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Strategy to Identify Areas of Use of Amazon River dolphins

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Unsustainable fisheries practices carried out in large parts of the Amazon, Tocantins, and Orinoco basins have contributed to the decline in the populations of the Amazon River dolphins (*Inia* spp.), considered Endangered by the International Union for Conservation of Nature (IUCN). Amazon River dolphin byproducts are often obtained through unregulated fisheries and from stranded and incidentally caught individuals that are traded for the flesh and blubber used for *Calophysus macropterus* fisheries, traditional and other medicinal purposes, and more recently for human consumption. To identify localities of use of Amazon River dolphins, we conducted a systematic review of the related literature published since 1980, complemented with structured surveys of researchers that allowed the identification of 57 localities for uses of *Inia* (33 in the Amazon, two in the Tocantins, and 22 in the Orinoco basins), and two more on the Brazilian Atlantic coast, with recent reports of targeted consumption in the upper Orinoco River. Subsequently, the localities of use or bushmeat markets where Amazon River dolphin byproducts are trafficked were identified. This information was integrated with a kernel density analysis of the distribution of the *Inia* spp. populations establishing core areas. Our spatial analysis indicated that the use of *Inia* spp. is geographically widespread in the evaluated basins. It is urgent that decision-makers direct policies towards mitigating the socioeconomic and cultural circumstances associated with illegal practices affecting Amazon River dolphin populations in South America.

Keywords: amazon basin, Inia spp, artisanal fisheries, conservation, fishery-dolphin interactions, intentional catches, orinoco basin, tocantins basin

INTRODUCTION

The use of aquatic mammals for bait in fisheries for traditional and medicinal purposes or as human consumption is geographically widespread and affects at least 42 species (Mintzer et al., 2018). The incidental capture of whales, dolphins, manatees, and pinnipeds with fishing gear, as well as targeted harvesting, is recognized as a major threat for these aquatic mammals and represents a significant cause of mortality that remains poorly quantified (Crespo and Hall, 2002; Heppell et al., 2005; Clapham and Van Waerebeek, 2007; Costello and Baker, 2011; Diniz, 2011; Lewison and Moore, 2012; Iriarte and Marmontel, 2013a; Mintzer et al., 2013). Products from wild aquatic megafauna are obtained through illegal or unregulated hunting, as well as from stranded (dead or alive) and/or incidentally caught animals and are defined with the term "*aquatic bushmeat*" (CMS, 2016).

The use of body parts of Amazon River dolphins has been reported for traditional and medicinal purposes and as bait in the Amazon, Tocantins, and Orinoco basins (Best and da Silva, 1993; Cravalho, 1999; Aliaga Rossel, 2003; Alves and Rosa, 2008; Gravena et al., 2008; da Silva et al., 2017; da Silva V.M.F. et al., 2018; Siciliano et al., 2018). Individuals are often obtained as products from fishing activities (e.g., such as operational and ecological interactions) or targeted captures (Mintzer et al., 2013; Mintzer et al., 2018). Since the beginning of the 2000s, *Inia* spp. have been hunted illegally for their meat to use as bait for fishing the scavenger catfish *Calophysus macropterus* (known as *blanquillo* in Bolivia, *piracatinga* or *douradinha* in Brazil, *mota* or *zamurito* in Colombia and Ecuador, *simi* or *mota punteada* in Peru, and *mapurite* in Venezuela; Flores et al., 2008; Trujillo et al., 2010; Alves et al., 2012; Cosentino and Fisher, 2016; Trujillo et al., 2020). This catfish largely replaces either explicitly or implicitly the overfished *Pimelodus grosskopfii*, or *capaz* distributed in the Magdalena-Cauca basin in Colombia (Gómez et al., 2008; Salinas et al., 2014; Mosquera-Guerra et al., 2015); and its trading has spread to domestic markets in Brazil (Cunha et al., 2015), and Venezuela (Diniz, 2011).

One of the main reasons for the current re-categorization of *I. geoffrensis* from Data Deficient to Endangered by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species is the increase in mortality of individuals in the last three decades due to conflicts with fishermen in a significant portion of its distribution (da Silva V. et al., 2018) and in smaller proportion as traditional uses or consumption (da Silva V.M.F. et al., 2018; Trujillo et al., 2020). In addition, the populations of this top predator of aquatic food webs (Gómez-Salazar et al., 2011) and regulator of the structure and composition of fish populations (da Silva, 1983; Best and da Silva, 1989) are being threatened by the degradation of their habitats by tensors like the following: (1) construction and operation of 307 dams in the Amazon basin, 10 in Tocantins basin, and four in the Orinoco basin, (2) mining, (3) high rates of deforestation and fire in flood plains, and (4) the negative effects of climate change on the flood pulse (Mosquera-Guerra et al., 2018; Anderson et al., 2019; Mosquera-Guerra et al., 2019a; Mosquera-Guerra et al., 2019b; Campbell et al., 2020; Armenteras et al., 2021; Barbosa et al., 2021; Brum et al., 2021; Fearnside et al., 2021; Pivari et al., 2021). In this context, Amazon River dolphins are considered among the most threatened aquatic mammals globally (Reeves et al., 2003; Trujillo et al., 2010).

