Indus (WWF-Pakistan 2011, Braulik et al. 2015) and Amazon River dolphins (Torres et al. 2007). Identified contaminants included DDT (dichlorodiphenyltrichloroethane), PCBs (polychlorinated biphenyls) along with other commonly used pesticides (Cypermethrin, Deltamethrin, and Endosulfan). The pathophysiological effects of these chemicals on river cetaceans are unknown. In other aquatic mammals, these contaminants have had various physiological effects, including suppression of the immune system, damage to the adrenal cortex, and affecting reproductive success (Reddy et al. 2001, Wright et al. 2007, Durante et al. 2016).

3.3.3. Heavy metals

Mercury pollution can come from natural deposits, mining, and other industrial processes (7 publications, 35% co-authors). Tissue samples from Yangtze finless porpoises have shown that mercury accumulation in the liver was correlated with body size and was passed to new-born calves (Dong et al. 2006, Xiong et al. 2019). Mercury concentrations were also correlated with high concentrations of selenium, which seems to be produced by the animal (Xiong et al. 2019) implying a protective function as it has been observed in coastal dolphins (Turnbull & Cowan 1998, Kehrig et al. 2016). The use of mercury in small-scale mining to amalgamate gold affects several river basins, including the Ayeyarwady (Smith & Hobbs 2002), Mahakam (Kreb & Budiono 2005), and Amazon-Orinoco (including the Arauca, Tapajós, and Iténez rivers) (Lailson-Brito Jr. et al. 2008, Roach et al. 2013, Mosquera-Guerra et al. 2019b, Barbosa et al. 2021). Preliminary studies have shown that Amazon River dolphins and tucuxis had high mercury concentrations in all analysed tissue samples (Mosquera-Guerra et al. 2019b). The effects of high mercury concentrations in river cetaceans are unknown, but in marine cetaceans it has been linked to immunosuppression (Camara-Pelliso et al. 2008, Mahfouz et al. 2014), endocrine disruption (Schaefer et al. 2011), and neurological disorders (Das et al. 2002, Wright et al.2007, López-Berenguer et al. 2020).

3.3.4. Plastic

Although Smith and Smith (1998) described plastic debris as a growing threat, there has since been limited progress in understanding risks. Recent studies have identified the presence of plastics in dolphin habitats (Schmidt et al. 2017, Li et al. 2018, Rodrigues et al. 2019, Aliaga-Rossel & Guizada 2020). One study concluded that the risk of entanglement of Ganges River dolphins from ghost nets is high (Nelms et al. 2020). Studies of marine dolphins indicate they ingest plastics directly or through trophic transfer (Williams et al. 2011, Nelms et al. 2018, Xiong et al. 2018) but this has not yet been documented for river cetaceans.

3.4 Other human interactions

Increasing human populations affect river cetaceans in multiple ways. Bashir et al. (2013) found that as human exposure increased, the local presence of Ganges River dolphins decreased. This is particularly important as the Ganges River often supports large human aggregations close to riverbanks (e.g., due to religious ceremonies) (Bashir et al. 2013). Similarly, the Indus River dolphins were more abundant in areas with low human disturbance, especially during the low water season, when habitat was limited but disturbance was high (Khan 2016). Human settlement size can also indicate overall ecological health; for example, in the Amazon-Orinoco basin, human population size is significantly correlated with habitats and water quality degradation (Gomez-Salazar et al. 2012a).

Vessel traffic brings the threat of wounding and death from both propellers and impact. This was especially true for the baiji (Turvey et al. 2007) and continues to endanger the Yangtze finless porpoise (Wang et al. 2000, Turvey et al. 2013, Dong et al. 2015, Mei et al. 2019). Boat strikes have also been reported as a threat to the Ganges River dolphin (Smith et al. 2001) and as being responsible for fatalities in the Irrawaddy dolphin population in the Mahakam River (Kreb & Rahadi 2004). River cetaceans may be more vulnerable to collisions during calving and nursing periods (Reeves et al. 2000). As dams make some rivers easier to navigate and riverine human populations increase, vessel strikes could be an increasing threat.

3.4.1. Tourism

Tourism has been demonstrated to have negative effects on dolphins (12 publications, mentioned by 8% co-authors). Tourism brings an increase in human presence, which can lead to collisions with dolphin-watching boats, increased fishing activity and fish consumption to feed visitors, and pollution. Most publications addressing tourism focused on the Amazon River dolphin in Brazil (Romagnoli 2009, Alves et al. 2011, Gravena et al. 2019) and on the Irrawaddy dolphins in the Mekong River and Chilika Lagoon, India (Beasley et al. 2010, Liza et al. 2017, D'Lima et al. 2018). Poorly managed wildlife-focused tourism affects river dolphin behaviour, especially if feeding is involved (Alves et al. 2011, Gravena et al. 2019). Many poor management practises have been highlighted, including a lack of significant economic input reaching local stakeholders, deficient health and safety infrastructure, and ineffective communication with tourists about conservation (Romagnoli 2009, Beasley et al. 2010, Alves et al. 2013). As wildlife watching is often proposed as an alternative to more traditional livelihoods (e.g., fishing, Alves et al. 2013), the communities dependent on dolphin tourism must understand the long-term benefits that the industry can generate if conducted and managed in a regulated, responsible manner (e.g., Aliaga-Rossel et al. 2014).

3.4.2. Traditional use

Reports on medicinal and traditional uses of dolphin parts were largely focused on the Amazon River dolphin and tucuxi (8 publications, not mentioned by co-authors) where products locally called puçanga, including genitals and eyes, are sold as amulets and oil is sold as medicine (Cravalho 1999, Aliaga-Rossel 2002, Alves & Rosa 2008, Gravena et al. 2008, Siciliano et al. 2018). Although this is an illegal trade, dolphin products can be found readily in markets in Brazil (Dos Santos et al. 2018), Peru (Schmeda-Hirschmann et al. 2014), and Bolivia (Aliaga-Rossel 2002), suggesting that improved law enforcement and environmental education are needed. Additional sporadic reports involve the use of Irrawaddy dolphin skin as a treatment for skin allergies (Kreb & Budiono 2005), Ganges River dolphin genitals as aphrodisiacs (Choudhary et al. 2006), and oil from Indus dolphin and Yangtze finless porpoise as liniment (Reeves et al. 1991, 2000, Waqas et al. 2012, Turvey et al. 2013). The impact of the trade in dolphin body parts and products on river dolphin populations is unknown.

4. Moving Conservation Forward

4.1 Emerging research methods

Novel methodologies have the potential to advance river cetacean research and better inform conservation efforts. Most existing data on river cetacean populations have been collected using direct counts (Smith & Reeves 2000b, Kreb 2002, Baird & Beasley 2005, Braulik 2006), distance sampling (Zhao et al. 2008, Gomez-Salazar et al. 2012b, Mei et al. 2014, Huang et al. 2020), and mark-recapture with photo- identification (Kreb 2004, Ryan et al. 2011, Beasley et al. 2013, Gómez-Salazar et al. 2014, Mintzer et al. 2016). These studies can be costly and have logistical limitations (e.g., some areas can be hard to reach; work can be done only in the daytime). Emerging methods can generate new or complementary data more quickly and at a lower cost. Many have been tested in parallel with direct counts and acoustic monitoring to measure their effectiveness, with promising results.

4.1.1. Acoustic monitoring

Passive acoustic monitoring (PAM) can sample and monitor cetaceans by recording the distinctive sounds they make (Sousa-Lima et al. 2013). It is non-invasive, can record for long periods, detect cetaceans when they are submerged, reach areas where visual surveys are difficult to undertake, and operates independently of weather conditions and daylight (Sousa-Lima et al. 2013, Miller et al. 2015). Disadvantages include the equipment costs, the expertise of the researchers in data processing and analysis, and most importantly, that the dolphins need to be vocalising in order for detection to occur. There have been numerous applications of PAM to study river cetaceans, primarily in Asia. It has been used to monitor populations (Kimura et al. 2009), study foraging behaviour (Tregenza et al. 2007, Kelkar et al. 2018), distribution (Kimura et al. 2012, Yamamoto et al. 2016, Campbell et al. 2017, Wang et al. 2020), movement patterns (Sasaki-Yamamoto et al. 2012), and to make suggestions for the design of protected areas (Dong et al. 2015). By employing PAM, researchers were able to study how boat presence affects cetacean communication (Wang et al. 2014) and how increasing ambient noise alters dolphin acoustic responses (Dey et al. 2019, Wang et al. 2020). Richman et al. (2014) found that combined visual and acoustic surveys more effectively detected Ganges River dolphin decline than surveys that used only one method. They also showed that among the methods that account for detectability error, acoustic equipment was cheaper than other methods (Richman et al. 2014).

4.1.2. Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) have the advantage of improving accuracy and repeatability of data and sample collection, and they can reach survey areas that are isolated or otherwise inaccessible while having a minimum impact on the behaviour of study species (Hodgson et al. 2013, 2017, Torres et al. 2018). Researchers from Brazil and India have used balloon-mounted cameras, drones, and blimps to observe and count river dolphins (Fürstenau Oliveira et al. 2017, Sugimatsu et al. 2017, Oliveira-da-Costa et al. 2020). In the Ganges River, balloon-mounted cameras were successfully paired with observers on boats to compare detection rates of Ganges River dolphins (Sugimatsu et al. 2017, 2019). Unmanned aerial surveys in the Brazilian Amazon showed that detection of groups and individual dolphins was greater in aerial photographs than from canoes (Fürstenau Oliveira et al. 2017). Drones were also tested in the Juruá River, (Brazil) and compared to detections by onboard observers. Although onboard observers made more observations, drones presented certain advantages, for example, researchers could replay recordings and make a more accurate count of individuals in groups (Oliveira-da-Costa et al. 2020). UAVs also have disadvantages since strong winds can affect take-off and landing, and manual processing of data takes time (Sugimatsu et al. 2017, Oliveira-Da-Costa et al. 2019). However, as camera resolution increases (Sugimatsu et al. 2017), and better-automated detection algorithms are developed (Oliveira-Da-Costa et al. 2019), the efficiency of UAV surveys may well increase.

4.1.3. Environmental DNA

Environmental DNA (eDNA) detection is a relatively new method that works best for detecting cryptic species that occur at low-density, and/or are logistically difficult to study in non-invasive ways (Ficetola et al. 2008, Jerde et al. 2011, Foote et al. 2012, Rees et al. 2014, Lozano Mojica & Caballero 2021). Initial attempts have been made to detect Amazon River dolphin and tucuxi in Peru (Alfaro-Shigueto et al. 2018), Amazon River dolphins in Colombia (Martinelli-Marin et al. 2020), and Yangtze finless porpoise in China (Ma et al. 2016, Tang et al. 2019, Qu et al. 2020). Tang et al. (2019) had higher detection rates for Yangtze finless porpoise using eDNA compared to direct observations. In the Tian e-Zhou National Nature Reserve in Hubei, China, data on eDNA detections showed how spatial occurrence varied seasonally in breeding and post-breeding periods (Stewart et al. 2017). Methodological constraints include the effect of environmental factors, such as water pH, temperature, and turbidity. However, eDNA has the potential to provide data on river cetaceans using fewer people and less time in the field.

4.2 Potential Conservation Interventions

4.2.1. Protected areas

Spatial protection, through protected areas (PAs), has been suggested as an important tool for cetacean conservation (Gormley et al. 2012, Notarbartolo et al. 2016). However, it is challenging to demonstrate the effectiveness of PAs for highly mobile marine vertebrates (Gormley et al. 2012, Cook et al. 2013). PAs have been designed explicitly for conserving the baiji and Yangtze finless porpoise (Wang 2009, Mei et al. 2014), Irrawaddy dolphin (Kreb & Budiono 2005), and Ganges and Indus River dolphins (Choudhary et al. 2006, Smith et al. 2010, Braulik et al. 2015). Though no PAs have been established specifically for the Amazon River dolphin or the tucuxi, PAs with high densities of both species exist in Brazil, Colombia, Venezuela, Ecuador, and Peru (Portocarrero Aya et al. 2010, Gomez-Salazar et al. 2012c, Mintzer et al. 2016, 2020, Mosquera-Guerra et al. 2018).

While many PAs have been established to conserve Asian river cetaceans, too often they lack clear management plans or infrastructure to meet conservation goals (Braulik et al. 2015). Recurring illegal disturbances such as sand mining, and even dolphin hunting have been reported inside PAs (Choudhary et al. 2006, Wang 2009, Zhao et al. 2013, Nabi et al. 2018b, Mei et al. 2019). Dams constructed near or within PAs can lead to downgrading, downsizing, or fully removing protections in the area (Thieme et al. 2020). Globally, 14% of proposed dams are in extant PAs (Thieme et al. 2020), with some directly affecting river cetaceans.

Population modelling suggests PAs could be an effective conservation tool to protect Amazon River dolphins if redesigned to incorporate essential habitat and managed effectively (Mintzer et al. 2016, 2020). PA management should be science- based, community inclusive, and ready to integrate new data (Kingsford et al. 2011, Mintzer et al. 2020). It should include incentives for local communities; community outreach (including interactive exhibitions that result in measurable changes in local communities' knowledge, attitudes, and practises (Kreb et al. 2010, Mansur et al. 2014a, Acreman et al. 2019); guidance on reducing or eliminating fatal entanglements in fishing gears; enforcement of fishing rules (including time-area closures and gear restrictions) (Azevedo-Santos et al. 2019); and regulations (e.g. plastic laminated calendars and maps illustrating time-area closures and, rulers showing legal mesh, fish, and crustacean sizes). Key impediments include getting governments to develop policies, direct funds, and provide adequate management toward supporting PAs (Reeves et al. 2000, Kreb & Budiono 2005, Kreb et al. 2010, Whitty 2015). Sustainable finance is a key consideration. Options evaluated for three wildlife sanctuaries for Ganges River and Irrawaddy dolphins in the Sundarbans, Bangladesh, included private sector offset finance, government earmarking of tourism revenue, conservation trust funds, community eco-tourism, and payment for ecosystem services (Iyer et al. 2019).

4.2.2. Ex-situ conservation

Ex-situ conservation is an alternate strategy for highly threatened species. In the mid-1980s, two *ex-situ* semi-natural reserves were developed in China, initially to support conservation of the baiji but secondarily for conservation of the Yangtze finless porpoise (Wang et al. 2006). These reserves, the Tian E-Zhou National Nature Reserve in Hubei province and the Tongling Reserve in Anhui Province, China, were established to receive translocated cetaceans and isolate them from the Yangtze river's threats, as the basis for an *ex-situ* breeding programme. Although only one baiji was ever translocated to Tian E-Zhou, this initiative has made positive progress for Yangtze finless porpoise conservation, with natural foraging, reproduction, and population growth occurring in the reserve (Wang 2009). Two further semi-natural porpoise reserves, Hewangmiao/Jicheng and Xijiang, have more recently been established. Approximately 160 Yangtze finless porpoises are now living in the four semi-natural *ex situ* reserves in China (Taylor et al. 2020).

Progress has also been made on another *ex-situ* strategy, captive breeding of porpoises at the Institute of Hydrobiology, Wuhan, with the first porpoise calf born in 2005 (Wang et al. 2005). However, the subsequent births failed, with all calves dying within 3 to 50 days after birth, until healthy calves were born in 2018 (Deng et al. 2019) and 2020 (Wang unpubl. data). Additionally, two successful births occurred in a floating pen at the Tian-E-Zhou Reserve (Wang unpubl. data). However, the long-term success of these strategies depends on measures being taken to avoid inbreeding (Xia et al. 2005), and on conserving natural habitat (Huang et al. 2017). In the future, if population numbers keep decreasing, this approach may also be necessary for other river cetaceans to avoid extinction.

The International Union for Conservation of Nature (IUCN) has developed the One Plan approach that considers both the *in situ* and *ex situ* conservation communities (Byers et al. 2013). A workshop held in 2018 recommended that knowledge of the status and threats to all species be prioritised, as well as data collection related to small cetacean handling, animal husbandry, and veterinary field protocols (Taylor et al. 2020). Some of these data can be collected during live strandings, tagging work, or when dolphins are entrapped in irrigation canals, providing practical experience and data that can be used if *ex situ* conservation is needed (Taylor et al. 2020). As discovered in the case of the vaquita (*Phocoena sinus*), longer-term contingency planning is required before a species becomes critically endangered (Rojas-Bracho et al. 2019).

4.2.3. Community engagement

Community engagement is likely linked to conservation effectiveness, although it is context specific and culturally sensitive (Choudhary et al. 2006, Braulik et al. 2015). The ongoing involvement of local riparian communities in the "Ganga Mitra" (friends of the Ganges River) and "Bal Ganga Mitra" (child friend of the Ganges River) projects has led to a sense of ownership and stewardship of the river among local people. The Ganga Mitra plays an active role in educating fellow community members, monitoring the habitat, and persuading policymakers to act for conservation (WWF India 2017). Another example is the Mamirauá Sustainable Development Reserve (MSDR) in Brazil, in which fishers participate in annual dolphin capture-recapture programmes for scientific studies, environmental education campaigns, and ecotourism initiatives (Martin et al. 2004, Martin & da Silva 2004, 2006, 2018). Surveys found that fishers who participated in MSDR activities had a more positive opinion of Amazon River dolphins (Mintzer et al. 2015). Additionally, a quarter of interviewed fishers reported that their opinions of Amazon River dolphins had changed over time for the better, and some attributed this change to their exposure to dolphin research and conservation activities (Mintzer et al. 2015). Although the use of dolphins as bait for piracatinga is common in and near the MSDR (Iriarte & Marmontel 2013, Mintzer et al. 2013, da Silva et al. 2018b, Trujillo et al. 2020b), communities closer to the enforcement centre appear to kill fewer dolphins (Mintzer et al. 2015).

In the Ayeyarwady River in Myanmar, fishers cooperate with Irrawaddy dolphins in a cast-net fishery, resulting in increased catches for the fishers and foraging efficiency for the dolphins (Smith et al. 2009b). Fishers also receive economic returns from tourists watching their human-dolphin cooperative fishing activities (Smith et al. 2009b). Since 2019, villagers have been conducting community patrols in the Mahakam River to monitor illegal fishing activities, provide early warning if dolphins enter swamps where they may become trapped, and remove large-mesh sized gillnets set in deep water (Kreb, unpubl. data). Local communities were involved in the design and implementation of a 430 km^2 aquatic conservation area that obtained a district decree in 2020 and is about to be established at the national level (Kreb, unpubl. data).

4.2.4. SMART enforcement and monitoring patrols

A successful strategy to protect wildlife around the world is the use of a Spatial Monitoring and Reporting Tool (SMART). SMART usage can improve the effectiveness of enforcement and monitoring patrols in protected areas by enabling the collection, storage, communication, and evaluation of data on patrol effort (e.g., time spent on patrols, areas visited, distances covered) and results (e.g., amount of illegal fishing gear detected and confiscated, arrests made) (Thomas & Gulland 2017). In the Mekong, 72 river guards, comprising fisheries officers, police officers, and local community members operating from 16 posts employed a SMART approach to enforce fishing rules, confiscate illegal gear, and monitor threats (Thomas & Gulland 2017). From 2015 to 2019, the river guards removed an average of > 102 km of gillnets annually, as well as long-lines with multiple hooks, with 48,682 hooks removed in 2019 alone. They also arrested 44 people for electrofishing (Thomas & Gulland 2017, Khan & Willems 2021). Between 2016 and 2018, SMART patrols conducted by the Forest Department in the Sundarbans, Bangladesh, resulted in the confiscation of 1,143 small boats and 4,306 illegal fishing gears (IWC 2020).

4. Knowledge gaps

After analysing the results of our expert questionnaire, we can highlight the priority knowledge gaps hindering river cetacean conservation (Fig 5a, Table S1 for list). These gaps are primarily related to status assessments, threats, and ecosystem requirements.

5.1 Abundance estimates

The most frequently mentioned data gap was that of range-wide abundance for all river cetacean species. Despite an increase in data availability, some species and populations still lack population level abundance data (Table 1). The conservation status of river cetaceans demands strategically planned survey coverage, with systematic methods and geographic placement that deliver statistically robust results. We recommend setting up monitoring studies that are repeated periodically, standardised, and scientifically accurate, with the potential to detect population trends at key sites. This type of study has been implemented to monitor Yangtze finless porpoise populations, repeating a standardised method every 5 to 6 years (Zhao et al. 2008, Mei et al. 2014, Huang et al. 2020). Community interviews are another option that can rapidly provide an index of relative freshwater cetacean abundance. In the Yangtze, interview data was statistically congruent with distribution data obtained from boat-based surveys (Turvey et al. 2013).

5.2 Life history

Second, we need a better understanding of these species life histories. Information on reproduction and growth is needed for adequate population modelling. Long-term studies employing mark /recapture methods have, thus far, been the most conducive for understanding key reproduction parameters (Martin & da Silva 2018), life span (Moore et al. 2018), and physiological attributes related to life history (Robeck et al. 2019), and they should be extended. Stranding networks that provide data on population structure, the presence of diseases, and the rates and causes of mortality (Smith et al. 2007, Kreb et al. 2010, Wang et al. 2015) have also been useful; they could be strengthened and replicated in additional areas.

5.3 Fisheries and Prey

We identified a significant knowledge gap in data relating to freshwater fisheries and their interactions with cetaceans. We recommend prioritising the gathering of two types of data. The first is information about the fisheries that interact with cetaceans, including fishing effort, seasonality, catch composition, and gear attributes (e.g., Whitty 2016, Richman et al. 2019). The second is information about what these cetaceans eat and the availability of their prey (e.g., Aliaga Rossel et al. 2016), an important factor for determining habitat preference and that could help to elucidate possible competition with fisheries.

5.4 Spatial/Temporal ecology and ecosystem requirements

We need a better understanding of the habitat requirements of river cetaceans. Information on where they live and how they move and how these are affected by temporal and environmental factors (e.g., floodplain flow, levels of productivity) could help delineate new PAs. Minimum habitat requirements are also not well understood. These data will be especially important for conservation efforts in areas where dams have been constructed or are being proposed. Past research has used direct observation (e.g., Martin & da Silva 2004, 2006, Choudhary et al. 2012, Mintzer et al. 2016, Chen et al. 2017), but tracking technologies such as VHF and satellite telemetry have been successful with Amazon River dolphins (Martin et al. 2006, Mosquera-Guerra et al. 2021) and could be applied to other species.

5.5 Human-induced mortality

There are few estimates of the impact of bycatch, deliberate killing, or boat strikes and other human-caused deaths on cetacean populations. These impacts may vary by species and population. Interview-based assessments of bycatch rates and characteristics are widely considered the most cost- and time-effective method for estimating small-scale fisheries bycatch and have been applied extensively (Moore et al. 2010, Turvey et al. 2013, Pilcher et al. 2017, Whitty 2018, Hines et al. 2020). To complement these data, it will also be important to investigate the relative proportion of bycatch versus targeted catch. This information will help to assess and design mitigation initiatives. Although not without fiscal and logistical challenges, mortality data gaps could alternatively be addressed with onboard or land-based observers (Smith & Jefferson 2002), and voluntary reporting from collaborating fishers (Smith &

Jefferson 2002, Dewhurst-Richman et al. 2016). In areas of particular interest, camera technologies could be considered with participating fishers (Bartholomew et al. 2018).

