SC/67B/SM/16

Analysis of distribution of river dolphins (Inia and Sotalia) in protected and transformed areas in the Amazon and Orinoco basins

Federico Mosquera-Guerra, Fernando Trujillo, Danni Parks, Marcelo Oliveira-da- Costa, Miriam Marmontel, Dolors Armenteras-Pascual, Saulo Usma, Daphne Willems, Juan David Carvajal-Castro, Hugo Mantilla-Meluk, Nicole Franco, Diego Amorocho, R

INTERNATIONAL
WHALING COMMISSION

Analysis of distribution of river dolphins (*Inia* and *Sotalia*) in protected and transformed areas in the Amazon and Orinoco basins

Federico Mosquera-Guerra [1,2], Fernando Trujillo[1], Danni Parks[3], Marcelo Oliveira-da-Costa[4], Miriam Marmontel[5], Dolors Armenteras-Pascual[2], Saulo Usma[4], Daphne Willems[4], Juan David Carvajal-Castro[6], Hugo Mantilla-Meluk[6], Nicole Franco[1], Diego Amorocho[4], Roberto Maldonado[4], Karina Berg[4], Lila Sainz[4], Paul A. Van Damme[7], Elizabeth Cambell[8].

[1] Fundación Omacha: Calle 84 No. 21 – 64 - Barrio el Polo - Bogotá, D.C, Colombia. federico.mosqueraguerra@gmail.com

[2] Grupo de Ecología del Paisaje y Modelación de Ecosistemas-ECOLMOD: Departamento de Biología, Universidad Nacional de Colombia - Cra 30 No. 45-03 - Bogotá D.C, Colombia.

[3] Whitley Fund for Nature : 110 Princedale Road l - London W11 4NH, United Kingdom.

[4] WWF – Brazil; Bolivia; Colombia; Ecuador, Peru, Netherlands; Deutschland; United Kingdom. Rue Mauverney, 28 1196 Gland, Switzerland

[5] Mamiraguá: Estrada do Bexiga, 2.584 Bairro Fonte Boa Cx. Postal 38 69.553-225 – Tefé (AM), Brasil.

[6] Universidad del Quindiìo: Programa de Biologiìa, Carrera 15 No. 12 Norte. Quindiìo - Armenia - Colombia.

[7] Faunagua: Av. Max Fernández final s/n - Plazuela del Chillijchi (Arocagua) – Cochabamba, Bolivia.

[8] Prodelphinus: Enrique Palacios 630 – 204, Lima 18 – Miraflores - Lima, Peru.

Abstract

The South American river dolphins have evolved in the continental aquatic ecosystems of the Amazon, Grande, Iténez - Mamoré, Araguaia - Tocantis and Orinoco rivers. The spatial and temporal distribution and the habitat use of these cetaceans do in these systems, are determined by distinct environmental characteristics such as precipitation regimes, elevation, productivity and biomass specific to each system. In addition, geomorphological accidents, such as rapids, have emerged as barriers that separate dolphin populations, potentially promoting processes of speciation. To date, there is no comprehensive analysis of river dolphins distribution and representativeness in protected areas or areas transformed by hydroelectric plants. In the present work, through niche and spatial modeling tools, we research the representativeness of both protected areas and areas transformed by hydroelectric plants in the Amazon and Orinoco basins in the distribution of river dolphins (*Inia* and *Sotalia*). The models presented here were constructed using the MaxEnt algorithm through the integration of 35,594 georeferenced records and 19 environmental variables derived from the Bioclim and Hydroshed database, which were parameterised in the R programme. A good representation of the distribution of river dolphins within the protected areas was evidenced, although the limited management of the aquatic ecosystems inside the protected areas does not guarantee the conservation of these species. A major threat identified for river dolphins in South America is the loss of habitat and fragmentation as a result of the construction of hydroelectric dams. We examined the degree of overlap between the distribution of *Inia* and *Sotalia* and hydroelectric projects in construction, operation and planning phases and provided an initial quantification of this tensor. Finally, we consider that the cumulative impacts (fragmentation, regulation of the flood pulse, retention of limiting nutrients and alteration in the levels of productivity) generated by this type of infrastructure at the macrobasin scale will exacerbate the level of the threats to the conservation of river dolphins and their habitats in the Amazon and Orinoco basins.