In this paper, we identify the geographic distribution of illegal practices using Amazon River dolphins across their area of occurrence. Additionally, we implemented spatial analyses to determine areas of risk for the *Inia* spp. populations. Specifically, our objectives were the following: (1) to identify the localities where these types of practices have been reported, and (2) to establish the core areas for Amazon River dolphin populations.

METHODS

Systematic Review of Literature and Surveys

We accessed 57 literature references (dated between 1980 and 2021) to obtain information on the use of Amazon River dolphins as bushmeat, medicinal and traditional purposes, and human consumption. The search and selection of publications followed the PRISMA methodological approach (Moher et al., 2009; Nakagawa et al., 2017). A search for information was conducted in the following databases: (1) Scopus, (2) Science Direct, (3) Springer Link, and (4) Google Scholar. Different search terms were used: (1) Amazon River dolphin (TI) AND targeted captures AND bushmeat AND piracathinga fishery*, (2) Amazon River dolphin (TI) AND flesh and blubber OR bushmeat (TI) AND piracathinga fishery*, (3) [TITLE-ABS KEY (Amazon River dolphin * AND piracathinga fishery) * AND (flesh * OR blubber * OR bushmeat * OR traditional medicine * AND piracathinga fishery *) AND TITLE (Amazon River dolphin *)]. In addition, 14 structured surveys were carried out with researchers of Bolivia, Brazil, Colombia, Perú, and Venezuela to identify areas where Amazon River dolphin are captured and opportunistic uses are reported. Subsequently, the information was classified in a database considering the following criteria: (1) country, (2) locality, (3) river, (4) basin, (5) subspecies, (6) category of use: traditional/medicinal purposes, bycatch/bushmeat, and consumption, (7) period(s) of recorded bushmeat use (1980-2000/2001-2021), and (8) references.

Spatial Analysis

Spatial analyses included the mapped localities of use of *Inia* spp. in the assessed basins, derived from the literatura review. Additionally, 39,135 georeferenced locations from 23 boat-surveys (*n* = 11,519 locations) conducted in the Amazon (*n* = 16), Tocantins (*n* = 1) and the Orinoco basins (*n* = 6), and 33 tagged individuals from satellite monitoring (*n* = 27,616 locations) in Amazon (*n* = 20 individuals) and Orinoco basins (*n* = 13 individuals; **Figure 1**) were integrated into a kernel density (KD) estimation analysis on percentage volume contours from (K_{10}) 10% to (K_{90}) 90% at 10% intervals (Oshima et al., 2010; Sveegaard et al., 2011; Wells et al., 2017; Mosquera-Guerra et al., 2021). This means that the area within the (K_{10}) 10% contour represented the areas with the highest density or core area and the (K_{90}) 90% contour represented almost the entire range of Amazon River dolphins (Sveegaard et al., 2011). Kernel density analyses allowed us to spatially locate the *Inia* spp. populations at greater risk from use by calculating the following spatial metrics: (1) number of the core areas (K_{50}), (2) distance from the nearest the Amazon River dolphin core area to a locality use, and (3) distance from the nearest core area to a protected area for the assessed basin (Protected Planet Report, 2020). Mapping was performed using the geostatistical analyst and spatial analyst extensions in ESRI ArcGIS version 10.8.1 (ESRI Environmental Systems Research Institute, 2021; **Table 1**).

Statistical Analysis

Shapiro-Wilk normality test was performed to the variables: (1) *Inia* spp. population size, (2) *Inia* spp. population density, (3) Number of the Amazon River dolphin use localities,