6. Primary challenges in conservation

The authors identified a total of fourteen challenges to river cetacean conservation (Fig. 5b, Table S3). These challenges included the limited number of existing PAs, lack of long-term projects with participatory management, difficulty in accessing study areas, as well as the existing knowledge gaps mentioned above. Herein, we provide more detail on challenges that are consistent across all species. They are possibly the most difficult to address in terms of complexity and scale, and we provide suggestions on how the research/conservation community might proceed (summarised in Table 3).

6.1 Lack of governance

One key challenge is a lack of good governance in freshwater systems, which is linked to two other issues raised by experts: inconsistent government involvement and corruption. Many countries where river cetaceans are distributed need stronger legislative frameworks, the capacity for enforcement and a means for implementation that is resilient to corruption and changing administrations. Governance in aquatic ecosystems is particularly difficult due to the logistical challenges (including costs and personnel) of accessing and covering some areas. Many strategies to reduce fishery interactions depend on law enforcement, such as the 10-year fishing ban in the Yangtze River (Xiaoyi & Yameng 2021) and the Colombian (MADR/AUNAP 2018) and Brazilian moratoria on exploitation of piracatinga (Ministério da Agricultura & Secretaria de Aquicultura e Pesca 2020). Developmental paradigms need to shift, but this takes time and depends on various factors working in concert (Cowx & Portocarrero-Aya 2011, Cooke et al 2013). Improving law enforcement is not a simple task, but decentralising governance and fishery management could be a practical and realistic approach (Lopes et al. 2021).

Aquatic governance could be more resilient to change if it included local governments and marginal and vulnerable groups, as more community-involvement helps build trust, mitigate conflicts, and legitimise goals and decisions (Plummer et al. 2015, see below - 7.3 Work with communities). Co-management leads to better compliance with fishery regulations, reduction in transaction and administration costs for governments, and increased awareness of regulations and participation in local communities (Plummer et al. 2015, Dewhurst-Richman et al. 2016).

6.2 Insufficient funding

Funding for river cetacean research and conservation is scarce, a problem for both initial research and the continuity of longer projects. When duplication of research is eliminated and more regional collaboration exists, funding can go further (Mace et al. 2000). Scientists and practitioners need to spend wisely, and research and prioritisation exercises like this one can help us do that. We could also work to diversify our sources of funding (see below- 7.6 Diversification of funding).

6.3 Lack of alternative livelihoods for fishers

Limited livelihood alternatives for fishers also complicate conservation work. Riverine fishing communities typically have very low incomes and educational opportunities (Bashir et al. 2010, Paudel et al. 2016, Mei et al. 2019), a situation that may worsen if fish stocks are not managed sustainably. Additionally, prohibitive regulations usually come with fiscal penalties that increase these economic woes (Dewhurst-Richman et al. 2019). Diversifying fisher livelihoods could provide a practicable and sustainable solution for reducing fishery interactions, thus lessening the pressure on both cetacean and fish populations. This goal is challenging for developing countries where fisheries are extensive and varied. Governmental agents, with economic and social expertise, should incorporate fishers' needs and opinions and develop alternative livelihood schemes, prioritising gillnet fisheries. Previous studies have proposed financial compensation schemes, aquaculture programmes

(Mei et al. 2019), and wildlife watching (Kelkar et al. 2010), all options that could be more fully explored in many systems.

6.4 Personnel constraints

There is too large a gap between the conservation work that needs to be done and the number of professionals available to do it. The number of institutions working on aquatic mammal conservation in countries with river cetaceans is also limited, so the avenues available for interested students and early career professionals to develop relevant careers are restricted. This limitation also leads to an over reliance on foreign experts. Moving forward, funders and projects should invest in enhanced capacity of local researchers. This transition appears to be taking place, (see below- 7.1 Capacity building) but there are opportunities for it to continue to increase.

6.5 Miscommunication among researchers

Thirteen authors mentioned miscommunication, competition, abuse of power, and animosity among researchers as a hindrance to better conservation action. This is not uncommon in the scientific and conservation fields (Anderson et al. 2007, Fang & Casadevall 2015, Powell 2018), where it can negatively affect data sharing and disrupt relationships. This can be particularly negative for early-career researchers who can be burdened with additional activities (e.g., communicating results, engaging with policy makers) while training in their particular research skills (Cosentino & Souviron-Priego 2021).

7. Primary opportunities in conservation

In this section, we describe our top-ranked strengths and opportunities for river cetacean conservation (see Fig. 5b, Table 3, Table S3).

7.1 Spatial Protection

More work is needed to protect river dolphin habitats, as most existing freshwater PAs were not designed for this purpose. Establishing new PAs and improving existing ones could provide partial habitat protection. Adaptive monitoring approaches for freshwater PAs have been developed, that could promote greater protection of freshwater ecosystems (e.g., Kingsford et al. 2011, Hermoso et al. 2016, Acreman et al. 2019). These include frequent evaluations of PA efficacy, designing PAs to incorporate various habitats and their connectivity, and local community participation in regulatory operations (Acreman et al. 2019). River cetacean population modelling, such as that performed by Mintzer et al. 2020, can be used to examine and assess the success of PAs, as well as improve reserve layouts.

7.2 Capacity building

A new generation of scientists is currently being trained in river cetacean research (Fig. 5c). This increase in the number of researchers, coupled with local capacity building initiatives, will ensure that there are trained researchers in every country with river cetaceans who can collaborate and work together towards cetacean conservation. Capacity building should extend to include conservation practitioners – not just scientists. Indeed, solely focusing on science can contribute to the problem (Clark et al. 2018)– as practical conservation is rarely done or communicated by scientists (Pullin & Knight 2001). Collaborating with social scientists would also help understand the human dimensions of the threats we are trying to reduce (Fischer et al 2011, Bennet et al 2017). Rangers, reserve managers, and other relevant stakeholders in PAs, and community members should be included as well to ensure training in rescue handling and scientific monitoring. Importantly, granting agencies should allow funds to go to sustaining capacity building.

7.3 Management plans

Conservation management plans (CMP) or species management plans (SMP) specify intended objectives for the conservation and management of a species or population, including clearly defined responsibilities and timelines for accomplishing tasks (Burgener et al. 2012). These long-term plans help ensure governmental commitments, as well as coordination among stakeholders. Management plans exist at a national level in China for the

Yangtze finless porpoise, in India for the Ganges River dolphin, Indonesia for the Irrawaddy dolphin, and in every Amazon River dolphin and tucuxi range country (e.g., Sinha et al. 2010, Utreras et al. 2013, Trujillo et al. 2014, Mustika et al. 2015). International management plans also exist, such as the Ganges River dolphin concerted action plan supported by the CMS (UNEP/CMS/Concerted Action 13.6 2020), and the IWC Conservation Management Plans accepted for South American river dolphins (Trujillo et al. 2020a) and proposed for Asian river cetaceans (Khan et al. 2020). Progress on how these goals and activities develop should be regularly assessed to achieve objectives in a timely manner.

7.4 Work with communities

Many authors point to existing community partnerships as a strength because they can expand conservation initiatives that change local people's perceptions of freshwater cetaceans and ecosystems. (Kreb & Budiono 2005, Mintzer et al. 2015, Thomas & Gulland 2017). Future research and conservation actions should include local communities, as doing so can lead to a greater sense of ownership, increase wildlife knowledge, promote understanding of natural resource management (Sinha & Kannan 2014), and ensure socially-responsible conservation actions. In addition, participatory monitoring can be a useful tool for addressing personnel shortages in data collection (Turvey et al. 2013). Educational campaigns could also help reduce the negative perception of river cetaceans in some communities (Mintzer et al. 2015).

7.5 Growing knowledge and public awareness

In the last few years, an increasing volume of research has been produced on river cetaceans. Public awareness has also grown in many regions. We think that’s in part due to local environmental education and volunteer campaigns run by local and international NGOs (e.g., Mansur et al. 2014a, Mintzer et al. 2015). Traditional media and social media campaigns have also made good use of the charismatic nature of river cetaceans to increase public awareness of their threatened status.

7.6 Regional collaboration

Regional collaboration among researchers was mentioned as a strength in our expert questionnaire. Because riverine species often move across boundaries, conservation and research are more effective when coordinated throughout the full ranges of species. International agreements such as the Convention on Wetlands of International Importance (Ramsar), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the International Whaling Commission (IWC), the Convention on Migratory Species (CMS), and the IUCN have also likely contributed to this increase in collaborative initiatives. The WWF-led South American River Dolphin Initiative (SARDI) and the IWC- South Asian River Dolphin Task Team (IWC 2020) are examples of regional collaboration. Outputs from these are task-force plans (IWC 2020), research activities implemented at a regional scale (Mosquera-Guerra et al. 2019b, 2021), and public awareness activities with events held in every member country (e.g., World River Dolphin Day).

7.7 Diversification of funding

Sustainable funding is critical to the development of research and conservation action (Waldron et al. 2013). Among the available alternatives, the authors particularly recommended supporting conservation and research activities with income from non-traditional sources, if possible. One option is to form partnerships with the private sector, especially with organisations that work in areas where river cetaceans are distributed. Such successful existing partnerships are currently limited but show that the potential exists (Clark et al. 2018). Crowdfunding platforms have also gained popularity as a means for researchers to raise funds independently and have been successful in some cases (Gallo-Cajiao et al. 2018).

Eco-tourism linked to research programmes could be another potential source of funding. These projects must be carefully monitored to minimise their impact on cetacean populations. Education, awareness, and standard protocols (e.g., Beasley et al. 2010, Aliaga-Rossel et al. 2014) for dolphin eco-tourism can also raise the quality of the tourist experience. This will then gradually shift towards sustainability by supporting livelihoods in the local community, creating awareness, and generating a more conscious pool of tourists engaging with river dolphin conservation.

8. Conclusion

With this review we have sought to synthesise available information and opinions about threats to river cetaceans that should be addressed with urgency, and to suggest possible pathways to overcome obstacles in river cetacean conservation. We have highlighted that significant effort is being expended to undertake river cetacean research, that PAs and fishery regulations have been implemented to protect dolphins, and that local capacity building for research and conservation of river cetaceans has increased. The literature and expert opinion concur that fisheries, mainly through targeted catch and bycatch, and habitat degradation, via the construction and operation of dams, are the most significant threats to river cetacean populations. Important data gaps exist in understanding ecosystem requirements, river cetacean life history and spatial distribution, and human-induced mortality. Given the dire status of river cetaceans, we need to focus on conservation actions based on the current best available knowledge. Habitat degradation is expanding, and fishery interactions continue to negatively impact populations. Future work should principally focus on reducing these two threats. To do this, we propose increasing capacity, developing management plans to promote government involvement, collaborating closely with communities, increasing public awareness and regional collaborations, and diversifying funding.

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Table 1 Summary of species range and most recent populations numbers.
NA = Not currently available

Common name	Scientific name	Range	Population	IUCN Red list
Yangtze river dolphin (Baiji)	*Lipotes vexillifer*	Yangtze River basin *(China)*	Possibly Extinct (Turvey et al. 2007)	Critically Endangered (Possibly Extinct)
Yangtze Finless porpoise	*Neophocaena asiaeorientalis* ssp*. asiaeorientalis*	Middle-lower Yangtze River basin and adjacent Poyang and Dongting Lakes (*China*)	1012 (95% CI: 791–1233) (Huang et al, 2020)	Critically Endangered (CR)
Ganges River dolphin (Susu)	*Platanista gangetica*	Ganges-Brahmaputra-Megna and Karnaphuli-Sangu river systems *(India, Nepal and Bangladesh)*	3,500-4,000 (UNEP/CMS/ Concerted Action 13.6 2020)	Endangered (EN)
Indus River dolphin	*Platanista. minor*	Lower Indus basin	965 (843-1171) (Braulik, 2006)	Endangered (EN)

(Bhulan)		(*Pakistan)*		
Irrawaddy dolphin	*Orcaella brevirostris*[1]	Ayeyarwady River (*Myanmar*) Mahakam River (*Indonesia*) Mekong River (C*ambodia,Lao People's Democratic Republic*)	58-72 (Smith et al. 2007); 79 (95% CL 65-99, CV = 3%), (D. Kreb, unpub. data) in 2019; 80 (95% CL 64-100; Phan et al. 2015)	Critically Endangered (CR)
Tucuxi	*Sotalia fluviatilis*	Amazon basin (*Brazil, Colombia, Ecuador, Peru*)	NA	Endangered (EN)
Amazon River dolphin (Boto)	*Inia geoffrensis* ssp*. geoffrensis*[2]	Amazon and Orinoco river basins (*Brazil, Colombia,*	NA	Endangered (EN; classified at species level)

		Ecuador, Peru, Venezuela)		
Bolivian river dolphin (Bolivian bufeo)	*Inia geoffrensis* ssp. *boliviensis*	Iténez-Guaporé, Mamoré, and Rio Grande River basins (*Bolivia*) Madeira River, *(Brazil)*	NA	

[1.] The Irrawaddy dolphin (*Orcaella brevirostris)* is a facultative river cetacean which has both marine and freshwater populations.

[2.] A second *Inia* species, the Araguaian boto (*I. araguaiaensis)*, has been described (Hrbek et al. 2014) but has yet to be recognised by the Committee on Taxonomy of the Society for Marine Mammalogy because of the need for additional data supporting species designation (Committee on Taxonomy & Society for Marine Mammalogy 2020).

Table 2 Threat classification used in the review publication database

Broad Threat Categories	Included Sub Threats	Impacts	Examples
Fisheries	Bycatch Targeted catch Illegal fishing Overfishing	Increase in mortality Extirpation in parts of range Prey limitation	(Kreb et al. 2010, Iriarte & Marmontel 2014, Brum et al. 2015, da Silva et al.

			2018a, Brownell Jr. et al. 2019)
Habitat degradation	Infrastructure (Dams, barrages) Climate change Deforestation Sand mining	Population fragmentation Displacement	(Karim & Bindra 2016, Pavanato et al. 2016, Aliaga-Rossel & Escobar-WW 2020)
Other human Interactions	Human populations Vessel collision Tourism Traditional use	Displacement Mortality	(Aliaga-Rossel 2002, Gravena et al. 2008, Romagnoli 2009)
Pollution	Heavy metals Plastic Noise Chemical contaminants	Physiology and health impacts Modifications in communication	(Lailson-Brito Jr. et al. 2008, Yang et al. 2008, Mosquera-Guerra et al. 2019b)

Table 3 Threats to river cetaceans, the associated knowledge gaps and recommended actions needed to address them

Threats	Knowledge gaps	Recommended actions	Cross-cutting recommendations
<u>High Priority</u>			
Bycatch and Targeted Catch	– Abundance estimates – Human-Induced Mortality – Fishery characteristics – Life history	– Establish methods to study abundance, population trends (e.g., stranding networks, periodic surveys, questionnaires, emerging methods) – Develop alternative livelihood schemes – Test bycatch mitigation measures	– Work closely with communities in conservation projects, when establishing PAs and fishery regulations – Regional collaboration for research and conservation actions (e.g., SARDI, IWC Task Teams) – Establish and implement management plans with local government – Continue to build local capacity in range countries – Diversify funding sources
	– Composition of river cetacean diet and availability of their prey	– Work with communities for better law enforcement (e.g., SMART Patrols, Ganga-Mitra programme) – Implement new PAs and strengthen existing ones	

Infrastructure projects	– Spatial/Temporal ecology and ecosystem requirements	– Deter the construction of dams – Implement new PAs and strengthen existing ones
Climate Change	– Ecosystem requirements	– Assess tolerance of temperature and salinity variance in cetacean populations
	– Diet/ Prey Availability	– Research effects of climate change on prey distribution
Lower Priority		
Pollution	– Long-term effects on health of noise, contaminants, and heavy metals – Population consequences of pollution – Life history	– Improve regulations on chemical disposal to reduce the amount of chemicals entering freshwater environments – Establish long term monitoring projects to study reproduction, growth, baseline health status for every species

Other human interactions	– Abundance estimates – Human-Induced Mortality	– Establish methods to study abundance (above) – Monitor vessel traffic and collisions – Develop standard protocols for river cetacean ecotourism

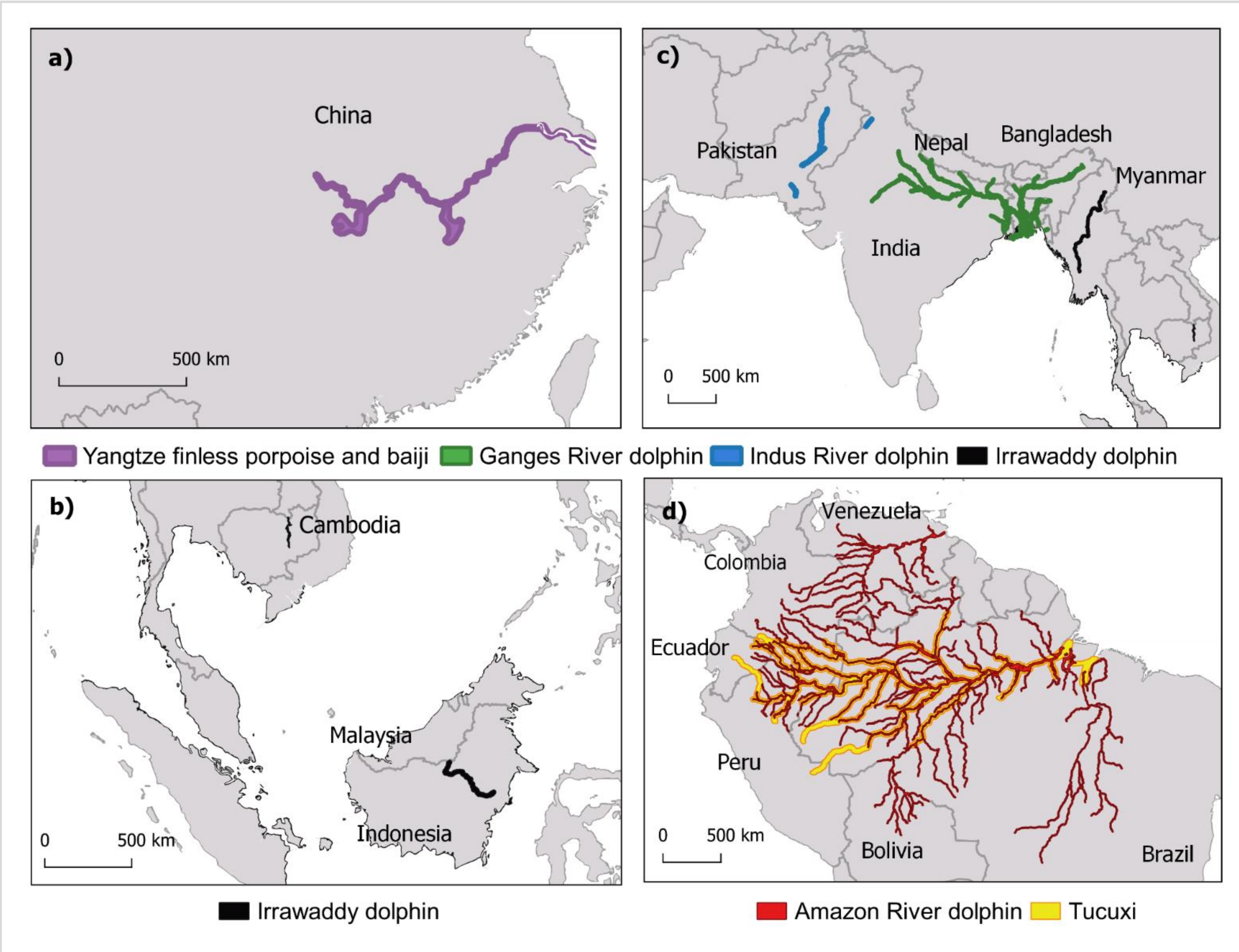

Figure 1 River Cetacean distributions in a) China, b) Southeast Asia, c) South Asia and d) South America. Spatial ranges were obtained from the most recent IUCN Red List assessment (IUCN 2021)

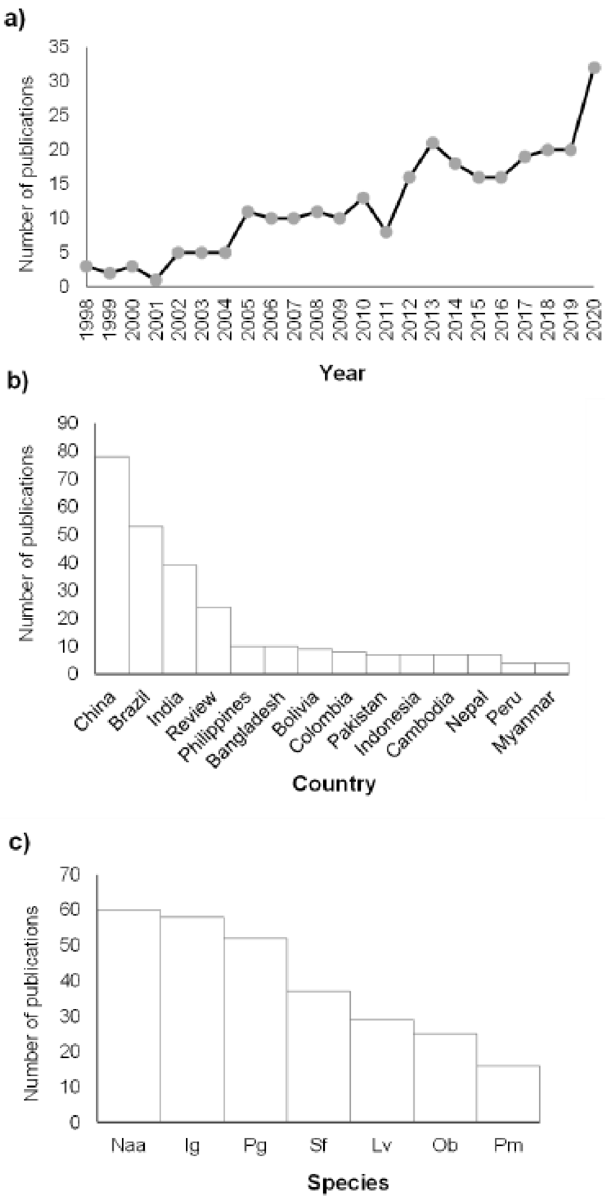

Figure 2 Publication trends Number of publications on river cetacean species a) by year published (1998-2020), b) by the country where the research was undertaken, c) species (Naa: *Neophocaena asiaeorientalis asiaeorientalis;* Ig: *Inia geoffrensis*; Pg: *Platanista gangetica;* Sf: *Sotalia fluviatilis;* Lv:*Lipotes vexillifer*; Ob: *Orcaella brevirostris*; Pg: *Platanista minor*). Common names are provided in Table 1.