Key words: Conservation, distribution, human impact, hydroelectric dams, river dolphins.

Introduction

The South American river dolphins are represented by the subspecies and species of the genus *Inia* and *Sotalia*. They are widely distributed in the aquatic ecosystems of the Amazon, Orinoco, Tocantins basins and Orinoco delta (Caballero et al. 2007; Reeves et al. 2011; Secchi et al. 2012; Carvajal-Castro et al. 2015; Caballero et al. 2017). Throughout their distribution it has been identified that geological interruptions, particularly rapids, act as effective barriers separating natural populations of river dolphins and promoting processes of differentiation between populations (Rice 1998).

To date, three subspecies of *Inia geoffrensis* are recognized with distribution throughout the Amazon basin (*I. g. geoffrensis*) and the Orinoco basin (*I. g. humboldtiana*) with a suggested vicarious isolation caused by the formation of the Canal del Casiquiare on the ecological border between the Colombian Orinoquia and the Venezuelan Amazon (Da Silva & Martin 2000). *I. g. boliviensis* seems to have been isolated from *I. g. geoffrensis* because of the 400 km of rapids from Porto Velho on the Madeira river to Riberalta on the Beni river in Bolivia (Rice 1998). Currently the Bolivian bufeo (*I. g. boliviensis*) occurs in the basin of the Madeira, Iténez and Grande river basins in Bolivia and Brazil (Trujillo et al.1999; Banguera- Hinestroza et al. 2002; Ruiz-García et al. 2008; Ruiz-García 2010; Reeves et al. 2011; 2013). However, the taxonomy for the genus *Inia* has been discussed and even a new species has been described: the Araguaia river dolphin (*Inia araguaiaensis*), present in the hydrographic complex formed by the Araguaia - Tocantins rivers (Hrbek et al. 2014).

The genus *Sotalia* includes two species based on cranial morphology and genetic evidence (Madeira et al. 2004; Cunha et al. 2005; Caballero et al. 2007; 2010; 2017). *Sotalia guianensis* (P-J. Van Bénedén 1864) presents populations distributed along the coasts and estuaries of the Atlantic Ocean from Honduras to Brazil, and in the north of South America, including individuals established in Lake Maracaibo, middle and delta parts of the Orinoco river in Venezuela. Recent genetic studies determined that there is a divergence of 600,000 years between continental and coastal populations (Carvajal-Castro et al. 2015; Caballero et al. 2017). The species *Sotalia fluviatilis* (Gervais y Deville, In Gervais 1853) is found in the Amazon river basin (riparian zone) and is sympatric with *Inia geoffrensis* in Brazil, Colombia, Ecuador, Peru and French Guiana in the Amazon river basin (Borobia et al. 1989; Da Silva 1994; Martin y Da Silva 2004; Cunha et al. 2005; Caballero et al. 2007; Flores and Da Silva 2009; Trujillo et al. 2010; Secchi et al. 2012; Carvajal-Castro et al. 2015; Caballero et al. 2017).

Although river dolphins are obligate aquatic mammals, external environment variables external to this environment associated with the river basins they inhabit, such as precipitation and atmospheric temperature, may be determining aspects of their ecology, directly or indirectly affecting their occurrence in a particular area. Historically, the Orinoco, Amazon and the Araguaia-Tocantins complexes have been identified as different biogeographical and ecological units characterized by contrasting climatic conditions (McClain and Naiman 2008; Edmond et al. 1996; WCS 2017). These deferring conditions affect in many ways the hydric dynamics of their basins, determining the composition and structure of the biota associated with the course of its main and tributary rivers. Despite analyses of the potential influence that external variables may have on aquatic biota, to date, there is no comprehensive analysis in the South American territory on the representativeness of the distribution of river dolphins in protected areas or areas transformed by hydroelectric plants.