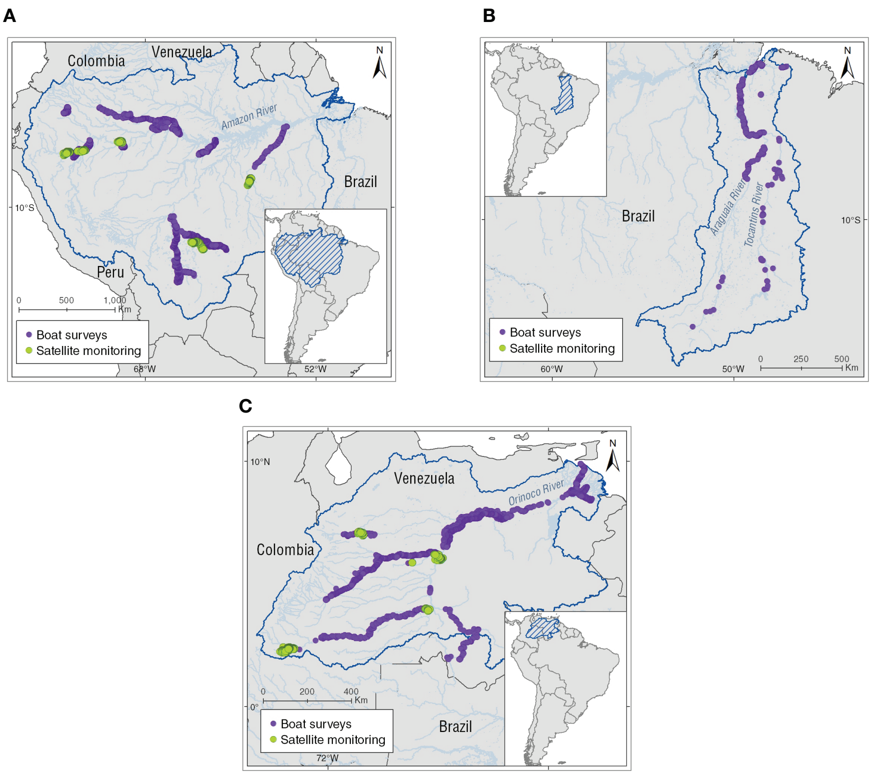

FIGURE 1 | Locations of Amazon River dolphins obtained through boat surveys and satellite monitoring that were used in the spatial analyses. **(A)** Amazon basin, **(B)** Tocantins basin, and **(C)** Orinoco basin.

TABLE 1 | Locations of *Inia* spp. used in the spatial analyses in South America.

Basin	Rivers	Countries	Number of records obtained in boat-surveys	Number of records obtained from satellite monitoring	References
Upper Amazon	Napo, Amazonas, Loretoyacú, Púrus, Samiria, Marañon, and Caquetá/Japurá.	Peru, Colombia, and Brazil.	3,602	9,190	Trujillo-González et al., 2019; Paschoalini et al., 2021
Middle Amazon	Amazonas, Iténez, Mamoré, and Grande.	Bolivia and Brazil.	2,892	2,640	Trujillo-González et al., 2019; Paschoalini et al., 2021
Lower Amazon	Tapajos	Brazil	137	2,865	Pavanato et al., 2016; Trujillo-González et al., 2019
Lower Tocantins	Tocantins	Brazil	979	–	Trujillo-González et al., 2019; Paschoalini et al., 2020
Upper Orinoco	Guayabero, Guaviare, Inírida, Orinoco, Bita, Meta, and Arauca.	Colombia, and Venezuela.	1,946	12,921	Trujillo-González et al., 2019; Mosquera-Guerra et al., 2019b; Mosquera-Guerra et al., 2019c; Paschoalini et al., 2021
Middle Orinoco	Orinoco	Venezuela	83	–	Trujillo-González et al., 2019; Mosquera-Guerra et al., 2019b; Paschoalini et al., 2021
Lower Orinoco	Orinoco	Venezuela	1,880	–	Trujillo-González et al., 2019

(4) Number of core areas (K_{50}) in the assessed river basin sections, (5) Distance of core area (K_{50}) to the nearest locality of use, and (6) Distance of core area (K_{50}) to the nearest protected areas. These tests were developed using the open-source software R.4.0.3 (R Core Team, 2020). In all cases, a value of $p < 0.05$ was considered statistically significant.

RESULTS

Localities that Reported the Use of Amazon River Dolphins

We identified 57 localities where *Inia* spp. individuals were used under the evaluated categories in the study areas, and reported two more on the Brazilian Atlantic coast. The localities were distributed in the basins as follow: Amazon (n = 33, 58%), Tocantins (n = 2, 3%), and Orinoco basins (n = 22, 39%). Based on the number of records, the country with the highest number of localities is Brazil (n = 20, 34%), followed by Venezuela (n = 17, 29%), Peru (n = 13, 22%), Colombia (n = 7, 12%), and Bolivia (n = 2, 3%; see **Figure 2** and **Supplementary Table 1**).