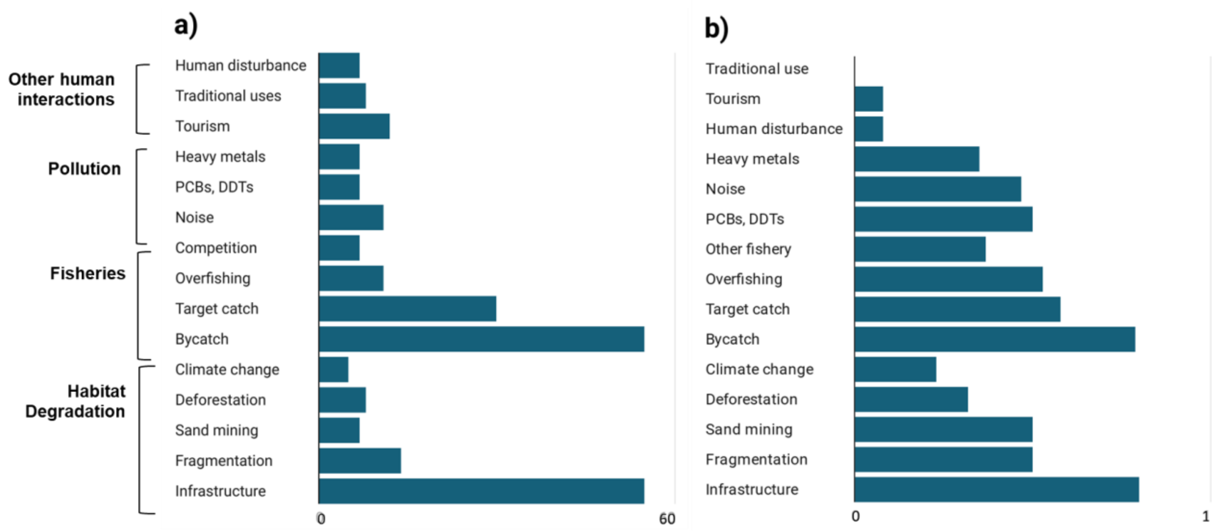

Figure 3 Overview of threats to river cetaceans. (a) Number of publications that mentioned each threat and (b) proportion of co-authors that mentioned each threat in their questionnaire. We divided threats into 4 overarching themes: Habitat degradation, Fisheries, Pollution, Other human interactions. Subthemes were sorted by prevalence within themes

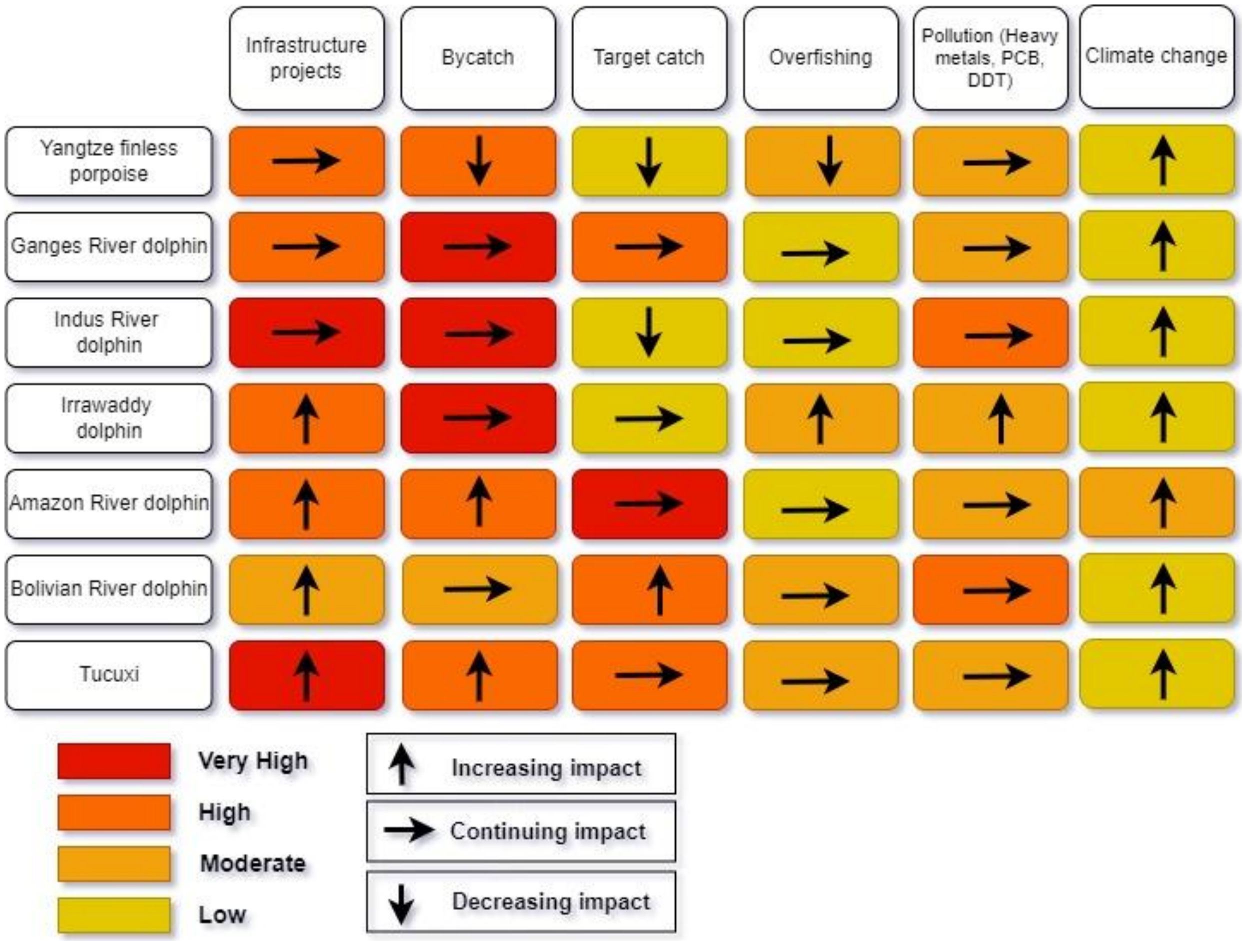

Figure 4 Threats ranked by their impact on river cetacean species conservation, based on the results of the questionnaires and further discussion among authors. Style after Millennium Ecosystem Assessment (2005).

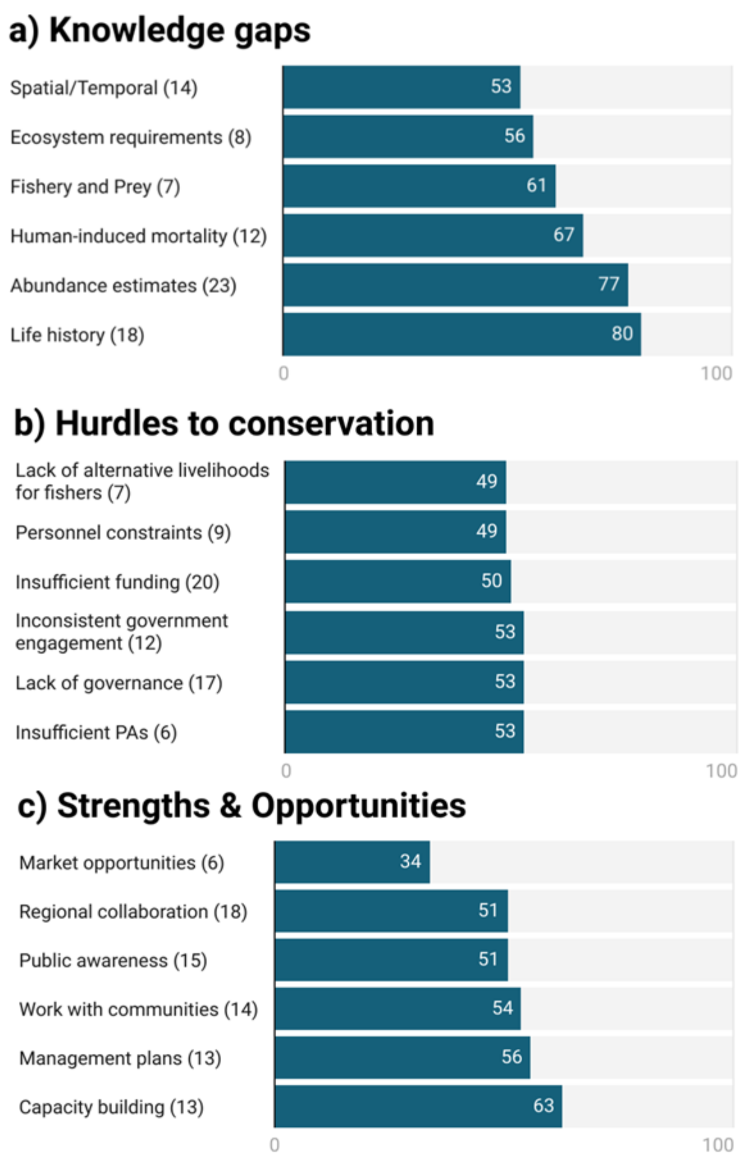

Figure 5 Questionnaire results where (a) knowledge gaps, (b) hurdles to effective conservation and (c) strengths and opportunities were ranked by authors. The maximal value is 100 if all authors classified the category as the most important/valuable. The number of times the theme was mentioned is included in parentheses. PA: protected area

Supplementary Information

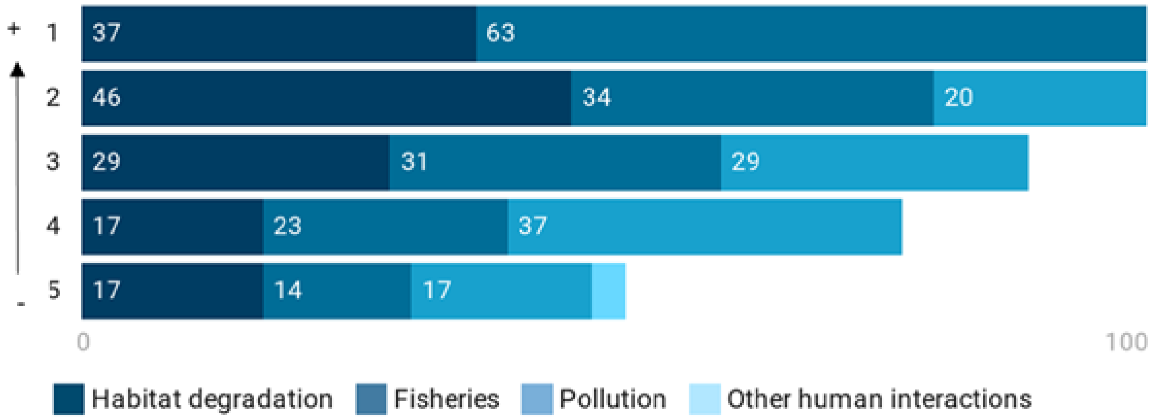

Figure S1 Distribution of categories by rank by authors. Here, 1 is the most significant threat, whereas 5 is the least significant. Not all experts ranked more than 2 threats.

Table S3 Full list of sections and themes mentioned by authors in the questionnaires.

Knowledge gaps	Number of times mentioned (Max 35)	Average rank
Life history	18	80
Abundance estimates	23	77
Human induced mortality	12	67
Fishery and Prey	7	61
Ecosystem requirements	8	56
Spatial/Temporal	14	53

Unclear taxonomy of *Inia* genus	4	27
Information on riverine communities	3	27
Genetic diversity	6	24
Uncertainty of climate change effects	6	23
Effects of pollution on health	9	22
Information for delineation of Protected areas	5	14
Knowledge of successful/unsuccessful conservation approaches	1	3
Hurdles		
Inconsistent government engagement	12	59
Insufficient Pas	6	53
Lack of governance	17	53
Insufficient funding	20	50
Personnel constraints	9	49
Lack of alternative livelihoods for fishers	7	49
Knowledge gaps	9	44
No ecosystem-based management	7	44
Miscommunication among researchers	13	39
Lack of participatory initiatives	5	29

Corruption	6	26
Species perception	4	23
Animals have a large/regional distribution	7	15
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Chapter 3: Coexisting in the Peruvian Amazon: Interactions between fisheries and river dolphins

Elizabeth Campbell, Jeffrey C. Mangel, Joanna Alfaro-Shigueto, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley

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Abstract

The freshwater tucuxi (*Sotalia fluviatilis*) and the Amazon River dolphin (*Inia geoffrensis*) are endemic to the Amazon-Orinoco River basin. Their conservation is hindered by human disturbance and uncertainty about total population size and distribution. In this study, we used rapid assessment questionnaires to identify threats to river dolphins found in Peru and to identify priority areas for their further study and conservation. We administered questionnaires to fishers (surveyed 2010 n=162, 2015 n=251) and community members (surveyed 2015 only; n=118) at 12 landing ports of the Peruvian Amazon, asking questions about their knowledge, perception, and interactions with river dolphins. Dolphins were observed by interviewed fishers based across all ports except for Aguaytia port, which was subsequently excluded from further analysis. Across the sampled ports in 2010, an average of 86% of fishers (range: 59-100%; n=8 ports) associated dolphins with negative economic impacts, largely due to net damage, with similar findings in the more extensive survey in 2015 (74%, range: 27-100%; n=11 ports). Bycatch of dolphins was also reported in 11 ports, with a higher incidence in the state of Loreto, where up to 10 bycaught individuals per fisher per year were reported for both time periods. The use of dolphins as bait has been practised from at least 2010 (2010: 31% of fishers, 11-57%; 2015: 31%, 0-63%) and is prevalent (>40%) in four of the surveyed ports (Caballococha, Bagazan, Requena and Manantay). Our study can be used as a first reference to guide monitoring of river dolphin populations in priority areas. Future efforts should revisit and extend this survey to other ports in Peru. Doing so will enable detection of trends in fisheries conflicts with river dolphins and improve the estimation of bycatch and direct take of dolphins in the Peruvian Amazon.

Introduction

Fishing is one of the leading economic activities in the Peruvian Amazon basin, with landings of up to 80,000 tonnes and revenue of 80 million USD annually (Garcia et al., 2009; Tello & Bayley, 2001). Amazon fisheries can be divided into subsistence and commercial fisheries (RM No 147-2001-PE, 2001). Subsistence fishing is an activity practiced by most families living in riverside settlements (Tello-Martin & Montreuil- Frias, 1994) where they capture resources to meet their basic needs and sell the surplus of fresh fish in local markets, or salt and dry it for sale to merchants that operate in larger cities (Vargas et al., 2012). A total of 75% of the landings are for subsistence, as fish is the primary source of animal protein in local communities (Tello & Bayley, 2001; Vargas et al., 2012). The other 25% of landings is from the commercial fleet, dominated by fisheries for three target species (boquichico *Prochilodus nigrians*, llambina *Potamorhina altamazonica*, ractacara *Curimata spp*), supplying regional markets in cities of the states of Loreto and Ucayali (Garcia et al., 2009). Despite their importance to the local and regional economy, these freshwater fisheries remain under-studied in comparison with Peruvian marine fisheries (Alfaro-Shigueto et al., 2010; Fréon et al., 2014).

Fisheries interactions are a severe threat to many long-lived and slowly reproducing species (Alfaro-Shigueto et al., 2011; Crawford et al., 2017; Crowder et al., 2008). Marine mammals, specifically, are vulnerable to targeted fisheries and as bycatch within industrial and small-scale fisheries (Avila et al., 2018; Read et al., 2006; Reeves et al., 2013). Cetaceans that have limited distributions and small population sizes are particularly vulnerable to the impacts of human activities (I. C. Avila et al., 2018). An example of this is the vaquita (*Phocoena sinus*), a porpoise found exclusively in the Gulf of Mexico, now close to extinction, with estimates of fewer than 30 individuals remaining (Jaramillo-Legorreta et al., 2017; Rojas-Bracho et al., 2019).

Another vulnerable group of aquatic mammals are the freshwater dolphins inhabiting large rivers systems. Their freshwater habitats are among the most threatened ecosystems in the world (Anderson et al., 2018; Pavanato et al., 2016) and, as human populations grow, the strain on rivers and lakes increases. Factors such as pollution, infrastructure (e.g., dams, artificial waterways) and fisheries pressure can diminish freshwater habitat quality (Latrubesse et al., 2017; Pavanato et al., 2016; Revenga et al., 2005). The baiji (*Lipotes vexillifer*) was endemic to the Yangtze River and was proposed functionally extinct in 2007 (Turvey et al., 2007, 2013). Its decline was attributed to the high incidence of bycatch in fishing gear and the industrialization of the Yangtze River ecosystem (Turvey et al., 2007, 2013). The Ganges River dolphin (*Platanista gangetica*) and the Indus River dolphin (*Platanista minor*) are both listed as Endangered by the International Union for Conservation of Nature (IUCN), while the Irrawaddy dolphin (*Orcaella brevirostris*) is considered Vulnerable (Braulik et al., 2012; Braulik & Smith, 2019). These three species overlap with fisheries in their habitats and are reported to occur as bycatch (Baird & Beasley, 2005; Brownell Jr. et al., 2019; Sinha, 2002; Smith et al., 2006). Additionally, there is a direct take of Indus and Ganges dolphins driven by the use of blubber oil as bait in catfish fisheries (Sinha, 2002).

The freshwater tucuxi dolphin (*Sotalia flluviatilis*) (hereafter referred to as *Sotalia*) and the Amazon River dolphin, also known as boto (*Inia geoffrensis*) (hereafter referred to as *Inia*) are endemic to the Amazon-Orinoco River basin (Jefferson et al., 2008). Currently *Inia* is listed as Endangered and *Sotalia* as Data Deficient by the IUCN (Secchi, 2012; da Silva, Trujillo, et al., 2018). South American river dolphins have been recorded as having been used as bait in the catfish (commonly known as piracatinga or mota; *Calophysus macropterus*) fisheries in Brazil (Loch et al., 2009; Mintzer et al., 2013; Brum et al., 2015), Colombia (Mosquera-Guerra et al., 2015) as well as in Bolivia and Venezuela (Aliaga-Rossel, 2003; Bolaños-Jiménez et al., 2015). The illegal harvest of Amazon River dolphins for this purpose has undoubtedly contributed to their population decline (da Silva, Freitas, et al., 2018; Mintzer et al., 2018; Williams et al., 2016). Additionally, traditional beliefs of dolphins enchanting, kidnapping and impregnating women have created an image of Inia as a mischievous being, and as such, people harvest their body parts to use as love charms and amulets in Brazil (Alves & Rosa, 2008; Siciliano et al., 2018). To date, research has primarily focused on the utility of protected areas for conserving dolphin populations (e.g., (McGuire, 2010; Mcguire et al., 2014) and in generating population estimates, distribution and density maps in Brazil and Colombia (Gomez-Salazar et al., 2012; Martin & da Silva, 2004). Data on the status and threats faced by these two legally protected species in Peru are particularly lacking (Campbell et al., 2017).

Here we report the results of two surveys undertaken five years apart, using a rapid, interview-based method modified from studies applied in other marine and riverine locations (Moore et al., 2010; Turvey et al., 2015). Our aims were to: (1) generate information on the perceptions and the interactions of Peruvian fishers and river dolphins, (2) to determine the practice of using dolphins as bait in Peruvian fisheries, and (3) to assess other factors (e.g., bycatch, traditional use) that may affect the conservation of these species.

Methods

Study area

Our study was conducted from April-June, 2010 and May-July, 2015 in ports and landing sites in the states of Loreto and Ucayali in the Peruvian Amazon (Fig 1). Loreto and Ucayali yield most of the continental fish products of Peru, with 28 054 tonnes and 8635 tonnes landed in 2015 in the two states, respectively (PRODUCE, 2015). Landings in these regions may come from the Amazon and Ucayali rivers as well as the Marañon, Huallaga, Napo, Tigre, Putumayo, Nanay, Yavari and Morona rivers. Sampled ports in Loreto state were Nauta, Requena, Bagazan, Nanay, and Puerto Pesquero and

Productores in Iquitos city. In Ucayali state, we sampled Calleria, and Yarinacocha ports (Fig 1). We chose these ports because they are the main landing sites for fish products, and they provide a wide spatial coverage of Peruvian Amazon fisheries. In 2015, we extended the study to include the following sites: Caballococha and Puerto Masusa in Loreto, and Manantay and Aguaytia in Ucayali state, thus covering 46% of major landing sites in the Peru Amazon (PRODUCE, 2015).

Questionnaires were administered to fishers who lived and fished near each landing site. We surveyed between 6 and 12% of fishers registered in each sampled area. The total number of fishers from each port was obtained from national census data (PRODUCE, 2013) or for ports that were not included in census data, we visited local government agencies for current estimations. We interviewed a total of 162 (81% Loreto, 19% Ucayali) and 251 (69% Loreto, 31% Ucayali) fishers in 2010 and 2015, respectively. In 2015, we also interviewed 118 community members (79% Loreto, 21% Ucayali).

Questionnaires were conducted by trained local scientists with previous experience relevant to this study. The survey was designed to evaluate fishing habits, fisher interactions with dolphins, and fisher perceptions of *Sotalia* and *Inia*. Specifically, the 33 questions (see Fig. S1) addressed: Fishery practices and areas, areas of presence/absence of river dolphins, conflicts between fisheries and dolphins, and traditional uses and beliefs related to dolphins. Each questionnaire took approximately 30 minutes to complete. Twenty-three of the questions were closed-ended. Participants were approached at ports, close to their boats, or at shops close to piers. At the beginning of each interview, respondents were informed about the general objectives of the study and were assured that the data would be collected and stored anonymously. Surveys were administered once participants gave their verbal consent and confirmed they were boat captains. The questionnaires were carried out 1:1 to the captains of each vessel to assure that only one fisher per vessel participated. As fishing is practised almost exclusively by men, all interviewed fishers were male and no particular age group or type of fisher (commercial, subsistence, or type of fishing gear used) was targeted. No problems were identified with fisher participation in surveys (zero refusal rate). In 2015, in addition to fishers, we also surveyed community members who were not directly involved in fishing activities at each sample site to better understand what residents of local communities know about river dolphins. These participants were approached in markets and city plazas, in the early hours of the afternoon. No gender or age group was targeted specifically. These surveys had 12 questions addressing river dolphins, beliefs and commerce of dolphin body parts, and perceptions relating to these species. These surveys took about 20 minutes and were also anonymous. We aimed to have at least ten participants at each site.

All responses from fisher and community interviews were annotated on printed survey sheets and entered into a spreadsheet database. For open-ended questions, we initially read through all respondents' answers and identified where a similar response was repeated by multiple participants. These responses were categorised into selected themes and assigned a code. Close-ended questions had multiple choices where each answer represented a code. Codes from both questions were then analysed as percentages. To gain a synthetic view of bycatch a minimum estimate was created per landing site by summing the estimates for all surveyed fishers. This project was approved by the Ethics Committee at the University of Exeter (eCORN001707).

Results

Fishery and fisher description

Most respondents were under 50 years of age (2010: 67% on average across all ports, range 32-93% at individual ports; 2015: 77%, range 57-100%) (from herein, average value for all ports is shown first, followed by a range of averages across the individual ports), most were between 30 to 50 years of age with less than 20 years of experience in the fishing sector (2010: 68% 32-86%; 2015: 59% 18-90%). Fishers most often reported using "peque peque" boats, canoes with outboard motors of up to 12 horsepower (HP) (2010: 72.5%, 28-100%; 2015: 60.3%, 0-100%). The boats used by fishers included larger vessels, which simultaneously transport food, construction materials, passengers and other resources to the ports from other riverine communities. These boats have engines with a maximum of 20 HP (2010: 24.6% range 0-64%; 2015: 31.3% 0-100%). Fishers also used boats without motors (2010: 2.9%, 0-10%; 2015: 8.3%, 0-100%).