New tecnological approaches based on Geographic Information Systems (GIS), currently allow the characterisation of the availability of habitat for species in a given area through suitability models at a regional scale. Regionally, ecological conditions such as elevation, temperature and precipitation in combination with latitude, determine, among others, the vegetation cover, which consequently at a local scale define aspects such as productivity, nutrient flow and conductivity in the related water ecosystems at a local scale. Although the relationship between regional and local variables has been studied relatively poorly, GIS analysis opens a window of possibility to understand the distribution and ecology of aquatic organisms such as river dolphins at the continental level.

In the present study, the results from river dolphin monitoring, based on sightings are integrated with environmental information through niche modeling tools, with the purpose of investigating the representativeness of the different species and subspecies in protected areas and areas transformed by hydroelectric plants in the Amazon and Orinoco basins.

Material and Methods

Obtaining records and environmental variables

The environmental conditions included 19 bioclimatic variables from the Worldclim database (Hijmans et al. 2005), in addition, radiation was obtained as an approximation of primary productivity. To obtain this information, the values of the 12 months of the year provided by Worldclim v.2 are averaged (Fick and Hijmans 2017). All the variables presented a resolution of 30 arc-seconds (~1 km^2 in Ecuador) (Table 1).

Table 1. Bioclimatic variables used in the potential distribution models of river dolphins (*Inia* and *Sotalia*) in the Amazon and Orinoco river basins.

Variables	Description
Elevation	Height in meters above sea level
Bio 1	Annual average temperature
Bio 2	Average daytime range (Mean of the month (Max Temp - Min Temp))
Bio 3	Isothermality ((Bio 2/Bio 7) * 100)
Bio 4	Seasonality of temperature (Standard deviation * 100)
Bio 5	Maximum temperatura of the hottest month
Bio 6	Minimum temperature of the coldest month
Bio 7	Annual temperature range (Bio 5 - Bio 6)
Bio 8	Average temperature of the wettest quarter
Bio 9	Average temperature of the driest quarter
Bio 10	Average temperature of the warmest quarter
Bio 11	Average temperature of the coldest quarter
Bio 12	Annual rainfall
Bio 13	Precipitation of the wettest month
Bio 14	Precipitation of the driest month
Bio 15	Seasonality of precipitation (Coefficient of variation)
Bio 16	Precipitation of the wettest quarter
Bio 17	Precipitation of the driest quarter
Bio 18	Precipitation of the warmest quarter
Bio 19	Precipitation of the coldest quarter
Rad	Solar radiation

Potential distribution models

The models of potential distribution of the subspecies and species of the genera *Inia* and *Sotalia* were generated using the environmental variables and the georeferenced records obtained through sightings in expeditions carried out within the framework of the South American River Dolphin Conservation Programme (2006-2018) and the records issued by river dolphins tagged with satellite telemetry in Colombia, Brazil and Bolivia (Table 2, Figures 1& 2). The algorithm used was the maximum entropy (MaxEnt) (Phillips et al. 2006). MaxEnt was chosen because it has been widely used and its best performance has been demonstrated to estimate the potential distribution of the species more accurate than other approaches (Graham and Hijmans 2006; Townsend et al. 2007). As MaxEnt only works with information on the presence of species, it must generate pseudoausencias, more appropriately called ‘background’ in order to obtain a calibration of the model (Phillips and Dudík 2008). Therefore, 10000 randomly generated points (background) were used through the northern zone of the Neotropic. 10 replicas were generated to perform an assembly methodology (Araújo and New 2007) and thus obtaining a consensus model among the replicas.

Table 2. Records of river dolphins (*Inia* and *Sotalia*) in the Amazon, Orinoco and Tocantins-Araguaia river basins.