Amazon Basin

The use of *I. g. geoffrensis* in the upper Amazon basin has been reported in 20 localities. The highest number of these is situated on the Amazon River from the Napo River to the tripartite border of Peru, Colombia, and Brazil. In the middle basin, six localities of use have been identified from the confluence of the Putumayo/Içá and Caquetá/Japurá rivers with the Amazon River to the Negro River in Brazil and in the Tijamuchi and Mamoré rivers in Bolivia in these last two rivers, where use is made of *I. g. boliviensis* individuals. Finally, in the lower basin, seven localities from the confluence of the Tapajos and Amazon rivers to the island of Marajó in the vicinity of the Belém city and the mouth of the Amazon River at the Atlantic Ocean in Brazil were identified (see **Figure 2** and **Supplementary Table 1**).

Tocantins Basin

The Tocantins basin is currently isolated from the Amazon River basin. This condition makes it a biogeographic area of interest for genetic and ecological studies of *Inia* spp.; recently populations of this basin were proposed as a new species *I. araguaiaensis* (Hrbek et al., 2014). Since the 2000s, the use of the Amazon River dolphin individuals in the Mocajuba in the Tocantins River and Ourém in the Guamá River have been documented. In addition, the following are reported Bragança and Tracuateua localities in the Caeté River in the Brazilian Atlantic Coast (see **Figure 2** and **Supplementary Table 1**).

Orinoco Basin

In the Upper Orinoco the Amazon River dolphin use is documented from the San Miguel River to the confluence of the Meta-Orinoco rivers in 12 localities located at the border between Colombia and Venezuela. In this section of the basin, consumption of individuals of *I. g. geoffrensis* is reported for the locality of Puerto Ayacucho (Venezuela). Smoked meat of the Amazon River dolphin is marketed as the meat of lowland tapir (*Tapir terrestris*) traditionally consumed by local communities. Furthermore, *Inia geoffrensis* oil is marketed from the city of Puerto Ayacucho to other localities such as Casuarito, Puerto Carreño and Inírida in Colombia to treat symptoms of respiratory ailments. In the middle basin, the use of Amazon River dolphins has been evidenced in the Camaguán, Caicara del Orinoco, San Fernando de Apure, and Puruey localities. In these, the use of *Inia*'s oil for the treatment of SARS-CoV-2 derived respiratory symptoms by indigenous communities who live in these localities has been documented. Finally, in the lower basin this use has been reported in the Ciudad Bolivar, Uverito, Puerto Barranca, San Felix, Tucupita, and Curipao localities (see **Figure 2** and **Supplementary Table 1**).

The most represented use category for Amazon River dolphins in the basins was bushmeat (n = 55, 64%), followed by traditional/medical purposes (n = 30, 35%), and finally consumption (n = 1, 1%). The taxa of the genus *Inia* that report the highest number of

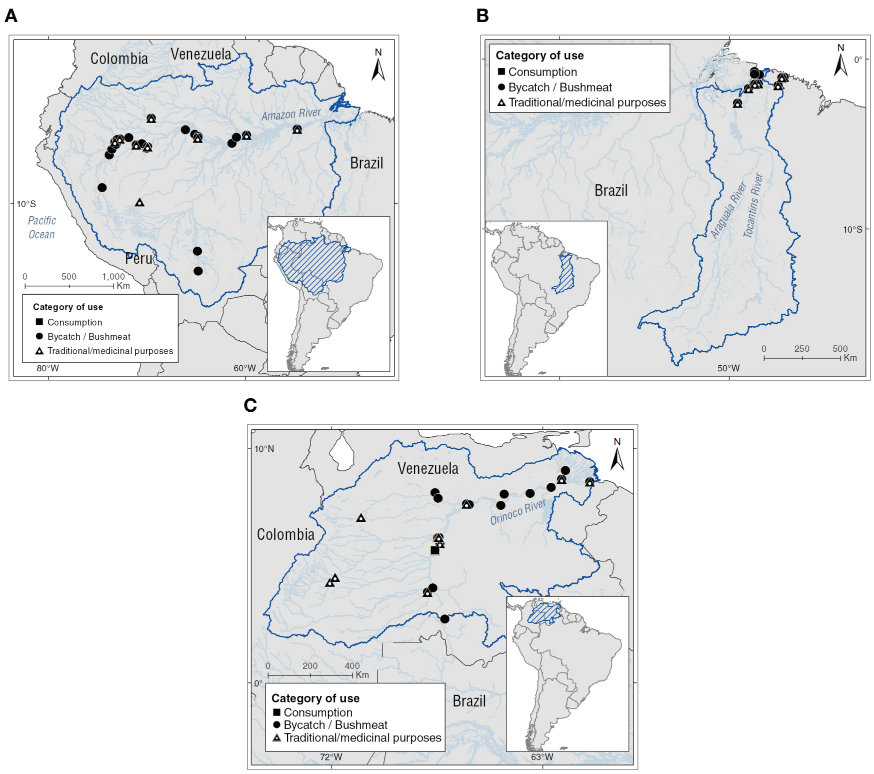

FIGURE 2 | Locations where use categories assessed for Amazon River dolphins are reported. **(A)** Amazon basin, **(B)** Tocantins basin, and **(C)** Orinoco basin.