The most commonly used fishing gear recorded in both survey years were gillnets “agallera” (Table 1, 2010: 30%, 4-54%; 2015: 56%, 0-100%) or “honderas”, similar to a purse seine (2010: 31%, 9-42%; 2015: 32%, 0-100%). Other frequently reported gears were hooks (2010: 8%, 0-19%; 2015: 10%, 0-27%) and traps (2010: 24%, 0-42%; 2015: 2%, 0-11%). Most respondents reported being opportunistic fishers (2010: 23%, 13-33%; 2015: 38%, 0-100%), meaning they catch what they can find. A variety of target catch species were recorded, the most frequently mentioned species was the boquichico (*Prochilodus nigricans*) (2010: 20%, 11-31%; 2015: 30%, 0-50%), followed by the palometa (*Mylossona sp*.) (2010: 13%, 5-19%; 2015: 18%, 0-50%) and the catfish zúngaro (*Brachyplatystoma spp*.) (2010: 11%, 2-25%; 2015: 5%, 0-23%). A minority of fishers from all ports responded that they targeted catfish piracatinga specifically (2010: 2.4%, 0-6%; 2015: 3%, 0-15%). Ports such as Pesquero and Productores contained higher concentrations of fishers who targeted piracatinga (12% and 15% of interviewed fishers, respectively) in 2015, in contrast to results from 2010 where the port with the highest percentage was Productores, at 6% of interviewed fishers.

In 2015, we added questions to the survey about the number of crew members and duration of fishing trips. Respondents reported fishing alone (SOM 2, 31%, 0-100%), with up to three crew members (2015: 26%, 0-100%), or larger crews of up to 10 members (24%, 0-81%). Trips lasted from one day (2015:

33%, 0-100%), up to five days (2015: 31%, 0-71%) or longer than 10 days (18%, 0-95%). These longer trips with more crew members were concentrated in Pesquero, Productores in Loreto and Calleria, Ucayali.

Dolphin-fisher interactions

We initially asked if the fishers had observed dolphins and if they knew how to differentiate between the two species, *Inia* and *Sotalia* (Table 2). Only the fishermen interviewed in Aguaytia answered that they had not seen dolphins in that region and therefore could not distinguish between the two species. Therefore, values from Aguaytia are excluded from all following analyses. In the other ports, most fishermen reported seeing both species in their lifetimes (2010: 94%, 67-100%; 2015:97%, 80-100%) and were able to distinguish between them (2010: 91%, 65-100%; 2015: 99%, 89-100%). This was confirmed by asking fishers what characteristics they use to differentiate species (size and/or coloration).

Most fishers interviewed reported conflicts with dolphins in their fishing areas (2010: 86%, 59-100%; 2015: 74%, 27-100%) (no difference between study years, Wilcoxon test $P > 0.05$). When asked what the problem was, in order of frequency the responses were entanglements in nets (dolphins break or damage fishing gear, 2010: 79%, 54-93%; 2015: 87%, 67-100%) followed by dolphins stealing fish (2010: 12%, 0-30%; 2015: 6%, 0-14%). Both options affect fishers economically. The third most frequent response was that Inia are aggressive towards boats (2010: 8%, 0-23%; 2015: 7%, 0-24%). Regarding this response, one participant noted that when many Inia were aggregated, they "try to turn the boats, hit the boat or follow us on our return to port”.

When asked about river dolphin bycatch, approximately half of fishers reported having at least one incident of river dolphin bycatch, either released dead or alive, during their fishing trips within the last year (2010: 58%, 5-100%; 2015: 68%, 45-100%) (Fig 2a). Respondents from some ports had higher reported incidence of bycatch: Loreto: Nauta (2010: 68%; 2015: 75%) Pesquero (2010: 68%; 2015:63%) Productores (2010: 56%; 2015: 80%) Requena (2010: 100%; 2015: 60%) and Ucayali: Calleria (2010: 50%; 2015: 75%). We asked fishers how many individuals were bycaught per year. For both periods of the study, one capture per year was the most common answer (2010: 27%, 6-61%; 2015: 25%, 0-100%). The number of fishers that reported more than 3 dolphins a year was small (2010: 19%, 3-34%; 2015: 11%, 0-40%), but still at a level important for overall dolphin conservation. Respondents indicated that most entangled dolphins were found alive (2010: 72%, 43-88%; 2015: 89%, 77-100%). Also, the majority of respondents answered that Inia is caught more frequently than *Sotalia* (2010: 59% 17-88%; 2015: 64% 27-92%).

Calculating the minimum estimate from our 2015 questionnaire results, we can roughly estimate that the 251 fishers we surveyed from the studied ports (encompassing approximately 10% of vessels) have an approximate annual bycatch of 182 dolphins (Table 3).

Use of river dolphins

Regarding the fates of the entangled dolphins, most of the respondents reported that dolphins were released, either alive or dead (2010: 84%, 55-100%; 2015: 81%, 67-100%). However, some fishers did reply that in some cases when dolphins are found entangled alive, they are killed and sold (2010: 5%, 0-18%; 2015:7%, 0-16%) or killed and discarded (2010: 4%, 0-18%; 2015: 3%, 0-17%). Both in 2010 and in 2015, approximately a third of fishers (2010: 31%, 11-57%; 2015: 31%, 0-63%) reported that they knew of someone using dolphin parts as bait, with considerable variation in the frequency of dolphin bait among sites (Fig 2b). No significant difference was found comparing between years for use of dolphins as bait (Wilcoxon test, $P > 0.05$), but some ports are worth highlighting as having high frequency of use of dolphin bait: Caballococha (2015: 46%), Bagazan (2015: 41%) Requena (2015: 63%) and Manantay (2015: 50%).

Community surveys

In 2015, we also surveyed community members. Aguaytia was again excluded from further analysis as dolphins were not known in the area. Ninety percent of respondents knew of river dolphins (range: 60-100%), and 76% reported seeing dolphins in their locality (60-100%). When asked where they had learned about river dolphins, 37% (0-72%) of respondents answered community surroundings, followed by family (30%, 7-100%), media and press (23% 0-60%), and at educational institutions (14%, 0-40%). When asked about the sale of dolphin parts, 56% (20-100%) of respondents indicated that they knew where dolphin parts were sold. When asked what the parts were used for, the most frequent answers were for bait (49%, 0-100%) and for traditional use (31%, 0-100%). In terms of their conservation, 81% (50-100%) of respondents thought that river dolphins are endangered and 26% (0-84%) reported knowing that they are legally protected species.

Discussion

This study is the first in Peru to assess and analyse perceptions of fishers and local community members regarding river dolphin occurrence and fishery interactions and our findings offer valuable insights into the current status of threats that both dolphin species face. Our research shows that fishers from the Peruvian Amazon are well acquainted with river dolphins. They correctly identified how to differentiate between species. In general, respondents had a more negative perception of *Inia*, which they considered to be an aggressive species. These perceptions could be related to legends of enchantment and kidnapping shared with other Amazon regions that lead to the use of dolphin body parts as love charms (Alves & Rosa, 2008; Mintzer et al., 2015; Siciliano et al., 2018).

Bycatch

We can conclude that there is river dolphin bycatch in all the ports surveyed, with the exception of Aguaytia. For 2015, we estimate that a minimum of 182 dolphins were bycaught annually in surveyed ports. In these ports we surveyed the captains of 251 fishing vessels with approximately 3 fishers per boat. Given there are an estimated 9735 fishers working across in Ucayali and Loreto (PRODUCE, 2013), bycatch numbers could, therefore, be at least an order of magnitude higher. This is a conservative estimate given fisheries census data are seven years old. Also, as catching river dolphins is forbidden, it is also possible that the number of dolphins captured was underreported by respondents. This tendency to under-report is common in cases where the study species are protected (Turvey et al., 2013). Our results demonstrate that bycatch occurs (and likely at higher levels than reported here) and point to potential conservation priority areas, where higher rates of bycatch occur.

River dolphin bycatch was first reported in Peru by Leatherwood and Reeves (1994) and was highlighted as the primary conservation concern at that time, demonstrating that pressure from fishing interactions has existed at least for the past two decades. There is no information on abundance available for either of the dolphin species in this part of the Peruvian Amazon basin (Secchi, 2012; da Silva, Trujillo, et al., 2018). Therefore, it is not possible for us to conclude whether the reported differences in bycatch incidence are related to variations in river dolphin abundance. There were higher rates of bycatch reported in the state of Loreto than in Ucayali, specifically in locations far from urban areas, such as Bagazán, Requena, and Caballococha. Loreto sees the landing of most of the freshwater hydrobiological resources of Peru (PRODUCE, 2015), this could indicate that there is greater fishing pressure in Loreto, which in turn could result in a higher bycatch rates. Freshwater fisheries have also changed in the last decade. Between 2005 and 2015, commercial species such as the pirarucu *Arapaima gigas* or the dorado *Brachyplatystoma rousseauxii* went from 7% to less than 1.5% of the total landings, with new species now dominating landings (Garcia Dávila et al., 2018). The widespread subsistence fisheries have also shifted, going from more selective gears such as harpoons or hook and line to less selective small mesh nets (Sueiro & De la Puente, 2015). The proliferation of nets in the Amazon could also be related to the frequency of bycatch. Most of the fishers interviewed in this study used either gillnets or purse-seines. Previous studies on river dolphin bycatch (Whitty, 2015, 2016; Dewhurst-Richman et al., 2019) have shown higher incidence of bycatch in areas that overlap with gillnet fishing areas.

Use as bait & the piracatinga fishery

Regarding the use of river dolphins as bait for the piracatinga fishery, our results show that, in 2010, the practice was already occurring in some areas of Peru and this continued in 2015. Using river dolphins as bait is illegal in Peru and we suspect that some of the participants feared legal repercussions if they confirmed the use of these protected species in their fishing communities. The use of river dolphins as bait is consistent with reports from other countries in the region, including Colombia and Brazil, where *Inia* and caimans have been reported as used as bait in the piracatinga fishery over the last decade (Salinas et al., 2014; Cunha et al., 2015; Mosquera-Guerra & Trujillo, 2015). Mintzer et al. (2015) found that 98% of interviewed fishers knew of the use of dolphins as bait, and 67% of them could identify at least one community, theirs or elsewhere, where directed take was occurring. A study developed in the western Brazilian Amazon monitored the piracatinga fishery and found that both dolphin species were used as bait in 30% of the fishing events (Iriarte & Marmontel, 2014). These results are higher than those reported in our study for Peru, which could be caused by underreporting or actual differences in the frequency of use of dolphin bait. The Brazilian government announced a 5-year moratorium on the commerce and trade of piracatinga effective January 2015 (Instrução Normativa Interministerial n° 6, of July 17th, 2014). As the effects of this moratorium in Peru are unknown, close monitoring of these issues in Peru could help generate more data to support our findings and generate actions to prevent this problem from increasing in frequency or expanding to other areas.

In the last 10 years there has been an increase in piracatinga landings, with consistently high landings reported between 2008 and 2011 averaging 216 tons a year (Garcia Dávila et al., 2018). These landings continue to increase, with 331 tons registered in 2016 for Loreto (Garcia Dávila et al., 2018). Among our respondents, there were a few who reported piracatinga as their main target fish and indicated the use of dolphins as bait. This could suggest that there is a growing market for piracatinga. Two respondents commented that these specialized fishers were foreigners, that "came to instruct local fishers on piracatinga fishing techniques" (*pers. comm*.) and that the catch was exported. The Peruvian customs authority (SUNAT) has not yet assigned codes to differentiate piracatinga from other species of catfish, making it impossible to track its importation or exportation.

Research in global context and next steps

Surveys with fishers and community members have helped us develop a first assessment of the incidence of river dolphin bycatch events in Peruvian Amazon fisheries. Our results suggest that fishery interactions in the forms of dolphin bycatch and deliberate take should be prioritised as a main conservation threat to *Sotalia* and *Inia* in the Peruvian Amazon. The use as bait was the main reason that IUCN red list status for Inia was changed to endangered (da Silva, Trujillo, et al., 2018), with steep population declines seen within protected areas in Brazil (da Silva, Freitas, et al., 2018). If bycatch and aquatic mammal bait are combined with other existing (Mosquera-Guerra & Trujillo, 2015; Pavanato et al., 2016) and potential threats such as infrastructure development (Alfaro-Shigueto et al., 2018; Finer & Jenkins, 2012), the negative effect on population numbers could be substantial (da Silva, Freitas, et al., 2018; Williams et al., 2016).

An important next step will be to more accurately define bycatch rates and overall numbers of dolphins killed as bycatch. This would be best accomplished with a more intensive monitoring program. For example, onboard observer and community landing site observer programmes have been successfully implemented in artisanal fisheries elsewhere for marine vertebrates (Humber et al., 2011) and could potentially be implemented in the Amazon. Bycatch mitigation techniques should be tested and implemented in areas with high bycatch. Pingers have been successful for reducing interactions between fishing gear and other cetacean species (Barlow & Cameron, 2003; Dawson et al., 2013). Studies focusing on pingers in freshwater habitats are limited, but they were tested on Sotalia in Brazil and individuals were found to be responsive to the acoustic alarms (Avila & Andrade, 2004). Further work could be done to see if this mitigation technique is viable in freshwater ecosystems.

We recommend that interviews with Amazon fishers be revisited in the near future. In addition, these could be expanded to other ports of Peru as well as administered during the dry season to see if our responses were affected by retrospective bias caused by the very different water levels during the wet season. The Brazilian moratorium on piracatinga fishing expired in January 2020 and through similar questionnaires we could obtain insights into how this legislation has affected fisheries in Peru. New legislation prohibiting piracatinga commerce and trade in Colombia (R1710-August 2017) could also affect demand and feasibility of exportations from Peru (e.g., legal, illegal, or underreported commerce). By administering these questionnaires, we will be able to detect longer-term trends in the use of dolphins as bait and of the piracatinga fishery.

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TABLE 1 Demographic and fishing activity characteristics of fishers who participated in the study. Caballococha, Masusa, Manantay and Aguaytia ports were not included in the 2010 study. Gear types refer to Honderas (Hond), Agalleras (Agall).

		2010								2015							
		% of Fishers >50 years old	% of fishers fishing >20 years	% of fishers with vessels			% of fisher using			% of fishers >50	% of fishers fishing >20 years	% of fishers with vessels			% of fisher using		
				No engine	≤12 HP	>12 HP	Hond	Agall	Hooks			No engine	≤12 HP	>12 HP	Hond	Agall	Hooks
Loreto	Bagazan	59	86	0	77	23	48	4	0	59	54	0	80	20	15	85	0
	Pesquero	59	86	0	77	23	30	37	19	69	18	0	19	81	100	0	0
	Nanay	78	63	5	69	26	42	32	16	83	44	0	78	22	22	56	22
	Nauta	71	68	0	92	8	18	38	18	96	54	0	83	17	21	54	25
	Productores	56	56	0	100	0	31	23	0	100	60	0	53	47	47	40	13
	Requena	32	32	10	90	0	9	36	5	80	74	0	93	7	23	73	4
	Caballococha									75	71	0	70	30	36	64	0
	Masusa									87	80	0	91	9	13	53	27
Ucayali	Calleria	92	76	0	47	53	29	54	4	70	50	0	0	100	85	15	0
	Yarinacocha	93	75	8	28	64	41	12	0	57	68	0	57	43	21	54	14
	Manantay									60	90	0	100	0	0	75	20
	Aguaytia									90	50	100	0	0	0	100	0
	Mean	**68**	**68**	**3**	**73**	**25**	**31**	**30**	**8**	**77**	**59**	**8**	**60**	**31**	**32**	**56**	**10**
	Minimum	**32**	**32**	**0**	**28**	**0**	**9**	**4**	**0**	**57**	**18**	**0**	**0**	**0**	**0**	**0**	**0**
	Maximum	**93**	**86**	**10**	**100**	**64**	**42**	**54**	**19**	**100**	**90**	**100**	**100**	**100**	**100**	**100**	**27**

TABLE 2 Summary results of fishers interactions with river dolphins. All values are the percentage of fishers that responded to that option, with the exception of the column describing bycaught individuals per year. Caballococha, Masusa, Manantay and Aguaytia ports were not included in the 2010 study.

		Do dolphins cause problems?	Type of problems			Bycatch during 2010	Dolphin is found alive	*Sotalia* is more frequent as bycatch	*Inia* is more frequent as bycatch	Bycaught dolphins per year			Use as bait
		Yes	Net damage	Steal fish	Aggressive					1	2-3	>3	
		2010											
Loreto	Bagazan	100	92	4	4	5	50	0	22	NR	NR	NR	11
	Pesquero	100	93	0	7	68	79	67	17	61	6	11	37
	Nanay	92	88	0	12	80	83	8	88	39	0	30	15
	Nauta	88	71	13	6	68	72	8	83	36	9	15	32
	Productores	78	86	14	0	56	43	42	42	8	0	3	43
	Requena	86	61	30	9	100	77	26	53	13	0	34	31
Ucayali	Calleria	84	54	23	23	50	88	12	88	22	0	22	57
	Yarinacocha	59	86	14	0	35	85	8	77	6	0	21	19
	Mean	**86**	**79**	**12**	**8**	**58**	**72**	**21**	**59**	**26**	**2**	**19**	**31**
	Minimum	**59**	**54**	**0**	**0**	**5**	**43**	**0**	**17**	**6**	**0**	**3**	**11**

	Maximum	**100**	**93**	**30**	**23**	**100**	**88**	**67**	**88**	**61**	**9**	**34**	**57**
		2015											
Loreto	Bagazan	100	92	8	0	67	88	56	44	12	12	19	41
	Pesquero	94	86	7	7	50	77	7	79	38	38	15	38
	Nanay	72	67	13	20	67	88	12	88	12	12	6	17
	Nauta	88	76	0	24	75	96	25	75	17	17	8	17
	Productores	40	83	0	17	80	100	8	92	8	8	0	33
	Requena	73	93	7	0	60	91	27	73	14	14	18	63
	Caballococha	82	91	9	0	61	92	10	45	16	16	40	46
	Masusa	27	100	0	0	100	87	22	67	0	100	0	0
Ucayali	Calleria	55	93	7	0	45	85	27	27	28	28	6	7
	Yarinacocha	82	82	14	4	64	85	47	53	33	33	7	32
	Manantay	100	95	5	0	75	88	44	56	0	0	0	50
	Aguaytia	0	0	0	0	0	0	0	0	0	0	0	0
	Mean	**74**	**87**	**6**	**7**	**68**	**89**	**26**	**64**	**25**	**12**	**11**	**31**
	Minimum	**27**	**67**	**0**	**0**	**45**	**77**	**7**	**27**	**0**	**0**	**0**	**0**

Maximum	**100**	**100**	**14**	**24**	**100**	**100**	**47**	**92**	**10** **0**	**21**	**40**	**63**

Table 3 Total number of fishers interviewed fishers at each port in 2010 and 2015. Percentages are the number of participants from each port from total participants, totalling 100% vertically. Data regarding the minimum estimate of bycatch of river dolphins (both species) in surveyed ports in 2015 are presented.

Region	Port	Total fishers per port	Fisher interviews		Minimum bycatch estimate
			2010 n (%)	2015 n (%)	
Loreto	Bagazan	87	22 (14%)	27 (11%)	23
	Pesquero	72	11 (7%)	16 (6%)	16
	Nanay	143	27 (16%)	18 (7%)	5
	Nauta	107	30 (19%)	24 (10%)	10
	Productores	116	20 (12%)	15 (6%)	6
	Requena	13	21 (13%)	30 (12%)	29
	Caballococha	276		28 (11%)	41
	Masusa	28		15 (6%)	12
Subtotal		*842*	*131*	*173*	*140*
Ucayali	Calleria	18	14 (9%)	20 (8%)	10
	Yarinacocha	84	17 (10%)	28 (11%)	23
	Manantay	52		20 (8%)	10

Aguaytia	17		10 (4%)	Not Included
Subtotal	*171*	*31*	*78*	*42*
Total		162	251	182

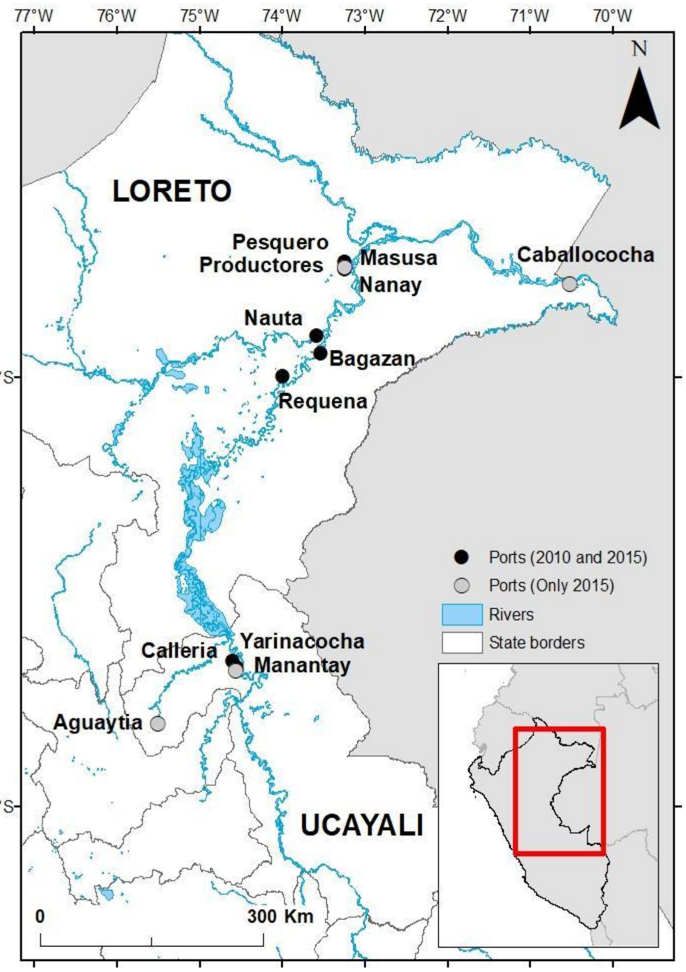

Figure 1 Location of ports visited for survey administration in the states of Loreto and Ucayali.