Taxones	Georeferenced sightings	Records issued by dolphins marked with satellite telemetry
I. g. geoffrensis	9.050	7.189
I. g. humboldtiana	4.452	714
I. g. boliviensis	2.388	4575
Inia araguaiaensis	974	
Sotalia fluviatilis	5.954	
Sotalia guianensis	303	
Total	23.121	12.473

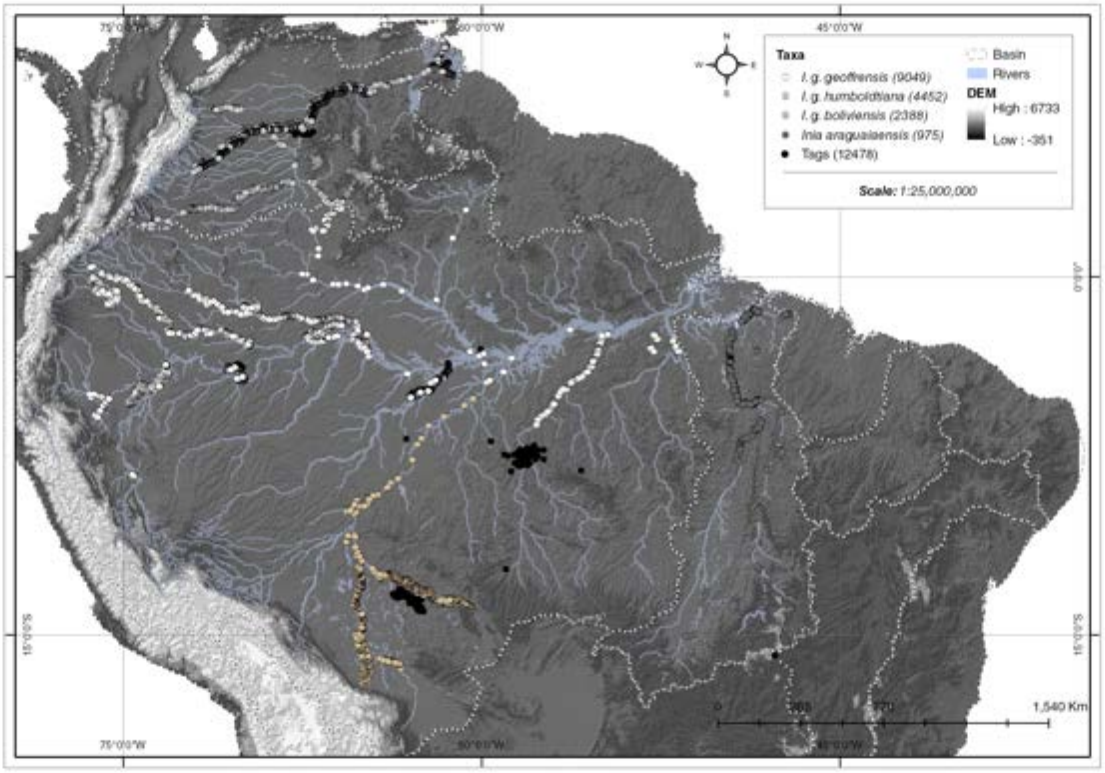

Figure 1. Georeferenced records for genus *Inia* in South America.