use localities in the basin evaluated is *I. g. geoffrensis* (*n* = 53, 90%), subsequently of *I. araguaiaensis* (*n* = 4, 7%), and finally *I. g. boliviensis* (*n* = 2, 3%; see **Figure 2** and **Supplementary Table 1**).

Spatial Analysis

Kernel density analyses show that most of the core areas (K_{50}) of *Inia* spp. are in heterogeneous habitat types as follow: (1) main rivers, (2) confluences, (4) lagoons, and (5) channels of the river basins. In the Amazon basin there are four core areas: (1) Napo-Amazonas rivers confluence, (2) Loretayacu-Amazonas rivers confluence, including the wetland complex of Tarapoto, (3) Iténez River, and (4) Tapajós River. The Orinoco basin has three core areas: (1) Guayabero River, (2) Guaviare-Inírida rivers confluence, and (3) Meta-Bita-Orinoco rivers confluence, and in the Tocantins basin, the core area was in the lower basin (**Figure 3**).

The values of the Shapiro-Wilk normality test concluded that the data for all variables do not come from a normal distribution (**Table 2**).

DISCUSSION

Geographic Distribution of the Illegal Uses of Amazon River Dolphin

Our results are in line with previous reports on the widespread use of Amazon River dolphin (*Inia* spp.), such as bait in the *C. macropterus* fisheries. This practice is an unsustainable practice that is widespread in the Amazonian countries of Bolivia, Brazil, Colombia, and Peru, along the lower Tocantins River in Brazil, and along the Orinoco basin shared between Colombia and Venezuela. It is considered a significant threat to the populations of these species (Brum, 2011; Iriarte and Marmontel, 2013a; Iriarte and Marmontel, 2013b; Mintzer et al., 2013; Botero-Arias et al., 2014; Brum et al., 2015; da Silva V.M.F. et al., 2018; Mintzer et al., 2018; Trujillo et al., 2020).

In the last thirty years, the increase of the human population in the hydrographic areas assessed, as well as the internal and external demand for the fishery resources in these countries, have led to overexploitation and the rapid decline of stocks of fishes of commercial interest to fisheries (e.g., large catfish *Brachyplatystoma* spp.), and has resulted in a shift of target species of fisheries from increasingly scarce large fish to smaller species (e.g., small catfishes with *C. macropterus*; Gómez et al., 2008; Barthem, 2013; Barthem et al., 2017). Change in the fisheries in the Amazon, Tocantins and Orinoco basins has involved the use of unsustainable practices (e.g., monofilament nets, trammel nets, and even the use of endangered species such as bait) thus increasing the biological and operational interactions with aquatic vertebrates (e.g., Amazon River dolphins). These events generally result in the incidental capture and retaliatory killing of individuals that in some cases are traded in the bushmeat markets for bait or traditional