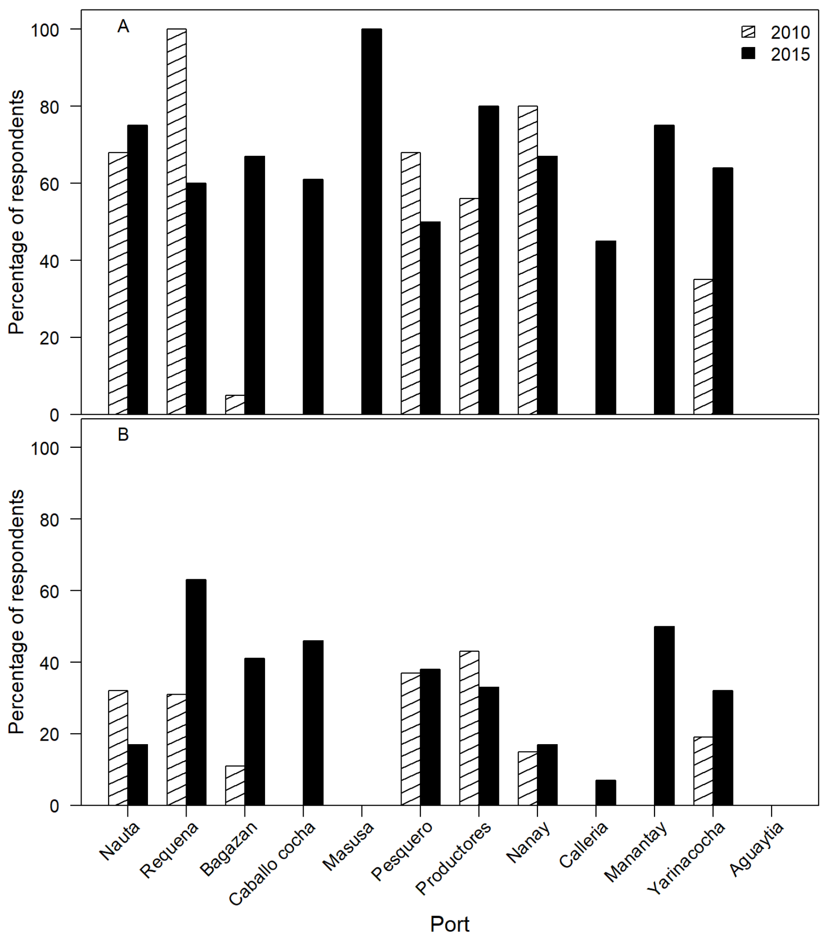

Figure 2 Frequency of response from fishers interviews of A) river dolphin bycatch during study year and B) use of dolphin as bait for the catfish fishery in all sampled ports. No significant difference was found comparing between years for use of dolphins as bait (Wilcoxon test, $P > 0.05$).

Supplementary Information

Nombre entrevistador______________ Fecha______Lugar desembarque_________________

Hola, mi nombre es ____. Soy parte del equipo técnico de la ONG ProDelphinus. Estamos investigando la pesca amazónica y como esta se relaciona con los mamíferos acuáticos. Esta es una entrevista voluntaria y anónima. No necesitamos su nombre ni compartiremos su respuesta personal con alguna persona fuera del equipo de investigación. Asimismo, no tiene que contestar una pregunta que no quiera y puede terminar la entrevista en el momento que desee. Muchas gracias por su participación.

SECCION PESCA

1. ¿Qué edad tiene? _________________
2. ¿En qué puerto vives?_________
3. ¿Por cuántos años se dedica a la pesca? ______________
4. ¿Usas motor? ¿Qué tipo de motor utilizas (caballos de fuerza)? ____
5. Nombre algunas de sus zonas de pesca más común ____
6. ¿Cuántos pescadores salen con usted al pescar? ____
7. ¿Cuántas horas/días de pesca tiene un viaje en promedio ______________
8. ¿Qué tipo de arte de pesca utilizas?___________________________
9. ¿Cuál es su pesca objetivo? _______________________________

PREGUNTAS DELFINES

10. ¿Ves delfines/bufeos en tu zona de pesca? ☐ Sí ☐ No
11. ***Si la respuesta es Sí*** ¿Qué tipo? Colorado__ Gris__ Ambos__
12. ¿Sabes diferenciar a las especies? ☐ Sí ☐ No
13. ¿Piensa que los delfines causan problemas en tu pesca? ☐ Sí ☐ No
14. **Explique** la situación: _____________________________________ ____
15. ¿Alguna vez te ha caído bufeos? ☐ Sí ☐ No
16. ¿Cuántos individuos te caen *al año*? ____________________________
17. ¿Cual tipo cae más? Colorado____ Gris____ Igual____ No se___
18. ¿En qué mes/temporada caen más? ______________________________
19. ¿Caen vivos o muertos? Vivos____ Muertos____
20. ¿Qué se hace con el animal luego? _____________________________
21. **Si contesto se vende**, ¿Como se vende y cuánto cuesta?
22. ¿Sabes si lo utilizan para carnada? ☐ Sí ☐ No
23. ¿Qué tipo se usa más como carnada? Colorado____ Gris____ Igual____ No se___
24. ¿Sabes si se usa su cuerpo o partes para medicinas, u otras cosas? ____
25. ¿Hay una zona donde el enredo de delfines sea mas común? ____

Interviewer Code _______________Date ______Port ________________________

Hi, my name is ________. I am researching with the NGO ProDelphinus. We want to know about your fishing activities and your relationship with aquatic mammals. This is a voluntary, anonymous interview. We don't need your name or share your response with anyone outside of the research team. Please understand that you can omit any questions you don't feel like answering or can terminate the interview whenever you like.

FISHING SECTION

1. Age ________________
2. Home Port:___________
3. Years fishing:_______________
4. Do you use an engine while fishing? What type of engine do you use (HP)? ____
5. Name your most frequent fishing areas: _________________________ ____
6. How many fishers go out to fish with you?____________________
7. How many hours/days does a fishing trip take (average)?__________
8. What fishing gear (s) do you use?_________________________
9. What are your target species? _____________________________

DOLPHINS

10. Do you see dolphins in your fishing areas? ☐Yes ☐No
11. ***If the answer is yes*** What kind? Colorado _ Grey __ both __
12. How do you differentiate species? ________________________________
13. Do dolphins cause problems in your fishing activity? ☐Yes ☐No
14. **Explain** the situation: _____________________________________ ____
15. Have dolphins ever been entangled in your fishing gear? ☐Yes ☐No
16. How many Individuals *per year*? ___________________________
17. What kind of dolphin is entangled more? Colorado ____ Grey _____ Equal _____ Don't know _____
18. In what month/season do they entangle more? ________________________________
19. Do you find them alive or dead? Alive _____ Dead _____
20. What is the dolphins fate? ___________________________
21. **If sold,** how do you sell it and how much does it cost?
22. Do you know if they use dolphins? ☐Yes ☐No
23. What kind by dolphin species is used more frequently as bait? Colorado ____ Grey _____ Equal _____ Don't know _____
24. Do you know if it is used for medicinal or traditional uses? ____
25. Is there an area where dolphin entanglement is more common? ____

Figure S1 Original questionnaire in Spanish and a version translated to English that was administered to fishers in 12 ports of the Peru Amazon in 2010 and 2015.

Table S1 Additional fisher characteristics from the 2015 survey.

		2015							
		Number of days fishing				Crew members			
		1 day	2-5 days	6-10 days	>10 days	Alone	2-3	4-6	6-10
Loreto	Bagazan	78	15	7	0	37	33	15	15
	Pesquero	0	6	13	81	0	0	19	81
	Nanay	39	50	6	6	11	50	11	28
	Nauta	13	71	17	0	37	33	13	17
	Productores	7	43	50	0	7	40	7	47
	Requena	37	33	27	3	30	27	23	20
	Caballococha	32	14	25	29	54	21	14	0
	Masusa	33	60	7	0	20	47	13	20
Ucayali	Calleria	0	0	5	95	0	0	93	7
	Yarinacocha	21	39	18	4	21	25	11	43
	Manantay	30	35	35	0	50	40	5	5
	Aguaytia	100	0	0	0	100	0	0	0
	Mean	33	31	18	18	31	26	19	24
	Minimum	0	0	0	0	0	0	0	0
	Maximum	100	71	50	95	100	50	93	81

Chapter 4: Satellite-monitored movements of the Amazon River dolphin and considerations for their conservation

Elizabeth Campbell, Jeffrey C. Mangel, Joanna Alfaro-Shigueto, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley, David March

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Abstract

The Amazon River dolphin, *Inia geoffrensis*, is found throughout the Amazon and Orinoco basins and is classified as Endangered by the IUCN. Using satellite tracking data from eight adults (1 female and 7 males) in the Peruvian Amazon we demonstrate that these dolphins inhabit a variety of habitat types and have core areas (50% utilization distributions (UD)) (7.2–35.8 km^2) and home range areas (95% UD) (12–105.8 km^2) of variable magnitude. To gain a better understanding of how threats affect these dolphins, we examined how close these individuals were situated to either current or future human threats. Dolphin home ranges overlapped with fisheries by 89% on average (range from 78-100%). Dolphins were found to be on average 252 km (range 121–410 km) from their nearest proposed dam and 125 km (range 21–257 km) from a potential dredging site. Given that many of these threats are still in the planning stages, we strongly recommend considering the negative effects that these activities have already had on other riverine species before proceeding. Additionally, efforts should be made to expand river dolphin tracking programmes spanning multiple seasons and increasing the individuals tracked at our study sites to include more females and in other areas to better understand movement patterns.

Introduction

Amazon River dolphins (*Inia geoffrensis*) are aquatic mammals found in the Amazon-Orinoco basin of Brazil, Peru, Colombia, Venezuela, and Ecuador. They are distributed across all aquatic habitats, including rivers, tributaries, lagoons, confluences, and flooded forests. Habitat use is strongly influenced by flood pulses, as the quantity and quality of available habitats changes annually (McGuire & Winemiller 1998, Martin & da Silva 2004b, Gomez-Salazar et al. 2012). In a regional study in South America, critical habitat hotspots with the highest dolphin density were identified as lakes, confluences, and areas within 200 meters of riverbanks (Martin & da Silva 2004b, Gomez-Salazar et al. 2012).

Data on the distribution and habitat use of aquatic mammals such as Amazon River dolphins can be difficult to obtain and has been identified as a key knowledge gap for this species group (Campbell et al. 2022). Many of these species are widely distributed, highly mobile and can occur in areas that are logistically difficult to access. In the past, habitat use of river cetaceans has mostly been estimated visually by boat-based surveys (Gomez-Salazar et al. 2010, 2012, Pavanato et al. 2019, Aliaga-Rossel & Escobar-Ww 2020). Acoustic surveys, in which hydrophones or acoustic data loggers record sounds (i.e., echo colocation clicks, whistles) emitted by the cetacean, have also been applied in freshwater settings. They have been able to provide a relative measure of abundance, elaborate diel patterns and habitat use under less favourable weather conditions, and when cetaceans are submerged (Tregenza et al. 2007, Yamamoto et al. 2016, Campbell et al. 2017). More recently, drones have been applied to study spatial distributions of these species, with promising results (Fürstenau Oliveira et al. 2017, Oliveira-Da-Costa et al. 2019).

The use of satellite transmitters to track focal individuals is another method of generating information on habitat use. Satellite tracking can provide detailed information on individual animal movements and habitat use, as well as combining temporal and spatial information at broader scales (Gredzens et al. 2014, Sveegaard et al. 2015). Satellite transmitters have been used successfully to track river dolphins, but examples are limited (Mosquera-Guerra et al. 2021). In addition to providing information on an animal's dispersal and migration movement, tracking can provide information on its behaviour, the relationship with environmental conditions and how these govern distribution, and the importance of these environments in their life history (Davis et al. 2014, Gredzens et al. 2014). Data from telemetry can also be used to identify spatial overlaps with negative anthropogenic effects or impacts in the areas the species inhabits (Queiroz et al. 2016, Hart et al. 2018, Frankish et al. 2021). This information is critical for identifying high priority habitats and developing conservation measures such as the designation and regulation of protected areas or the development of policies to mitigate human threats (Graham et al. 2012, Le Corre et al. 2012, Scott et al. 2012, Hays et al. 2019).

Amazon River dolphins are facing increasing human threats including fisheries which leads to competition, intentional killing, and bycatch (Campbell et al., 2020). Their habitat is degraded by mining, logging, and agricultural conversion (Gomez-Salazar et al. 2012b). The construction of dams, mainly in Brazil, is an expanding threat with 175 dams operating or under construction in the Amazon basin, as well as at least 428 more planned over the next 30 years (Forsberg et al. 2017, Anderson et al. 2018, Almeida et al. 2020). Additionally, the Amazon waterway has been approved and is under contract for construction. This proposed waterway involves dredging sites across four main rivers of the Amazon basin and the expansion of ports to facilitate ship navigation across the Amazon, Ucayali, and Marañón rivers (InfrAmazonia 2022). The goal is to create a network that allows for transportation within the Peruvian Amazon but also to and from Brazil, by opening an outlet to the Atlantic for Peruvian trade in the north and one to the Pacific for Brazil. Currently, The total population number for this species is currently unknown and it is listed by the International Union for Conservation of Nature (IUCN) as Endangered (da Silva et al. 2018). Understanding the ecology of the Amazon River dolphin, particularly their reliance on the various diverse habitats available, is critical to improving the species’ conservation prospects.

Here, we expand on our previous analysis of Amazon River dolphin movements (Mosquera-Guerra et al. 2021) to focus on the Peruvian Amazon. We aimed to estimate core areas and home ranges and put this information into a context of habitat disturbance due to anthropogenic activities regarding their conservation status and their prospects in the Peruvian Amazon.

Methods

Study areas

Tag deployment was undertaken before a period of rising waters (October–May) in August 2018 and two areas in the north-eastern Peruvian Amazon were chosen for deployment (Fig. 1). The first location was inside a protected area, Pacaya Samiria National Reserve (PSNR), specifically in the Yanayacu-Pucate river (-4° 39', -73° 49'), close to the confluence of the Marañón and Ucayali rivers in Loreto state. The PSNR is a Ramsar site with a relatively abundant population of Amazon River dolphins (Gomez-Salazar et al. 2012) that covers an area of 20,800 km^2. The second location was Nucuray, Loreto (-4° 58', -75° 32'), a tributary of the Marañón River, close to the confluence of the Marañón and Huallaga rivers.

Tag deployment

Dolphins were captured using the purse seine method described by Read & Westgate (1997) (Plate 1). Only adults were selected for tagging, based on body length, following previous descriptions (Martin & Da Silva 2018). We used Wildlife Computers SPOT-299A tags, measuring 21 x 31 cm, and weighing 70 grams in air. The tags were programmed to turn off during low satellite pass coverage (i.e., between 4-7:00 and 16-20:00 GMT) and give up to 250 locations per day. Transmitters were attached to the proximal part of the dorsal fin according to the methodology of (Wells et al. 2017) using a 6 mm cordless drill and a 1.5 mm polyoxymethylene bolt with silicone tubing. The attachment installation process took 17-20 minutes, and the dolphins were kept moist using sponges, and their eyes were covered to reduce disturbance. Veterinarians were present to ensure effective health monitoring.

Filtering data

Locations were received by ARGOS Data Collection and Location System. Near-duplicate positions, defined as animal positions that occurred 2 min or less after an existing position fix from the same animal, were removed (Ropert-Coudert et al. 2020, March et al. 2021). Raw Argos data were then filtered using a speed, distance and angle filter that removed all location class Z values and points with unrealistic swimming speeds (> 3 m s^{-1}) (da Silva 2003) or unlikely turning angles (locations creating angles less than 15 or 25 degrees were removed if their lengths were greater than 2.5 or 5 km, respectively) using the “argosfilter” R package (Freitas et al. 2008).

Post-processing location data

Many of the satellite locations were located outside the main river channel due to the error of ARGOS locations. Therefore, we created a river mask using OpenStreetMap data and we reallocated each position to the closest river cell (100 m resolution) within the error ellipses from the ARGOS Kalman Filter. Common speed filters, like the one used for the pre-filtering of the data, consider a euclidean space and do not account for the displacement across river boundaries. In fact, two closest points could be separated by larger distances if they were located in different tributaries. We, therefore, calculated speed between consecutive locations along the river path using the “gdistance” R package and estimated the maximum speed threshold by calculating the 95% quantile (*vmax*) (van Etten 2017). A location was removed if the speed from a previous or to a subsequent location exceeded *vmax*. This filtering approach was conducted twice. After filtering, we then interpolated the tracks at regular intervals (i.e., 2 hours) along the river. Tracks with data gaps in excess of 7 days were broken up for separate regularisation (i.e., no interpolation was conducted within gaps). We chose the location inside the river using the Argos location error ellipses. We depicted the ellipse with the river mask for each location, and from multiple possible locations inside the river, we selected the one closest to the Argos location centroid.

Home range estimates

We applied dynamic Brownian Bridge Movement Models (dBBMM) to estimate the utilisation distribution (UD) for all of our tracking data, using the "move” R package (Kranstauber et al. 2021). Unlike standard UD estimators (such as minimum convex polygon and kernel-density estimation), the dBBMM estimates home range by taking into account the temporal and behavioural features of movement trajectories (Kranstauber et al. 2012). In our model, we specified a location error of 2 km, and to estimate the variance of Brownian motion (σ2m) a moving window size of 11 locations and a margin of 29 locations was used to account for potential differences in behavioural movement patterns. We selected these parameters by trial and error, determining which parameters resulted in home and core ranges that best matched the location points, considering the speed and spatial restrictions the species has as well as the raster resolution. Estimates were then clipped with the raster layer of the Amazon River developed using Open Street Map features with a resolution of 200 m. Values for the 50% and 95% volume contours were extracted from the dBBMM model for core use and home ranges respectively.

Spatial threat overlap

We gathered spatial data layers to show the scope of a set of proximal threats in the Peruvian Amazon. We considered three main human threats: dams, the Amazon waterway and fisheries, as they are considered the most significant threats towards river cetaceans, globally (Pavanato et al. 2016, Brownell Jr. et al. 2017, 2019, Campbell et al., 2022). Because of the nature of the available data, the temporal span of threat layers varies. As a result, we included layers that do not completely overlap with tracking periods. Dam data were sourced from (Anderson et al. 2018). This study included dams that were existing, under construction, or proposed. The second threat was the Amazon waterway. For spatial information on the waterway (location of dredging and port sites), data was accessed from the InfraAmazonia platform (www.inframazonia.com), a private organisation that has evaluated the project since its proposal (InfraAmazonia 2018). The distance was calculated from each dolphin's home range from the closest point to the closest dredging site and existing and proposed dams along the river network. For fisheries data, we used the fishery catch data (kg) from the official fisheries government agency, DIREPRO-Loreto (Wildlife Conservation Society 2020) which is provided by fishing zones (927 fishing zones in 29 rivers/tributaries in the Loreto state). We utilised the same classification categories as the original source, ranging from the lowest category (75-50,000 kg) to the highest extraction rate (2,500,000- 7,867,282 kg). We calculated the percentage of the dolphin's home range area (95% UD) in each category of magnitude of fishery catch from 2016 to 2019 and percentage of overlap with the PSNR.

Results

Satellite tag-linked locations were analysed for 8 adult Amazon River dolphins (1 female, 7 males). The body length of tracked individuals ranged from 170 to 197 cm (179.6 ± 7.7 cm, mean ± SD) and their weight from 64 to 117.4 kg (92 ± 14.8 kg). The number of satellite locations averaged 802 ± 464 SD and ranged from 389 to 1829. Tags provided data for a mean of 88 days ± 57 SD (range: 33-187 days), (Table 1). The mean minimum distance travelled per day was 3.5 km ± 0.5 SD, the longest by an individual was 8.5 km, the shortest was 2.3 km. The maximum displacement from the deployment site averaged 31 km ± 16.4 SD and ranged from 12.5 to 48.8 km (Fig 2, Table 1). We found no correlation between maximum displacement and overall tracking duration ($r(6) = 0.14$, $p = 0.7$).

Home range analysis showed that the tagged dolphins moved in tributaries (Yanayacu-Pucate, Nucuray), main rivers (Marañón) and confluences (Marañón and Huallaga rivers, and Marañón and Amazon rivers) (Fig 2). The average home range area (95% UD) for tagged individuals was 53.9 ± 29 km^2 (range = 29.3 – 105.7 km^2). When averaged by the deployment site, dolphins from the PSNR had a smaller mean home range than those from Nucuray, the unprotected area, with a home range of 38 km^2 ± 6 SD and 69 km^2 ± 39 SD, respectively (Table 1, Fig 2). Regarding the core areas (50% UD), the average core area for the eight animals was 17 ± 10 km^2. When assessed by site, animals tagged in the unprotected area, Nucuray, had a core area of 22 km^2 ±11 SD, whereas in the reserve the core area was 11 km^2 ± 2 SD. The home range sizes had a moderate positive, but non-significant, correlation with the duration of tracking, $r(6) = 0.25$, $p = 0.55$.

Animals tagged in the protected area had an average overlap of 51% (range 40-62%) with the PSNR. Those that were tagged in Nucuray had a minimal overlap with the reserve, on average 11% (range 7-15%).

All satellite-tracked dolphins moved within areas where small-scale fisheries exist (Fig 3a and Fig 4), including overlap with low (range 20-84%), medium (15-49%) and high (1-30%) levels of fishery extraction. Dolphins tagged in the protected area had higher overlap with fishery extraction. In regard to their proximity to dams, the distance to the closest existing dam averaged 444 km ± 119.8 SD and ranged from 316 km to 592 km, while distance to a proposed dam averaged 252 km ± 94 SD and ranged from 121 km to 410 km (Supplemental Table 1, Fig 3b). Regarding their proximity to the proposed waterway's dredging sites, dolphins were close to two sites: Puinaha was on average 90 km ± 48 SD (range 21-156 km) and Progreso was 162 km ± 84 SD away (range 72-257 km) (Fig 3b).

Animals tagged in both sites had the same approximate average distance to the closest proposed dam (252.0 km ± 95.7 PSNR and 252 km ± 92.1 Nucuray) and dredging site (126.5 km ± 79.22 PSNR and 125.25 km ± 75.73 Nucuray).

Discussion

Home range results

Our results indicate that Amazon River dolphins have large home range areas covering more than 100 km^2. This is similar to previous studies with *Inia* species. For example, Mosquera *et al*. (2020) used kernel density estimators to analyse home ranges for 23 Amazon River dolphins in South America and estimated a mean of 59 km^2, with a range of 6.2 - 233 km^2. Similarly, (Martin & Da Silva 1998) used VHF radio transmitters and estimated distances covered by 53 dolphins in the Mamirauá Sustainable Development Reserve, Brazil with maximum displacements of up to 225 km (Martin & Da Silva 1998, Martin et al. 2004).

Individuals differed in the magnitude of movement they demonstrated within each study site; animals tagged in the reserve had smaller home ranges than those tagged in Nucuray. Although eight river dolphins is a small sample size, we can hypothesize possible factors that could contribute to differences in ranging behaviour. A potential cause is that there is higher prey density in the reserve, which means that there is less effort of displacement to search for food and therefore, home ranges can be smaller. The Amazon River dolphins' diet is diverse, with literature indicating that they consume at least 43 different species of fish from 19 different families (da Silva 1983). An individual *Inia's* stomach contained the remains of 15 fish with an average standard length of about 65 mm (McGuire & Winemiller 1998). Previous research has shown that a high density of dolphins correlates with a high density of characin fishes in main rivers (Mintzer et al. 2016) and that prey availability could be one of the main reasons behind elective movement between suitable habitats (Martin & da Silva 2004a). Confluences are also areas with high dolphin density as fish aggregate in nutrient-rich areas (Gomez-Salazar et al. 2012, Pivari et al. 2021).

Another possible factor is habitat availability. In our research, we found that the monitored dolphins moved in tributaries, confluences, and main rivers. Previous research based on boat surveys identified that Amazon River dolphins exhibit differing habitat use between low and high-water seasons, preferring main rivers when the water level is low and tributaries and flooded forests when rivers are at their highest levels (Martin et al. 2004, Gomez-Salazar et al. 2012). It could be that dolphins that were tagged in the unprotected area swam to the main river to forage for larger prey but preferred the Nucuray tributary for refuge and rest (Martin & da Silva 2004b), explaining the larger home ranges. Dolphins in the PSNR did not have to move far to access available areas for all of these activities. These variables were not tested but warrant further study with an increased sample size.