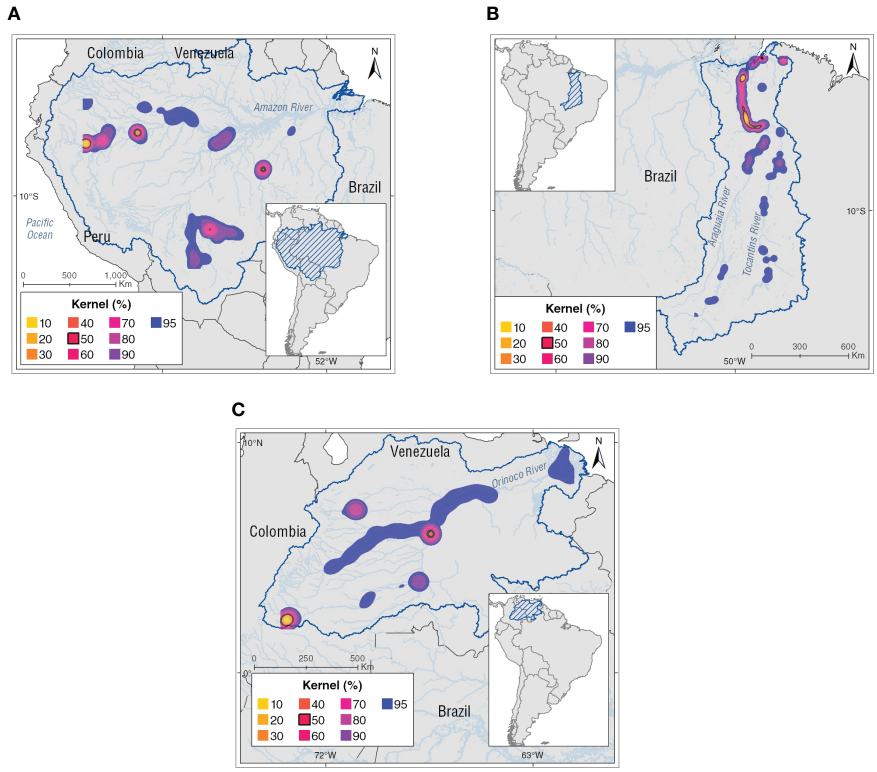

FIGURE 3 | Kernel density (KD) estimation analysis for the *Inia* spp. in the basins with percentage volume contours from (K_{10}) 10% to (K_{90}) 90% at 10% intervals. The black line indicates high-density areas for the Amazon River dolphins defined as the 50% kernel contour or core areas. **(A)** Amazon basin, **(B)** Tocantins basin, and **(C)** Orinoco basin.

purposes and in lower proportions for consumption (Hernández and Gonzalves, 2009; Diniz, 2011; da Silva et al., 2011; da Silva V.M.F. et al., 2018; Escobar-WW et al., 2020; Trujillo et al., 2020; Brum et al., 2021).

Governments of Brazil and Colombia have generated instruments such as moratoriums to regulate or prohibit the commercialization of *C. macropterus* (da Silva V.M.F. et al., 2018; Trujillo et al., 2020). This interaction is considered a serious threat for *Inia* spp. populations in management plans formulated in Brazil, Bolivia, Colombia, Peru, and Venezuela. However, the implementation of actions proposed in these strategies for the mitigation of this threat has not been effective due to factors such as a: (1) lack of transboundary regulatory instruments for the management of the fishery resource (e.g., moratoriums and ban unified between neighboring countries), (2) reduced institutional capacity to control extensive areas in transboundary zones, and (3) high levels of economic vulnerability and low levels of education of the local communities that facilitate their insertion into extractive models (e.g., illegal trade of wild species), and the use of species of fauna (e.g., river dolphins) for the treatment of diseases without scientific evidence.

Spatial Ecology of Amazon River Dolphins

Our kernel density results (K_{10} – K_{95}) coincide with those reported by Mosquera-Guerra et al. (2021) on the heterogenous distribution of the core areas in the different

TABLE 2 | Summary of the significance values of the Shapiro-Wilk test for the variables.

Category	Variables	Type	*p* value
Ecological	*Inia* spp. population size	Continuous	$4{,}2 \times 10^{-5}$*
Ecological	*Inia* spp. population density	Continuous	0,02*
Ecological	Number of the Amazon River dolphin use localities	Continuous	0,03*
Environmental	Number of core areas (K_{50}) in the assessed river basin sections	Continuous	$4{,}1 \times 10^{-6}$*
Spatial metric	Distance of core area (K_{50}) to the nearest locality of use	Continuous	0,02*
Spatial metric	Distance of core area (K_{50}) to the nearest protected areas	Continuous	0,0002*

Those significant for the explanatory predictors are marked with an asterisk (*).

habitat types used by Amazon River dolphins (e.g., confluences, channels, tributaries and lagoons) that are influenced by the ecology of the species and environmental aspects of the basin, such as: (1) wide variations in the home range sizes (K_{95} = 6.2 – 234 km², mean = 59 ± 13.5 km²), and core area sizes (K_{50} = 0.6 – 54.9 km², mean = 9 ± 2.6 km ²), (2) broad and specific habitat uses, (3) movements influenced by the lateral and longitudinal migration of fish, (4) sexual segregation of *Inia* individuals, and (5) ecological characteristics of the aquatic systems where they occur (productivity levels; Mosquera-Guerra et al., 2021).

Although *Inia* spp. is distributed over >1,000,000 km^2 of the Amazon, Orinoco, and Tocantins basins, its occurrence is represented by only 15% of their distribution inside protected areas (Mosquera-Guerra et al., 2018). This is evidence that *Inia* spp. populations throughout much of their range are exposed to different types of human-induced threats such as bycatch (Hernández and Gonzalves, 2009; da Silva et al., 2011; Diniz, 2011; da Silva V.M.F. et al., 2018; Escobar-WW et al., 2020; Trujillo et al., 2020; Brum et al., 2021).