Limitations

Our analysis was conditioned to a few aspects that are important to consider. The sex ratios for our study were biased towards males. Note that only one female was tagged, but her home range was found within the range of the males from the same site. Sex differences on home range size are not well understood yet. Past studies have shown that males are more common in major river habitats than females, and that females prefer habitats inside flooded forests (Martin & da Silva 2004b). In addition, mark-recapture studies have revealed that male Amazon River dolphins exhibit similar levels of site fidelity as females, despite their preference for large river systems (Martin et al. 2004). Therefore, we recommend that future satellite telemetry studies give priority to monitoring complementary females.

Another limitation of our study was that it was not designed to look at seasonal changes in movement patterns. Our tags lasted an average of 88 days, similar to the 107 days average of Mosquera et al. (2021). Because all of our individuals were tagged while water levels were rising, further monitoring could be conducted when water levels are low to see if and how dolphin movement changes. Therefore, we recommend studies using tag models with batteries that last longer (closer to a year) or tag deployments that are timed to monitor year-round. These could be coupled with non-invasive methods such as environmental DNA or passive acoustic monitoring to better monitor movement patterns. Water level fluctuation also affects the delineation of rivers spatial boundaries, having a potential impact on the river mask used for our analysis. Freshwater research and management could benefit from improved river maps. Developing robust, open-access data infrastructures with information about rivers has been identified as a priority to improve freshwater conservation (Maasri et al. 2022).

Present and potential future threats

The overlap of home range estimates with human threats shows important patterns that can help to identify priority areas for the conservation of river dolphins in Peru. All the monitored dolphins overlapped with fishing grounds. Although fishing catch does not necessarily correlate to fishing effort, we used it as a proximal indicator to represent fishing pressure in the area. However, a previous study found a positive correlation between effort (average 433 kg per trip, 12 trips per year) and landings in the Loreto fisheries (Tello & Bayley 2001). We therefore hypothesise that in areas with medium and high fishing catch, dolphins are more likely to encounter and be bycaught by fishing vessels. Bycatch is an understudied threat to river cetaceans due to the lack of a comprehensive impact assessments and the absence of consolidated data (Raby et al. 2011, Whitty 2016, Dewhurst-Richman et al. 2019); Campbell et al. 2022. Previous research in Peru has documented bycatch incidents (Campbell et al. 2020) but given the proximity of our findings to fishery extraction, even in protected areas, these numbers could be higher than previously reported. The PNSR allows managed fishing by local communities, and is done sustainably in areas close to small communities (Kirkland et al. 2020), however given the high overlap of dolphin home ranges tagged in the PNSR and fishery extraction further research is needed to understand the risk exposure. In priority areas, onboard observer programmes should be implemented to develop an estimate of the frequency and fate of bycaught dolphins. In addition, overfishing could also potentially be a threat, for example by depleting fish prey for dolphins, (Allan et al.

2005), although this threat has limited research regarding the Amazon River dolphins (Campbell et al. 2022*).*

Dams in Peru do not have the same proximity to river dolphin populations as they have in Brazil (Araújo & Wang 2015, Pavanato et al. 2016). Existing dams are distant from populations of river dolphins. However, all proposed dams are upstream and closer to dolphin populations, which are more likely to cause alterations to key habitat. Downstream effects of dams on river dolphin have been observed and should be considered in Peru before projects are constructed. In Brazil, Araguain dolphin densities were 68% lower downstream of the Tucuruí dam compared to upstream, and dolphins shifted their range in response to dam construction (Paschoalini et al. 2020). Similar effects have been found in other river cetacean species, such as the Yangtze finless porpoise (*Neophocaena asiaeorientalis ssp. asiaeorientalis)* after the construction of the Three Gorges and Gezhouba dams, where dams caused flow regime alterations and a reduction in fish spawning (Wang 2009, Fang et al. 2014, Chen et al. 2017).

Dredging could potentially have negative effects on the dolphin population, similar to those that have happened to the Yangtze finless porpoise where dredging correlated to higher cortisol and lower testosterone levels (Nabi et al. 2018). Entrainment, habitat degradation, noise, contaminant remobilisation, and sedimentation can all have an impact on benthic communities, which in turn can have an impact on cetaceans indirectly via prey displacement (Todd et al. 2015). Noise also directly impact dolphins as it often causes communication masking (when the ability to detect or recognise a sound of interest is reduced by the presence of another sound, (Erbe et al. 2016). The waterway is currently under contract to begin construction, but this has been delayed due to objections from Indigenous and local communities, as well as environmental groups, who claim that the project’s impact assessments and long-term viability are lacking (Sierra Praeli 2020). If it is put into operation, dredging will be undertaken on a regular basis to keep the rivers navigable. Greater vessel traffic in these areas could potentially lead to collisions with dolphins and an increase in underwater noise.

These studied threats are cumulative to others, including direct hunting for use as bait, climate change, and pollution (Palmer et al. 2008, Mintzer et al. 2013, Barbosa et al. 2021). While the Amazon River dolphin population is larger than other endangered river dolphin species, the total population size is unknown, and the species as a whole is thought to be declining at a rapid pace (Martin & Da Silva 2021). Therefore, a precautionary management approach is recommended. Peru is in a unique position as many of the drivers behind habitat degradation here presented are in a proposed stage. Existing threats such as fisheries should be better managed, and in the case of dams and the Amazon waterway, better studied if implementation goes ahead.

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Plate 1 Tag installation process in Amazon River dolphin. A) Amazon River dolphin is caught with a local purse-seine called "boliche". B) Transfer the dolphin to the shore, with help of the boat and net. C) Individual transported to the sampling station. D) The dolphin was placed on a stretcher; the tag was instrumented in 20 minutes. E) Dolphin was released with the satellite transmitter attached. Photographs taken by Mariela Pajuelo.

TABLE 1. Summary of individuals tag deployment duration, emissions and home range. TP = total period of detection; TD = Total detections

Installation Site (date of deployment)	ID (Sex)	Length (cm)	Weight (kg)	TP (d)	TD	95% UD (km^2)	50% UD (km^2)	Maximum displace-ment (km)
PSNR 13/08/2018	A (M)	177	63.9	49	563	40.8	13.6	19.2
	B (M)	182	72.5	45	520	29.3	11.9	13.1
	C (M)	197	97	118	1008	44.3	10	33.1
	D (F)	173	101.9	187	894	39	8.2	44.9
Nucuray 21/08/2018	E (M)	180	97	43	508	56.5	17.9	48.8
	F (M)	170	92.6	34	389	19.9	7.2	12.5
	G (M)	182	111.7	164	1829	95.4	29.1	16.3
	H (M)	176	99	60	708	105.7	35.8	55.8

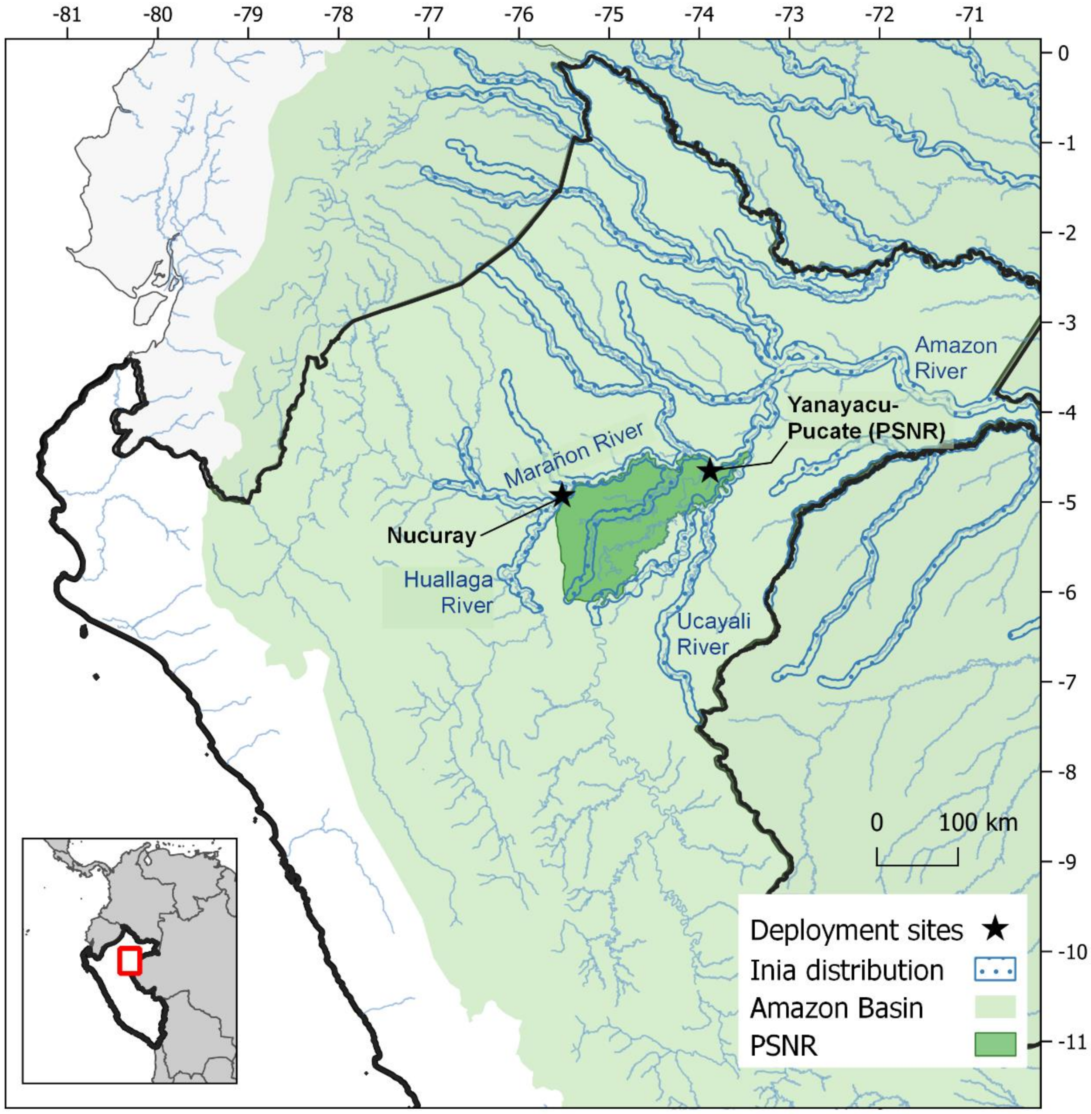

FIGURE 1 Overview of the study area shown in the red inset, and the location of the Pacaya Samiria Natural Reserve (PSNR) and the general distribution of the *Inia* genus (blue dots, Source: IUCN 2021). Black lines denote the Peru border.

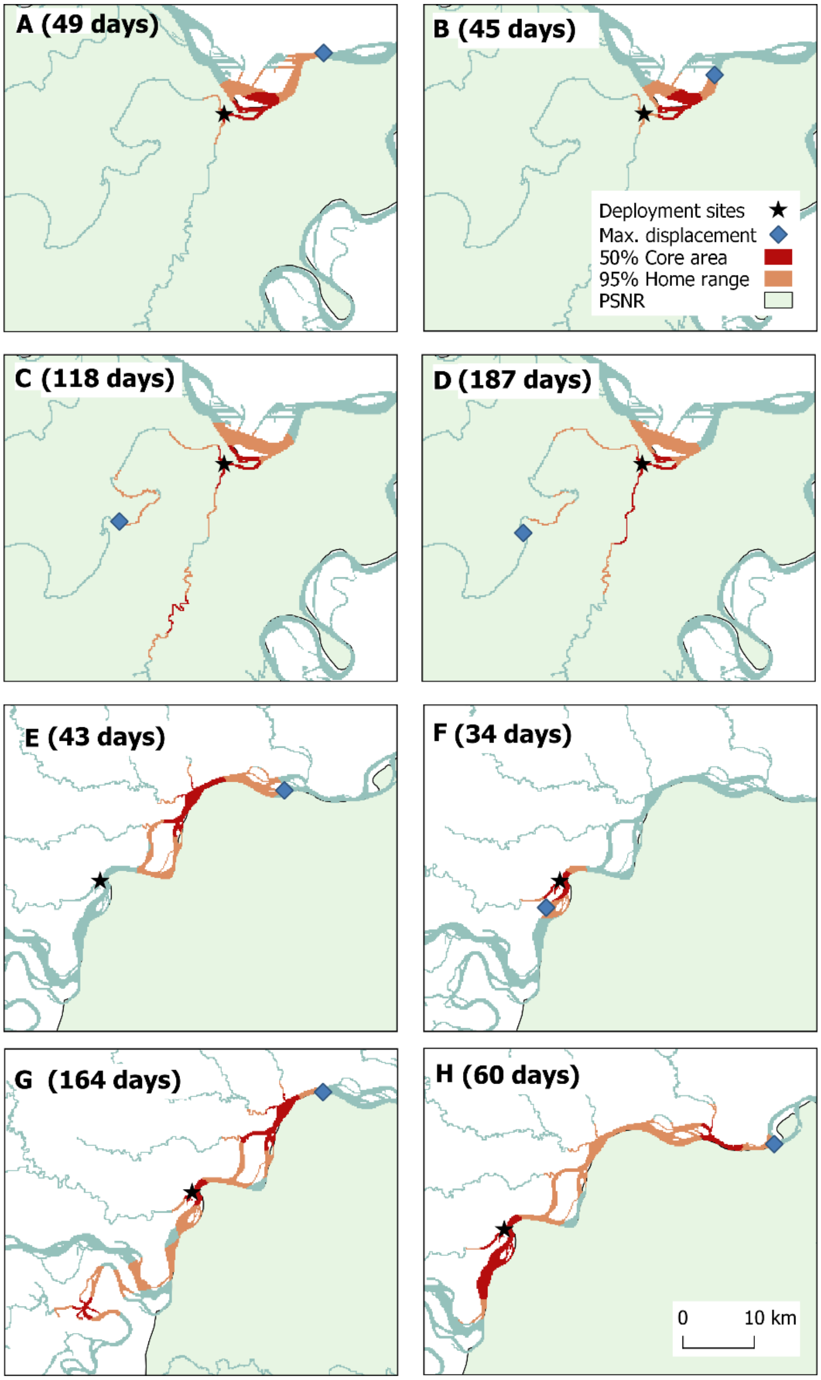

FIGURE 2 Home range estimations for core (red) and home range (orange) areas, with the maps displaying dolphins tagged in PSNR (A-D) and Nucuray (E-H). Total tracking duration is represented between parentheses.

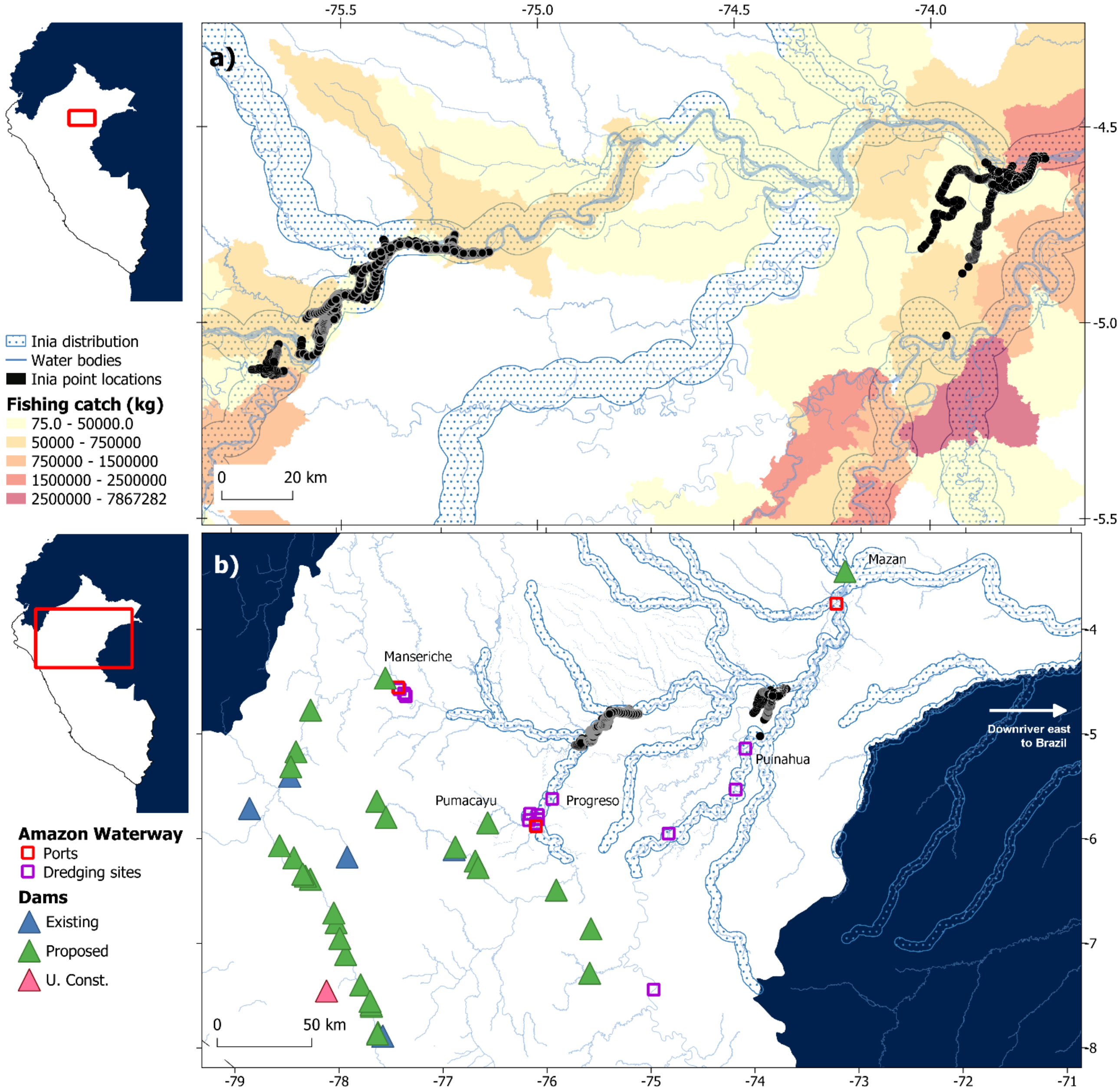

FIGURE 3 The spatial extent of (a) small-scale fishing catches (in kg), (b) Existing, under construction and proposed dam locations and the Amazon waterway project with proposed dredging sites (purple squares) and ports (red squares). Corrected dolphin locations from Argos are presented in black together with the previous reported species overall distribution (blue dots, Source: IUCN 2021).

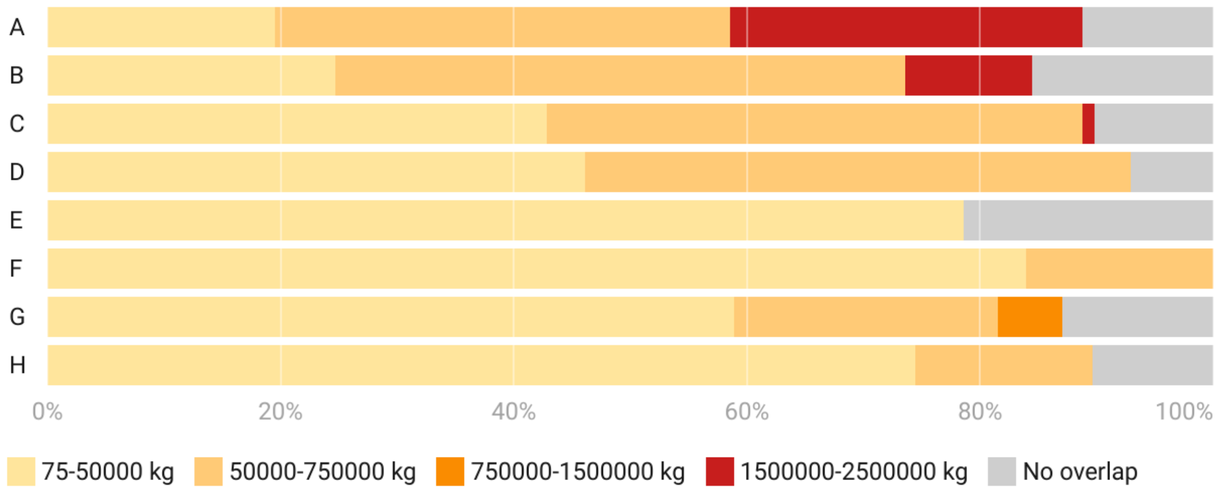

Figure 4 Fisheries catch overlap with monitored dolphins home range (95% UD). The letters on the left represent the dolphin code numbers (see Table 1). Note that dolphins A-D correspond to those tagged within the protected area and E-H to those tagged outside the reserve. The grey represents the missing percentage that could be due to a lack of data or the absence of fisheries.

Supplementary Information

Table S1 Minimum distance (km) to nearest dam and Amazon Waterway's proposed dredging sites per monitored dolphin. E= Existing dam, P= Proposed dam, all dredging sites are proposed.

ID	**Dams (km)**				**Dredging sites (km)**		**Overlap PAs (%)**
	Gera (E)	Mazan (P)	Manseriche (P)	Pumayacu (P)	Puinahua	Progreso	
A	592	141	410	329	61	257	40
B	567	148	392	303	21	230	43
C	552	308	225	148	156	84	62
D	541	283	213	124	141	62	60
E	336	146	395	312	37	239	15
F	332	267	224	137	119	72	7
G	316	140	410	327	58	255	9
H	316	274	236	161	127	95	13

Chapter 5: Exploring the Potential of eDNA to assess distribution of Amazon River Dolphins

Elizabeth Campbell, Joanna Alfaro-Shigueto, Jeffrey C. Mangel, Jose Luis Mena, Ruth H. Thurstan, Brendan J. Godley

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Abstract

To date, traditional visual counting methods have been used to determine the distribution of the Amazon River dolphin (*Inia geoffrensis)* and the tucuxi (*Sotalia fluviatilis)* in the Amazon and Orinoco River basins, but such field studies can be time-consuming and expensive. Environmental DNA (eDNA) is becoming a widely used tool to swiftly assess the presence of small, rare, or elusive animals. At 11 sites along the Huallaga and Marañón Rivers, in the Peruvian Amazon, we combined a distance sampling method to estimate the density and abundance of both species of river dolphins and in parallel sampled water for eDNA-assessment. Distance sampling estimated a mean density of 0.56 animals km^{-2} for Amazon River dolphins and 0.53 animals km^{-2} for tucuxi in main river habitats. eDNA was successfully detected across the site, with detection rates of 100% for *Inia* and 63% for *Sotalia*. This compared with detections of 36 Amazon River dolphins and 39 tucuxi by direct observation. Our findings demonstrate the general potential for using eDNA detection technologies to swiftly determine the distribution of river dolphins in the Amazon but highlight that further work is needed. Further testing may also allow comparison across habitats and seasons.