The results obtained through our statistical analysis show that the variables do not come from a normal distribution. This condition may be due to the widespread occurrence of this practice on the *Inia* spp. and the reduced management and control of the protected areas in the basins evaluated (da Silva V.M.F. et al., 2018; Trujillo et al., 2020). The population aspects considered in our analyses-such as population size of Amazon river dolphins- are influenced by: (1) the abundance and availability of fish prey, (2) the accessibility to foraging locations, determined mainly by the flooding pulse and river geomorphology, and (3) group sizes (Martin and da Silva, 1998; McGuire and Winemiller, 1998; Trujillo, 2000; Martin and da Silva, 2004; McGuire and Henningsen, 2007; Yamamoto et al., 2015; Mintzer et al., 2016; Mosquera-Guerra et al., 2021). Amazon River dolphins make up one of the smallest group sizes among odontocetes as a strategy to increase individual fitness and reduce competition for prey during declines in fish abundance during the high-water period (Gómez-Salazar et al., 2011).

Additionally, the spatial ecology of Amazon River dolphins is influenced by strong sexual segregation of individuals. The documented differential behaviors in the intensity of habitat use between males and females is reported by Trujillo (2000) for the lakes of Tarapoto and the Colombian Amazonas, Martin and da Silva (1998) and Martin and da Silva (2004) using data from 24 individuals monitored with radio telemetry in the Mamirauá Sustainable Development Reserve, and Mosquera-Guerra et al. (2021) from 24 individuals monitored by satellite in Bolivia, Brazil, Colombia, and Peru. This sexual segregation of *Inia* spp. differentially exposes males and females to targeted or incidental captures as well as other types of threats (Mintzer et al., 2016). The interactions between Amanimals with 20 individuals killed for use as bait inazon River dolphins and fisheries generally occur in highly productive habitats, such as: (1) confluences, (2) channels, and (3) lagoons, where capturing mostly sexually mature individuals and possibly larger numbers of females that have minor movements and are restricted to specific habitats where they care for their calfs. This could explain the rapid population decline in their area of occurrence (Williams et al., 2016; Martin and da Silva, 2021), possibly due to the special reproductive conditions of *Inia* spp. including (1) extended periods to reach sexual maturity of individuals that on average is considered to be 9.7 years, (2) extensive gestation periods (12.3–13 months), (3) prolonged parental care of calves (1.5–5.8 years), and (4) average intervals between births of 4.6 years (Martin and da Silva, 2018).

Knowledge Gaps

Our study highlights the need to continue with *Inia* population trend studies in order to monitor in a standardised way the fast population decline of Amazon River dolphins reported in the last three decades in the study areas (Williams et al., 2016; Martin and da Silva, 2021). This information is essential to complement spatial analyses and to focus conservation efforts in priority areas. Population studies conducted in the upper and middle Amazon and Orinoco rivers highlight the negative impact of bycatch on *I. g. geoffrensis* populations. For example, Williams et al. (2016) assess Amazon River dolphin abundance estimates made in the Colombian Amazon trapezoid in 1993, 2002 and 2007, and report an annual decline probability for *I. geoffrensis* of > 0.75. Hernández and Gonzalves (2009) report that the population of *I. geoffrensis* in the Javari River, a tributary of the Amazon River, is 250 animals with 20 individuals killed for use as bait in *C. macropterus* fisheries annually (8%). da Silva et al. (2011), and Martin and da Silva (2021) report between the 5.5–10% annual decline of populations of *I. g. geoffrensis* in the Central Amazon in the vicinity of the Mamiruá Reserve and document that 1650 Amazon River dolphins are captured annually near the Brazilian Amazonian city of Tefé. Finally, in the Venezuelan Orinoco basin, Diniz (2011) estimates that 840 individuals are killed for piracatinga fisheries (da Silva V.M.F. et al., 2018). In this context, it is a priority to continue with this type of population dynamic studies and thus contribute to an understanding of the effect of this threat on the health of *Inia* populations.

In this context, it is necessary to clarify the taxonomy of the genus *Inia* using integrative taxonomy studies since currently only two subspecies are recognized (Committee on Taxonomy, 2021); *I. g. geoffrensis* distributed across the Amazon, and Orinoco basins and *I. g. boliviensis*, found along the Mamoré, Iténez, and Madeira rivers (Aliaga-Rossel, 2002; Aliaga-Rossel et al., 2006; Gravena et al., 2014; da Silva and Martin, 2014; da Silva V. et al., 2018; Aliaga-Rossel and Guizada-Durán, 2020; Pivari et al., 2021). This condition does not allow for evidence of possible effects on the loss of genetic diversity for the genus caused by the reduction of populations. This is the case of the *Inia* spp. that are pressured by targeted and incidental catches in the middle Amazon (Bolivia and Brazil), and Tocantins Basins (Brazil). It has been proposed that *I. boliviensis* corresponds to a valid species (Banguera-Hinestroza et al., 2002; Ruíz-García, 2010, and Gravena et al., 2014); in the same way, Hrbek et al. (2014) have suggested *I. araguaiaensis* (Tocantins basin) as a new species in the genus, with a population size >3,000 individuals, seriously threatened by infrastructure projects like dams (Hrbek et al., 2014; Paschoalini et al., 2020; Brum et al., 2021). Although these taxa have not yet been recognized as valid species by a section of the scientific community