Introduction

Freshwater systems provide critical services to humans such as water supply, habitat and food provision, erosion prevention, climate regulation, and recreation (Hanna et al. 2018; Kaval 2019). Despite covering relatively small areas of the earth's land surface (> 7%), freshwater ecosystems support a great diversity of life (Lehner & Döll 2004, Reid et al. 2019). Broad scale studies have found that more than a third of described vertebrates are restricted to freshwater habitats (Balian et al. 2008), and marine and terrestrial fish diversity is comparable despite marine environments covering much greater areas (Carrete Vega & Wiens 2012). However, rivers, wetlands, and lakes are among the most threatened ecosystems on the planet, with species declining at a much faster rate than in the terrestrial and marine realms (He et al. 2017, Reid et al. 2019, Albert et al. 2020). Overfishing, pollution, flow modification, riparian habitat degradation, and invasive species all contribute to biodiversity loss (Dudgeon et al. 2006). In addition to these direct threats, climate change effects are a growing challenge (Reid et al. 2019).

Data on abundance and distribution of endangered species are critical for effective management and conservation. Species detection can, however, be difficult in many settings, for example, when monitoring aquatic megafauna (Campbell et al., 2017). These species can be highly cryptic, spend most of their time submerged, and can be highly mobile with extensive ranges. Traditional methods (i.e., direct counts, transects) require vessels or aircraft and are relatively costly. They are limited to use during daylight and optimal weather conditions (Aragonés et al. 1997, Dawson et al.

2004, Taylor et al. 2007). Complementary methods to assess abundance have been tested, such as passive acoustic monitoring (PAM) (Richman et al. 2014) and unmanned aerial vehicles (Fürstenau Oliveira et al. 2017, Oliveira-Da-Costa et al. 2019).

Environmental DNA (eDNA) detection has recently become a non-invasive method for monitoring species that are difficult to see, have low densities, or are logistically difficult to study (Tsuji et al. 2019). eDNA is the extraction of DNA from environmental samples such as sediments, ice, freshwater, and seawater (Thomsen & Willerslev 2015). This technique detects remnants of DNA released into the environment in faeces, mucus, gametes, shed skin and hair, or carcasses. This method has been demonstrated to be effective for a variety of species (Foote et al. 2012, Sigsgaard et al. 2016, Valentini et al. 2016), and ecosystems (Deiner et al. 2016, Mena et al. 2021, Lim & Then 2022)- including the freshwater cetacean, the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) (Stewart et al. 2017, Tang et al. 2019). In aquatic research, eDNA has been primarily used in conservation – focussed research to study invasive and endangered species (Belle et al. 2019). It is also time and cost-effective. For example, when monitoring freshwater turtles, the cost of detection by mark-recapture methods was two to ten times higher than eDNA detection (Robson et al. 2016). Similarly, Mena et al. (2021) found that traditional methods in tropical forests needed more people and double the time when compared to eDNA, and twice the funding.

Both the Amazon River dolphin, also known as the boto (*Inia geoffrensis,* hereafter *Inia*) and the freshwater tucuxi (*Sotalia fluviatilis,* hereafter *Sotalia*) are endemic to the Amazon-Orinoco River basin (Jefferson et al., 2008). Human disturbance, primarily dams (Paschoalini et al. 2020), fishery interactions in the form of targeted and bycatch (Mintzer et al. 2013, Campbell et al. 2020), and pollution (Lailson-Brito Jr. et al. 2008, Mosquera-Guerra et al. 2019) all have a significant impact on these species. The total population size of both species is unknown at this time, but they are declining at different rates (Williams et al. 2016, Martin & Da Silva 2021). Limited abundance data are available in range countries such as Peru, and the extent of their range is unknown (Campbell et al., 2017).

The aim of this study was to estimate river dolphin density and abundance in the Peruvian Amazon's Marañón and Huallaga rivers and undertake a preliminary test of the efficacy of eDNA in detecting the presence of river dolphin species. Furthermore, we test whether observed presence at or upstream from a site influenced our detection rate.

Methods

Study area

Our study areas were sections of the Marañón and Huallaga rivers in the Dátem del Marañón, Loreto state, Peru, beginning in Yurimaguas (5°54′S 76°05′W) and ending at San Lorenzo (4°49′S 76°33′W, Fig. 1). This section has an approximate area of 220 km^2 and is 320 km long. The research was conducted in July 2017 during the falling water season when most habitat types are available for the use of dolphins (i.e., flooded forests, tributaries).

Density and abundance estimations

For density estimation, we followed previously described distance sampling methods adapted to riverine environments (Gomez-Salazar et al. 2012, Paschoalini et al. 2021). A combination of transects running parallel (200 m strip-width transect) and at 45 degrees to the shore (cross-channel line transects) were used to conduct visual surveys (Vidal et al.1997, Gomez-Salazar et al. 2012, Paschoalini et al. 2021).The width of the the belt transects was ensured using laser range finders. Our vessel had two observation platforms, occupied by five observers: three in the bow and two in the stern with a height of approximately 7 metres and a platform for data recording. All observers had previous experience of sighting aquatic fauna. The date, location, species, and number of dolphins (group size) were all recorded for each sighting. Using a compass bearing in relation to the boat's heading, the angle between the observation platform and the first sighting was calculated. The distance between the platform and the dolphin was calculated using the naked eye and, on occasion, a laser range finder. The surveys were conducted over three days, and the vessel travelled at an average speed of 12 km h^{-1}. Visual transects were only performed in adequate environmental conditions (low or no glare, 0-2 Beaufort scale, no rain). Transect data were analysed using the statistical software R (version 3. 4.3) with the packages Distance (Miller 2017) and mrds (Laake et al. 2017) to fit the detection functions, estimate detection probabilities, and densities and abundances for the study area as per Paschoalini et al. (2021).

eDNA sampling and analyses

A total of eleven water samples were collected from successive sample sites (Fig. 1). These were chosen considering where water was at least a metre deep, and our vessel could navigate and anchor at an adjacent location. While e-DNA sampling was performed, transects were paused but direct observations were recorded. Sampling was done by using a filtration device (VigiBOAT, SPYGEN®) with a peristaltic MasterFlex pump Model 7015-21, a VigiDNA 0.45-µM crossflow filtration capsule (SPYGEN®) and disposable sterile tubing for each filtration capsule. We filtered approximately 3 L of water per site, timed approximately at 20-30 minutes. The water temperature averaged 25.8°C (range 22-29°C). All samples were collected at a depth of at least 3 m. One sample was discarded as it was sampled at less than 2 m depth and for less than 20 minutes. Following filtration, all capsules were immediately filled with 80 mL of CL1 preservative buffer (SPYGEN), labelled, and sealed.

The eDNA analysis was carried out at SPYGEN (Le Bourget du Lac, France) using vertebrate (V05) primers and mammalian (Mamm01) primers both of which are located on the 12S region (Riaz et al. 2011, Taberlet et al. 2018). DNA extraction and amplification followed the process described by Mena et al (2019) where sequence reads were analysed using programmes included in the OBITools package and the ngsfilter programme (Boyer et al. 2015, Valentini et al. 2016).

Sequences shorter than 20 bp that occurred less than 10 times per PCR replicate or were labelled "internal" by the obi-clean programme were discarded as these most likely correspond to PCR or sequencing errors. In each eDNA sampling site, the results were analysed as presence/absence. The amount of eDNA shed and hence probability of positive detections may also depend on abundance/density at or upstream from the site. Therefore, we measured density and correlated observed abundance with downstream detection probability.

Results

Abundance estimates

A total of 304 km was travelled in transects, of which 68 transects were band transects and 10 were linear transects. We recorded 36 *Inia* and 39 *Sotalia*. In terms of visualisation, 81% of the observations occurred in ideal weather conditions. Most observations were done within 200 metres of the riverbank (72% *Inia,* 66% *Sotalia).*

Species densities for main rivers were calculated to be 0.56 animals km^{-2} for *Inia* and 0.53 animals km^{-2} for *Sotalia*. Based on densities and the area of available habitat we estimate that the abundance of *Inia* is estimated to be 61 individuals (CV= 2.61) and approximately 53 *Sotalia* individuals (CV=2.96) in main river habitats. Group sizes ranged from 1 to 2 for *Inia* with a mean of 1.2 (CV= 0.33), and from 1 to 5 for *Sotalia* with a mean of 1.5 (CV= 0.57). However, this difference in group size was not significantly different (Mann-Whitney U-test, P =0.06, 1 df) (Fig.2).

eDNA results

Even though we classify our study area as low density, eDNA of both river dolphin species were detected. From the eleven selected sample sites, all detected *Inia* presence (n=11) and 63% (n=7) detected *Sotalia* presence with both species detected in 63% of sites (n=7, Fig. S1). At the sites positive for eDNA, we visually confirmed the presence of Inia in 36% (n=4) and Sotalia in 29% (n=2) at the same location and 83% (n=10) and Sotalia in 58% (n=7) at the site immediately up stream. We found no significant correlation between the presence of dolphins immediately upstream and the presence/absence of eDNA detection for either species (*Sotalia* Spearman's correlation coefficient test statistic: rho = 0.45, $P = 0.1$). It is worth noting, however, that in the majority of cases where *Sotalia* was not detected by eDNA, no observations were made at the sample site or upstream (Fig. 3).

Two other aquatic mammal species were detected via eDNA, in two of the sample sites. The Neotropical otter (*Lontra longicaudis*) was detected in Sapote (site 1) and the Amazon manatee (*Trichechus inunguis*) in the Marañón tributary, Pastaza River (site b). Neither of these species were observed during visual surveys.

Discussion

Our study was successful in estimating the abundance and density of *Inia* and *Sotalia* species in the Huallaga and Marañón rivers. Furthermore, eDNA for both species was generally detected in areas where we saw *Inia* and *Sotalia.* Furthermore, two additional aquatic mammal species were detected, that are threatened, cryptic, low-density, and with limited availability of data (Brum et al. 2021).

Densities

From our estimates we can classify this as a low-density area for both studied species, (0.53- 0.56 animals km^{-2}, Table S1). These densities are comparable to earlier density estimations conducted in similar major river ecosystems in other parts of Peru. In a study conducted in the tri-border of Peru, Colombia and Brazil, *Inia* and *Sotalia* presented densities of 0.6 animals km^{-2} and 0.9 animals km^{-2} respectively (Vidal et al. 1997). They found that dolphins had higher densities in habitats such as tributaries and lakes, reaching 4.8 animals km^{-2} for *Inia* and 8.60 animals km^{-2} for *Sotalia*. A regional study compared densities in the main rivers of the Amazon and the Orinoco of Peru, Colombia, Ecuador, Venezuela, Brazil, and Bolivia (Gomez-Salazar et al. 2012). The highest densities for main rivers were found in Peru, in the eastern Marañón river (near the city of Iquitos) densities were estimated at 2.72 animals km^{-2} *Inia* and 4.87 animals km^{-2} *Sotalia*. In tributaries of the Samiria River, densities of 5.94 animals km^{-2} of *Inia*, and 6.08 animals km^{-2} of *Sotalia* were estimated. These estimations were for rivers and habitats that are part of or border the Pacaya-Samiria Nature Reserve, which is a protected area with a lower degree of anthropogenic impact.

eDNA detection is affected by the density of the target species, including how taxon-specific differences in amplification and sequencing are handled during the data analysis stage, as well as differences in the amount of DNA shed by each species

(Kelly et al., 2014). Furthermore, variations in biomass, body surface area, and animal behaviour may influence the amount of eDNA shed (Andruszkiewicz Allan et al. 2021). *Inia* had more positive detections than *Sotalia* (Fig.3). For both species, we found that eDNA was positively detected at most sample sites where dolphins had been seen upstream. *Sotalia* can be seen jumping and swimming near the surface, whereas *Inia* rarely breaches and is cryptic and is only at the surface briefly. *Inia* has a larger body surface area, with a body length of up to 255 cm and a mass of 150-227 kg, while *Sotalia* is up to 1.5 metres long and weighs close to 50 kg. These factors and how they affect eDNA concentrations are not well understood and need to be further researched.

Limitations of eDNA

Despite its utility, eDNA detection has limitations, particularly for water samples. Our primary limitation is the relatively small number of eDNA samples collected for our expansive study area. Our eDNA detection rates were high, compared to other studies monitoring freshwater species (i.e., 36% Malaysian stingrays *Fluvitrygon kittipongi* (Lim and Then, 2022), 20% largetooth sawfish *Pristis pristis* (Simpfendorfer et al. 2016). Environmental factors such as sediment composition, pH, salinity, and biotic characteristics all influence eDNA detectability (Dejean et al. 2011, Barnes et al. 2014). Cold temperatures, alkaline conditions, and low radiation exposure, on the other hand, help DNA to be preserved for longer periods of time (Strickler et al. 2015). Furthermore, increased water flow dilutes eDNA concentrations, decreasing the likelihood of positive detections (Curtis et al., 2020).

Our window of positive eDNA detection is difficult to estimate, as eDNA detections could be from dolphins we observed directly or animals that were at the sample site orpreviously upstream. From research looking at how time affects detection, positive eDNA detections started to decline since day 25 after American bullfrogs (*Lithobates catesbeianus*) were removed from the study area, and up to 14 days with Siberian sturgeon (*Acipenser baerii*)(Dejean et al. 2011). eDNA detections were higher in the Yangtze finless porpoise during the summer season and near riverbanks, as high-water temperatures may increase the intensity of activity in aquatic animals, resulting in higher levels of secretion or shedding (Takahara et al. 2012, Tang et al. 2019). This is similar to studies that have found significant effect of temperature on the shedding of eDNA in tropical freshwater study areas (Robson et al. 2016). As a result, our findings should be interpreted as reflecting a recent distribution, as the detection probability of eDNA declines on a time scale of days or weeks in tropical freshwater riverine ecosystems (Thomsen & Willerslev 2015).

Future applications of eDNA

Despite these limitations, eDNA can be useful in advancing Amazon biodiversity conservation. There are no total estimates for *Inia* or *Sotalia*'s population, even though there has been considerable effort to achieve this. Given how heterogeneous and widespread their range is, estimating a total population number could be difficult or unachievable (Paschoalini et al. 2021), especially considering that there is already evidence that the population is declining (Martin & Da Silva 2021). This priority data gap is particularly true in Peru (Campbell et al. 2022). Most studies have centred on protected areas in northern Peru, near the Amazon River (Mcguire et al. 2014, Belanger et al. 2022). Other density estimates exist for portions of the Amazon and southern Ucayali rivers (Vidal et al. 1997, Gomez-Salazar et al. 2012, Campbell et al. 2017). Looking to the future, in areas where river dolphin distribution is uncertain, eDNA could be used as a preliminary tool to test areas where the range is unconfirmed, prior to the implementation of a more time-consuming and expensive visual survey (Dorazio & Erickson 2018).

Because eDNA can persist for weeks and will flow downstream, it may indicate presence upstream rather than at a specific location. Consequently, caution may be required, especially at downstream locations. Future research may find flow rate and decay rate modelling useful in determining how far eDNA can be detected from its source. Likewise, eDNA could be beneficial to test seasonal differences in the distribution of both species, particularly in areas where access is restricted due to water conditions, for example, flooded forests, lagoons, or lakes that are cut off from major rivers during the dry season. It could be a useful monitoring tool in protected areas (Gold et al. 2021), allowing for better design and more adaptable spatial protection.

These applications are also relevant to other endangered species, such as the Amazon manatee that we detected. Peru's data for the species is limited to research on their threats, captivity, and rehabilitation but there is a paucity of distribution and abundance data (Reeves et al. 1996, Perea Sicchar et al. 2011, Landeo-Yauri et al. 2014, Campbell & Alfaro-Shigueto 2016). eDNA could be applied to better map their range and as the technology advances, to study abundance (Pochardt et al. 2020). By detecting the eDNA of all species, for instance, possible correlations with fish or plant species could be identified and used to evaluate habitat ecological requirements (Ruppert et al. 2019) - one of the prioritised knowledge gaps for river cetaceans (Campbell et al. 2022).

Emerging tools and technologies like eDNA will be critical in managing threats and generating data to fill knowledge gaps for endangered species. Future research focusing on improving field methods and testing environmental factors could significantly improve detection rates of rare species like river dolphins.

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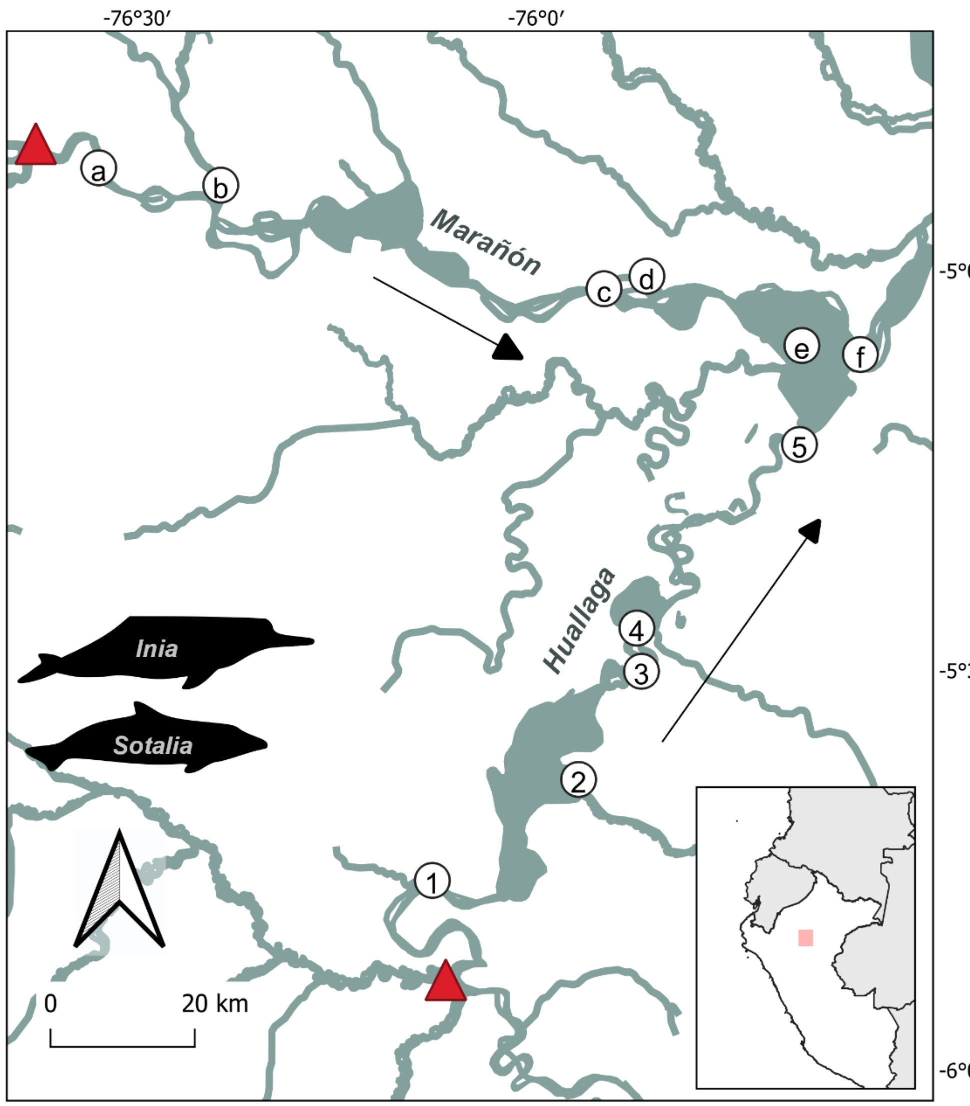

Figure 1 Study area showing the start and end of the study area (red triangles), including the eDNA sample sites in the Huallaga (circled numbers 1-6) and Marañón rivers (circled letters a-f). Arrows and order of eDNA samples follow direction of stream, not order of sample collection. All organism silhouettes are from PhyloPic (T. Michael Keesey, www.phylopic.org).

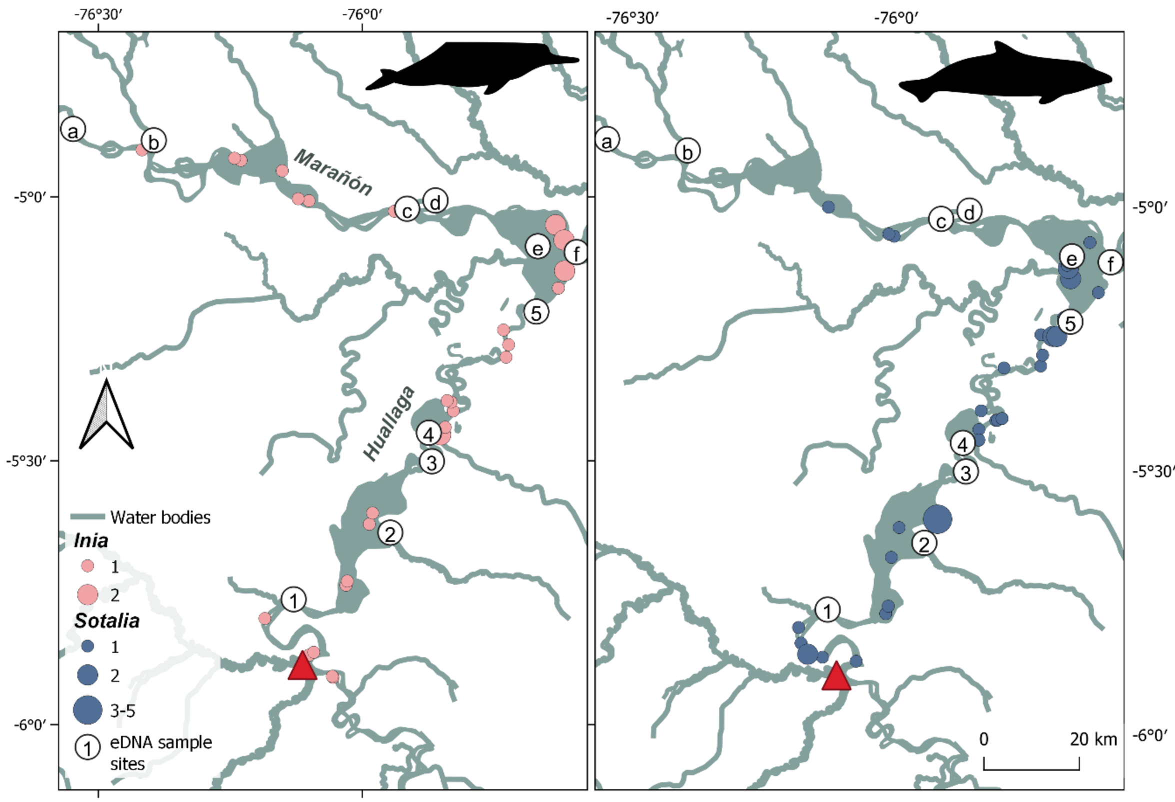

Figure 2 Group sizes for *Inia* (pink symbols) and *Sotalia* (grey symbols) in the rivers of Loreto state, Peru, including the eDNA sample sites in the Huallaga (circled numbers 1-6) and Marañón rivers (circled letters a-f).

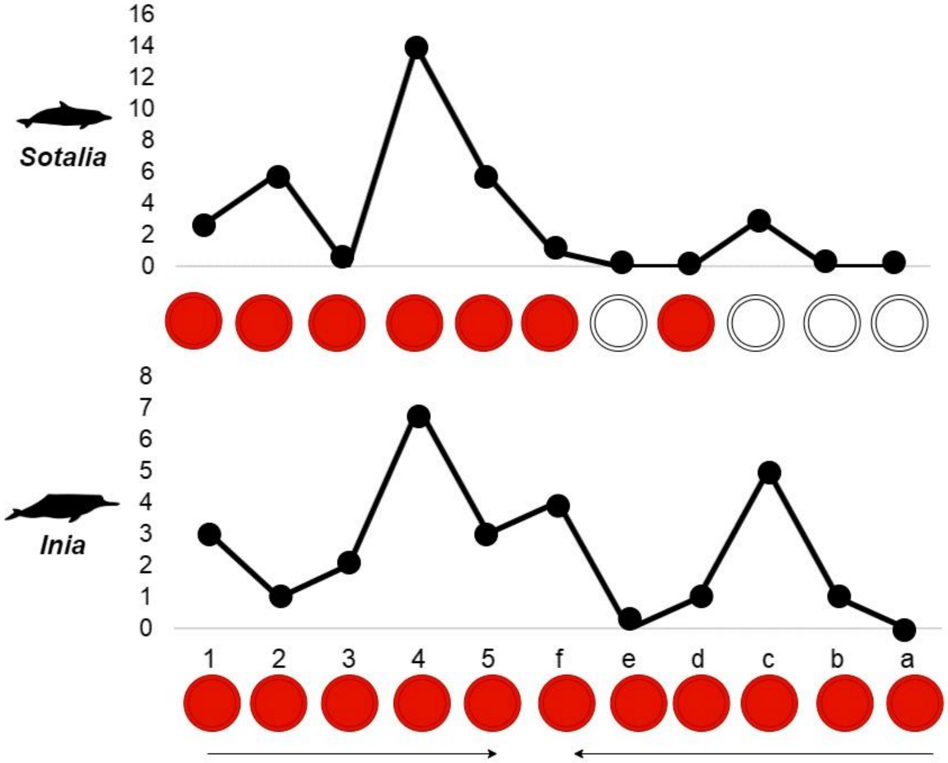

Figure 3 eDNA detection (red indicates positive detection, white indicates negative detection) and observed individuals of each river dolphin species upstream from each sample site. The stream direction is indicated by arrows.

Table 1 Reported density estimations from the Peruvian Amazon for both river dolphin species

River	Habitat	Method	*Inia*	*Sotalia*	Source
Huallaga-Marañón	Main River	Strip and Line transects	0.56 (1.45 SE)	0.53 (1.55 SE)	This study
Samiria-Marañón River	Main River		2.72 (3.88 SE)	4.87 (8.52 SE)	Gomez Salazar et al., 2012

	Tributary	Strip and Line transects	5.94 SE)	(4.65	6.08 SE)	(4.91	
	Channel		4.92 SE)	(0.56	3.09 SE)	(0.31	
	Confluence		4.22 SE)	(1.93	8.69 SE)	(1.43	
Samiria River		Direct count	1.5 CV)	(1.92	0.3 CV)	(1.13	McGuire & Aliaga-Rossel, 2010*
Marañón River			0.3 CV)	(1.07	0.4 CV)	(0.65	
Amazon River (Tri-border of Colombia, Brazil, and Peru)	Lakes	Strip and Line transects	1.53				Vidal et al., 1997
	Main River		2.02				
	Tributary		4.8				

*Encounter rates were provided instead of density estimates

Supplementary Information

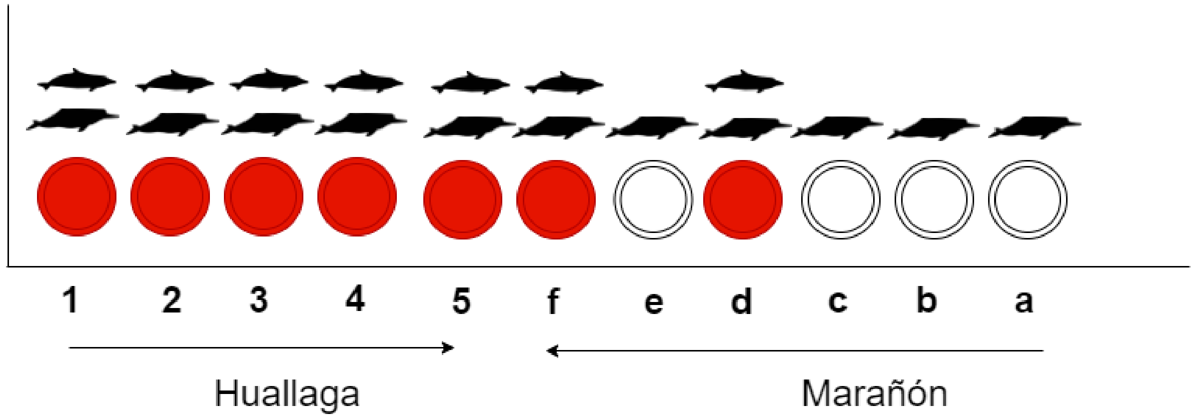

Figure S1 eDNA detection (red indicates positive detection, white indicates negative detection) from each sample site. Icon displays what species was detected at each site. Arrows show the direction of the river.

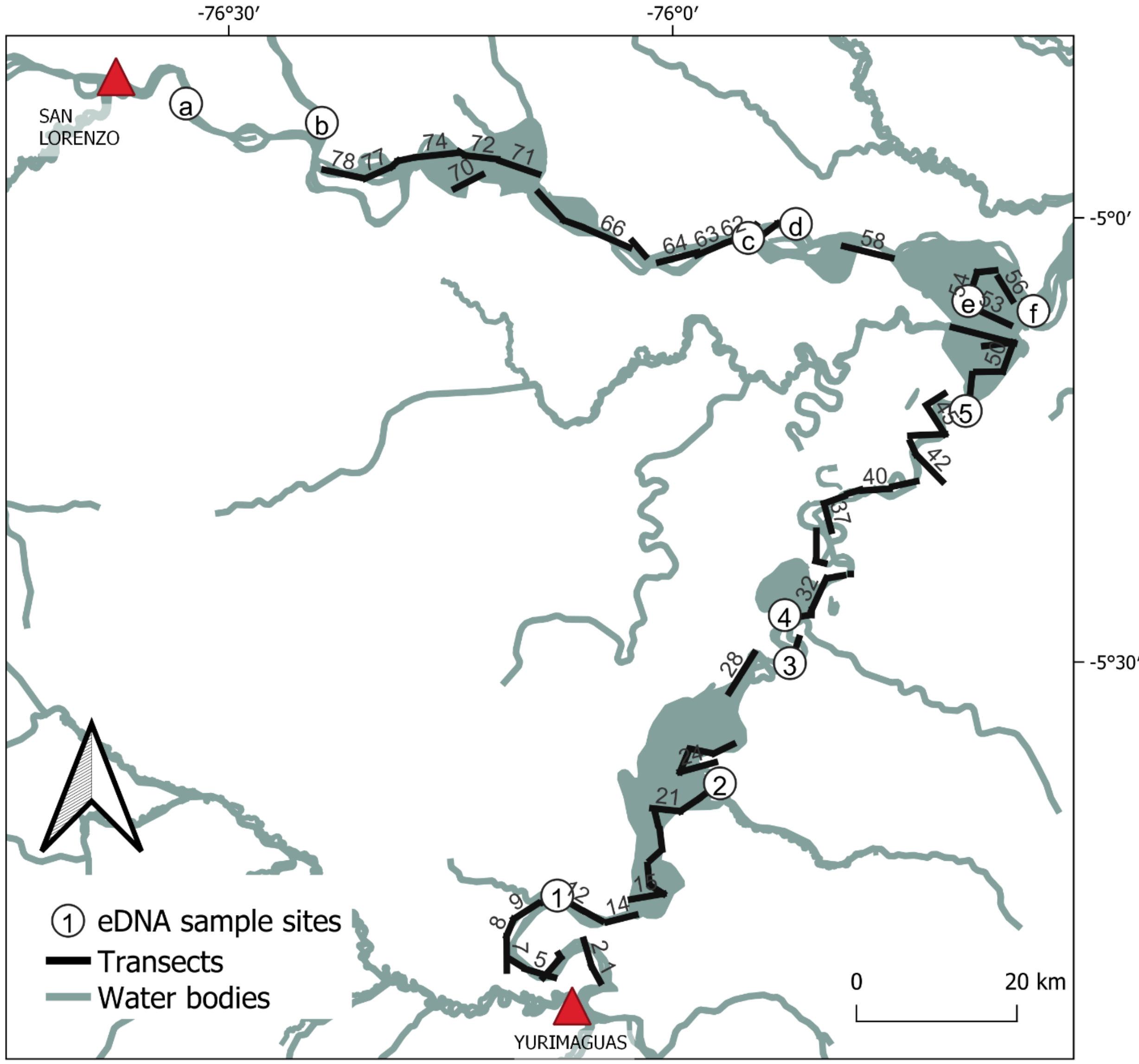

Figure S2 Distribution of eDNA sample sites and transects

Chapter 6: General Discussion

1. Overview

River cetaceans are one of the most threatened groups of mammals on earth (Campbell et al. 2022). The seven species occupy remote areas of South America and densely populated Asian river systems, where they face growing threats associated with human development. This thesis identifies key knowledge gaps, obstacles, and opportunities to better plan and implement conservation actions (Campbell et al. 2022, Chapter 2). In Chapter 2, I present an updated synthesis of global threats, priority knowledge gaps, and tools for addressing them. In Chapters 3 through 5, I focus on filling some of these critical gaps for river dolphins in the Peruvian Amazon. Using local knowledge and spatial monitoring of the Amazon River dolphin and tucuxi (Chapters 3 and 4), I identified conservation priority areas to quantify threats, primarily from water infrastructure projects and fisheries interactions. Then, I provide new information on the distribution and movement patterns of South American river dolphins, using novel methods that could be applied to other areas of river cetacean distribution or to other aquatic megafauna (Chapters 4 and 5).

2. Distribution and Abundance of River Dolphins

The lack of abundance and distribution data for South American river dolphins is a recurring theme in my thesis. This is due to detectability biases (Paschoalini et al., 2021; Richman et al., 2014) and visual surveys that are restricted to optimal sighting conditions, limiting knowledge of dolphins spatial and temporal movement throughout the year (Taylor et al., 2007). Even though available information has grown over the last decades (Chapter 2), these limitations mean that baseline information on river dolphin status and trends is lacking in large parts of their ranges, particularly in Peru, where studies have focused on small sections of their range (e.g., (Gomez-Salazar et al. 2012; Paschoalini et al. 2021). As a result, developing evidence-based conservation actions has been difficult for many populations. Traditional boat-based surveys could be used to assess abundance data in the future, but they could be supplemented with other methodologies such as acoustic monitoring (Richman et al., 2014), drones (Oliveira-Da-Costa et al., 2019a), or as in this thesis, satellite transmitters and e-DNA (Chapters 4 and 5). In Chapter 4, I describe movement patterns that generate information about habitat use, home range, and core range areas. In Chapter 5, I present new density estimates in previously unsurveyed areas of the range of both Amazon River dolphins and tucuxis, as well as test new methods for mapping presence-absence that could be replicated along long stretches of river with minimal effort. also provide abundance and density data for a previously unknown area, as well as test the applicability of e-DNA, a non-invasive, low-cost, and time-effective method.

3. Evaluating the threats to river cetaceans

Limited knowledge of threats affecting a speciesmight lead to the implementation of ineffective or inappropriate conservation efforts (Grantham et al., 2009; Wilson et al., 2007). The conservation status for all river cetaceans was summarised at a global scale and demonstrated similarities among the species and intraspecific regional differences regarding the threats they face (Chapter 2). I reviewed the conservation status of all species of river cetaceans and highlighted current knowledge gaps, the bias in the species and geographic areas that are studied and provided a comprehensive list of recommendations that can help inform subsequent research and conservation efforts. This work also provided an inventory of all published studies focussing on threats, innovative methodologies, and promising conservation interventions for the management of river cetaceans.

Local informant interviews highlighted a number of potentially significant threats to the dolphins in the Amazon-Ucayali rivers of Peru and mapped the presence of illegal activities (Campbell et al. 2020, Chapter 3). Numerous studies have established the effectiveness of interviews with local informants as a method for describing threats (e.g., Turvey et al. 2013; Whitty 2016). By interviewing fishers in 2010 and 2015, I found that threats such as direct catch for use as bait and bycatch were common during both periods but were observed in more ports in 2015. In Chapter 4, by monitoring Amazon River dolphins with satellite transmitters we found that most of their home range overlapped with small-scale fisheries (>78%) and were at close proximities to proposed dams (range 121–410 km) and dredging sites (range 21–257 km). Given the scale and expanding trend of some of the threats identified here, conserving the Amazon River dolphin and the tucuxi in the Amazon-Orinoco River basins will be complex and may require multifaceted approaches to curb threats.

4. Future Work

a. Assessment of population trends and distribution

A better understanding of population trends is needed. Currently, only three publications have estimated trends for river dolphins in the Amazon (da Silva et al., 2018; Martin & Da Silva, 2021a; Williams et al., 2016). These studies cover small portions of their range in Colombia and Brazil and although both found that populations are declining, their methodologies are not comparable, and the declines are at very differing rates. To better conserve river dolphins, robust studies to detect the trend of their populations should be designed. These studies should be carried out periodically and in key areas covering representative habitats of their range. This has been implemented for the Yangtze finless porpoise (Chen et al., 2020; Huang et al., 2020) and has helped identify slow recovery signs for the species. Potential areas for monitoring population trends include areas where threat incidence is well-researched and protected areas are in place, as this could aid in assessing the effectiveness of spatial protection for river cetaceans, which have not been evaluated.

In parallel, studies should continue to map distribution both species. In Peru, there are no estimates for dolphin populations for most of the rivers of the Amazon basin. For example the Ucayali, a river 2700 km long, remains unexplored but is a priority area for conservation as both bycatch and direct catch are common in ports along the river (e.g., Pucallpa, Requena). Similarly, their distribution in the southern-western Amazon is unknown. The emerging methods described in Chapter 2 and applied in Chapter 4 and 5 could be applied to detect areas where river dolphins are distributed and act as a complementary method to traditional boat survey to have a more precise description of each area.

b. Quantify human-induced mortality

Determining bycatch rates is a logical first step in identifying the scale of the threat and a way to highlight key problems that require additional research and management action. Given the unregulated and remote nature of many freshwater fisheries in developing countries, a mechanism for reporting bycatch in these situations remains difficult to find. Observer programmes in marine small scale fisheries typically collect data on the spatiotemporal distribution of bycatch, and have been successful in identifying and describing bycatch species and rates (Alfaro-Shigueto et al., 2010). However, many freshwater fisheries, particularly in Peru, operate on a very small scale (e.g., subsistence and artisanal fisheries), making the use of observer programmes impractical (e.g., no room on the vessel). As a result, self-reporting or participatory monitoring of bycatch rates is more realistic alternative.

Promising toolkits include the Bycatch Risk Assessment (ByRA) (Hines et al., 2020) or “Conservationscape” framework (Whitty, 2018). These are questionnaire-based interdisciplinary methods that can provide estimates of bycatch rates, specifically designed for areas with data gaps and potential high rates of bycatch (i.e., in countries with large gillnet fisheries) while also considering human dimensions related to the threats.

c. Design participatory-community conservation actions

Expert elicitation carried out in Chapter 2 identified challenges is the lack of effective governance in aquatic ecosystems. As threats and populations are monitored, management schemes to reduce negative impacts on river cetaceans will need to be implemented. Until now, most countries have enacted strict laws against the use of river cetaceans (e.g., Brazil's piracatinga moratorium, Yangtze River 10-year fishing ban), but these have been ineffective or only partially effective at reducing the direct capture of dolphins for use as bait or bycatch. However, in the absence of concurrent attempts to better the socioeconomic status of local communities, efforts to impose prohibitions and increase enforcement of fishery rules may unintentionally develop hostility towards conservationists and management systems, making efforts ultimately ineffectual (Dewhurst-Richman et al., 2019; Kelkar & Dey, 2020). To sustain populations of these endangered species within supportive local ecosystems, conservationists and policymakers must develop economic and ecological win-win conditions for both residents and river cetaceans. Long-term projects that involve communities in river cetacean conservation have been successful at participatory monitoring (Mintzer et al., 2015), cooperative fishing (Smith et al., 2009) and monitoring law enforcement (Khan et al., 2020; Thomas & Gulland, 2017). Community engagement also improves compliance with regulations (Gutiérrez et al., 2011). Designing and implementing pilot studies of participatory monitoring and law enforcement in key areas of Peru should be prioritised. This will also partially help to mitigate one of the challenges mentioned in Chapter 2, namely the lack of alternative livelihoods in riverine communities. It will require the involvement of multiple stakeholders, including policy makers, government officials, as well as researchers from a variety of disciplines, such as ecology, social science, economics, and politics.

5. Conclusions

Due to limited resources for monitoring river cetaceans, there are still significant gaps in our understanding of the threats, spatial and temporal patterns in the distribution and abundance of many populations. These knowledge gaps limit population spatial management and the prioritisation of populations in urgent need of protection. Local informant interviews and combined methodology surveys such as those used in all chapters of my thesis are complementary tools for improving knowledge about the status of freshwater cetaceans and building an evidence base for conservation actions. These tools are especially important given the critical state of many river cetacean populations in Asia and endangered species throughout South America. In the absence of efforts to develop inclusive, adaptive management actions that account for both current threats and emerging threats such as climate change, the threat status of many populations may worsen. Over the last two decades, significant efforts have been made to expand conservation efforts for most species. However, the future viability of river cetacean populations will have higher chances of survival if the well-being of local communities is considered when designing conservation actions.

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Annex 1

Impact Summary

Below is a list of publications, presentations, and public engagement outcomes generated during the course of this doctoral dissertation (October 2018–July 2022). Whenever a previously published work was considered part of this thesis, it is indicated.

PUBLISHED PAPERS

Campbell, E., Alfaro-Shigueto, J., Aliaga-Rossel, E., Beasley, I., Briceño, Y., Caballero, S., da Silva, V., Gilleman, C., Gravena, W., Hines, E., Shahnawaz Khan, M., Khan, U., Kreb, D., Mangel, J., Marmontel, M., Mei, Z., Mintzer, V., Mosquera-Guerra, F., Oliveira-da-Costa, M., … Godley, B. (2022). Challenges and priorities for river cetacean conservation. *Endangered Species Research.* https://doi.org/10.3354/esr01201 **(Chapter 2)**

Campbell, E., Mangel, J. C., Alfaro-Shigueto, J., Mena, J. L., Thurstan, R. H., & Godley, B. J. (2020). Coexisting in the Peruvian Amazon: Interactions between fisheries and river dolphins. *Journal for Nature Conservation*, 56(June), 125859. https://doi.org/10.1016/j.jnc.2020.125859 **(Chapter 3)**

Campbell, E.*, Pasara-Polack, A.*, Mangel, J. C., & Alfaro-Shigueto, J. (2020). Use of Small Cetaceans as Bait in Small-Scale Fisheries in Peru. *Frontiers in Marine Science*, 7(October), 1–9. https://doi.org/10.3389/fmars.2020.534507

Guidino, C., **Campbell, E.,** Alcorta, B., Gonzalez, V., Mangel, J. C., Pacheco, A. S., Silva, S., & Alfaro-Shigueto, J. (2020). Whale Watching in Northern Peru: An Economic Boom? *Tourism in Marine Environments*, 15(1), 1–10. https://doi.org/10.3727/154427320X15819596320544

Guidino, C., **Campbell, E**., Bielli, A., Pasara-Polack, A., Alfaro-Shigueto, J., & Mangel, J. C. (2022). Pingers Reduce Small Cetacean Bycatch in a Peruvian Small-Scale Driftnet Fishery, but Humpback Whale (*Megaptera novaeangliae*) Interactions Abound. *Aquatic Mammals*, 48(2), 117–125. https://doi.org/10.1578/AM.48.2.2022.117

Mosquera-Guerra, F., Trujillo, F., Oliveira-da_Costa, M., Marmontel, M., van Damme, P., Franco, N., Córdova, L., **Campbell, E.,** Alfaro-Shigueto, J., Mena, J., Mangel, J., Usma Oviedo, J., Carvajal-Castro, J., Mantilla-Meluk, H., & Armenteras-Pascual, D. (2021). Home range and movements of Amazon River

dolphins Inia geoffrensis in the Amazon and Orinoco River basins. *Endangered Species Research*. https://doi.org/10.3354/esr01133 **(Raw data from Chapter 4)**

Mosquera-Guerra, F., Trujillo, F., Pérez-Torres, J., Mantilla-Meluk, H., Franco-León, N., Paschoalini, M., Valderrama, M. J., Usma Oviedo, J. S., **Campbell, E.,** Alfaro-Shigueto, J., Mena, J. L., Mangel, J. C., Gilleman, C., Zumba, M., Briceño, Y., Valencia, K. Y., Torres-Forero, P. A., Sánchez, L., Ferrer, A., … Armenteras-Pascual, D. (2022). Strategy to Identify Areas of Use of Amazon River dolphins. *Frontiers in Marine Science*, 9(April), 1–11. **https://doi.org/10.3389/fmars.2022.838988**

Nelms, S., Alfaro-Shigueto, J., Arnould, J., Avila, I., Bengtson Nash, S., **Campbell, E.,** Carter, M., Collins, T., Currey, R., Domit, C., Franco-Trecu, V., Fuentes, M., Gilman, E., Harcourt, R., Hines, E., Hoelzel, A., Hooker, S., Johnston, D., Kelkar, N., … Godley, B. (2021). Marine mammal conservation: over the horizon. *Endangered Species Research,* 44, 291–325. https://doi.org/10.3354/esr01115

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PRESENTATIONS

7th International Bio-Logging Science Symposium. *Satellite-monitored movements of the Amazon River dolphin.* October 18-22, 2021.

XII Congress of the Latin American Society of Aquatic Mammals, SOLAMAC- RT 18– Lima, Peru, 5-8 November 2018

Award winner of Video Night- Video available here

Oral: Searching for river dolphins: density estimation of *Inia geoffrensis* and *Sotalia fluviatilis* in the Marañón River, Peru. Original Title: Buscando a los delfines de río: estimación de densidad de Inia geoffrensis y Sotalia fluviatilis en el río Marañón, Perú

Oral: Diagnosis of the conservation status of river dolphins in the Peruvian Amazon. Original Title: Diagnóstico sobre el estado de conservación de delfines de río en la Amazonia Peruana

Poster: Development and validation of mini barcodes for detection of Burmeister's porpoise (*Phocoena spinipinnis*) by means of environmental DNA. Original Title: Desarrollo y validación de mini-códigos de barras para detección de la marsopa espinosa mediante ADN ambiental

PRESS (in Spanish)

Interviewed for La República, a Peruvian national news agency on the preliminary results of **Chapter 4**, May 2019

Interviewed for Mongabay, on the preliminary results of **Chapter 4**, October 2018

Comment for Mongabay, on fishery interactions with river dolphins in South America, August 2018

Video about our field expedition from **Chapter 5**, developed and disseminated by RPP, a Peruvian national radio, media and news agency, 332k views

Interviewed for Rumbos, a Peruvian digital magazine specialised in travel and tourism, on the new National Conservation Action Plan, December 2018