(Committee on Taxonomy, 2021), a precautionary principle should be considered and efforts should be made to preserve the taxonomic diversity of the genus *Inia* (Trujillo et al., 2010; da Silva V.M.F. et al., 2018).

Additionally, it is a priority to promote the implementation of public health programs in the countries of the region that monitor concentrations of heavy metals in aquatic ecosystems as well as the zoonotic risks generated by the illegal bushmeat market. The best biological models for evidence of mercury concentrations in aquatic food webs are top predators (e.g., Amazon River dolphins; Mosquera-Guerra et al., 2019a; Barbosa et al., 2021), and benthic fish with omnivorous habits (*C. macropterus*; Mosquera-Guerra et al., 2015). These aquatic vertebrates are extensively used in the region, and this situation could become a public health problem for local communities and external consumers who make multiple uses of these species.

Finally, the bushmeat markets are widely distributed in the Neotropical region, illegally trading massive numbers of wildlife rodents, primates, xenarthrans, and ungulates (Olival et al., 2017), with a significant increment in the trading of *Inia* since the 2000s for bait for *C. macropterus* fisheries, and more recently for human consumption. The use of other products of *Inia* such as oil, eyes, and genitals organs for traditional purposes and non-evaluated treatments of respiratory ailments since the 1980s (Cravalho, 1999; Gravena et al., 2008; Loch et al., 2009; Trujillo et al., 2010; Martins, 2015; Cosentino and Fisher, 2016; Santos, 2017; da Silva V.M.F. et al., 2018; Mintzer et al., 2018; Siciliano et al., 2018), constitutes a risk for the emergence and transmition of zoonotic diseases and future pandemics. Bushmeat markets are centers for the interaction of viral loads of various vertebrate species (Olival et al., 2017), that could, at any time, cause a zoonotic jump in densely populated places with the Amazon basin where recent censuses have reported more than 40 million inhabitants.

CONCLUSION

Spatial analyses are powerful tools that at different scales contribute to an understanding of the distribution of areas of the ecological importance of the species with wide ranges of occurrence such as *Inia* spp.; as well they contribute to the identification of their threats, and focus conservation efforts. Species such as the Amazon River dolphin erroneously have been considered relatively safe from human-induced threats due to its wide area of distribution. However, this consideration ignores the broad and specific ecological requirements of river dolphins, as well as the cumulative effect of the multiple threats facing their populations and habitats throughout their range. An example of this condition was the recent ecological extinction in 2006 of the baiji (*Lipotes vexillifer*) that was widely distributed along 1,700 km in the middle of the Yangtzé River in China.

Over the last three decades in South America, researchers have endeavored to identify threats to the conservation of taxa of the genus *Inia*, including quantifying the number of individuals that have been captured and killed for illegal use. This scientific knowledge has been essential in the construction of different strategies for the conservation of Amazon River dolphin populations. However, despite the efforts made by civil society and governments, the implementation of these actions lacks effectiveness due to aspects such as the absence of transnational instruments to sustainably manage the habitats and the conservation of healthy populations of this endangered cetacean on a basin scale. The current state of decline *Inia* spp. populations mainly are caused by of the directed and incidental catch as well as the ecosystemic degradation of the natural environments suitable for Amazon River dolphins. One of the identified problems compromising the effectiveness of management is the reduced management capacity at the transnational level. Finally, in the context of the global health crisis caused by SARS-CoV-2, it is urgent to prevent future pandemics through public health surveillance strategies and the social management of the bushmeat markets, while considering the cultural and economic needs of local populations of these basins.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Pontificia Universidad Javeriana.

AUTHOR CONTRIBUTIONS

FM-G led and executed the systematic review and spatial analyses, synthesis, and preparation of the first draft. FT, JP-T, HM-M, NF-L, MP, MV, JU, EC, JA-S, JLM, JCM, CG, MZ, YB, KV, PT-F, LS, AF, SB, PD, and DA-P contributed the initial idea and from the first draft on, edited and organized the development of the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.838988/full#supplementary-material

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