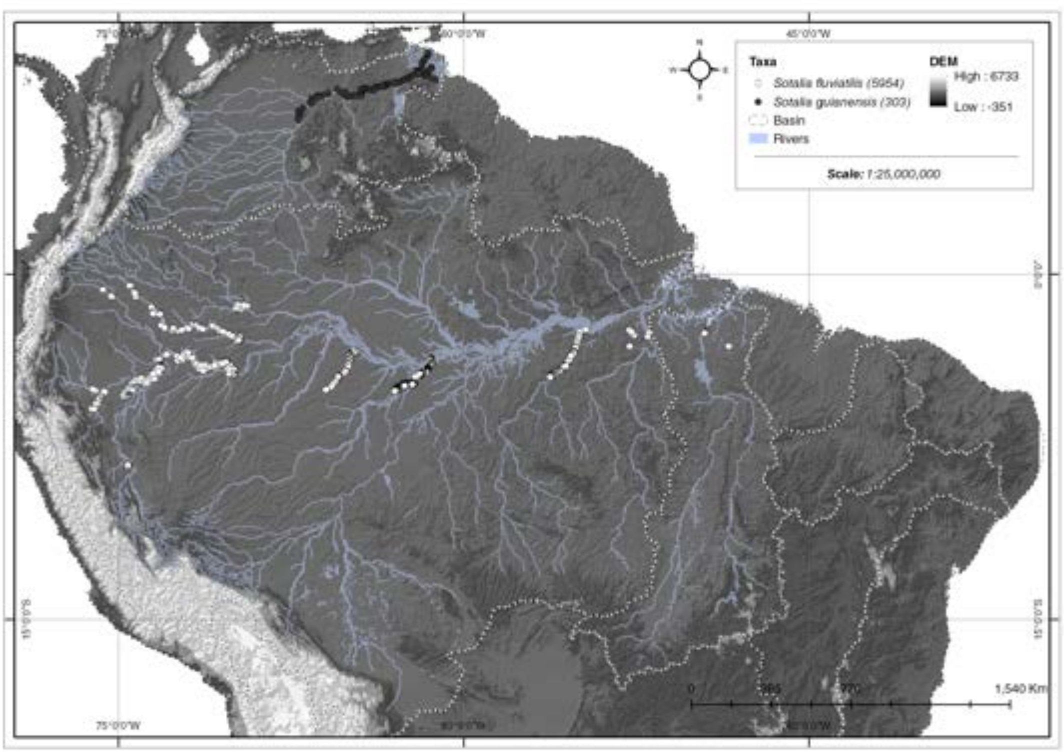

Figure 2. Georeferenced records for genus *Sotalia* in South America.

To evaluate the performance of the model, a "k fold partitioning" approach was used, with an area under the receiver curve (AUC) as the evaluation metric, using 75% of the occurrence data to perform modeling and 25% of the remaining occurrence data to test the model. The AUC value is used to evaluate the discrimination ability of the model: AUC values close to 1 are considered as a perfect prediction and values of 0.5 or less reflect that the model is not better than a random model. These analyses were carried out using the R software, using the dismo libraries (Hijmans et al. 2015), SDMTools (VanDerWal et al. 2014) and raster.

The consensus model generated by MaxEnt is a probability map, on which the probability of the presence of species is shown. This probability map was used to make a binary map representing the presence and absence of dolphins, establishing a threshold value as a criterion, defined as the maximum sum of specificity and sensitivity (MSS). Therefore, the probability values (probability map) that were equal to or greater than this threshold value were considered as demostrating the presence of river dolphins (the value of the pixel equal to 1); on the other hand, values below this threshold were considered as species' absence (pixel value equal to 0).

Representation of protected and transformed areas in the potential distribution of river dolphins (Inia *and* Sotalia)

A statistical analysis was carried out overlapping the models of potential distribution, with the protected areas (WDPA) (UNEP-WCMC 2010) downloaded from (www.protectedplanet.net) and areas transformed by hydroelectric plants in Brazil, Bolivia, Colombia, Ecuador, Peru and Venezuela (Anderson et al. 2018, Latrubesse et al. 2017). The number of pixels intersecting the distribution of species and protection zones were quantified as an indirect measure of the ability of protected areas to protect dolphins. At the same time, the areas transformed by hydroelectric dam construction, operation and planning in the Amazon, Orinoco and Araguaia-Tocantins basins were quantified in order to demonstrate the impact of this type of infrastructure on river dolphin populations. For the purpose of calculating these areas, the function of the library rgeos was used in the statistical software R.

Results

Potential distribution models

The generated models demonstrate a high correlation, with AUC values of 0.8852 (*I. g. geoffrensis*), 0.889 (*I. g. humboldtiana*), 0.9189 (*I. g. boliviensis*), 0.9738 (*I . araguaiaensis*), 0.948 (*Sotalia fluviatilis*) and 0.933 (*S. guianensis*). Figure 3 shows the modelled potential distrubution of the South American river dolphin species and subspecies (*Inia* and *Sotalia*).

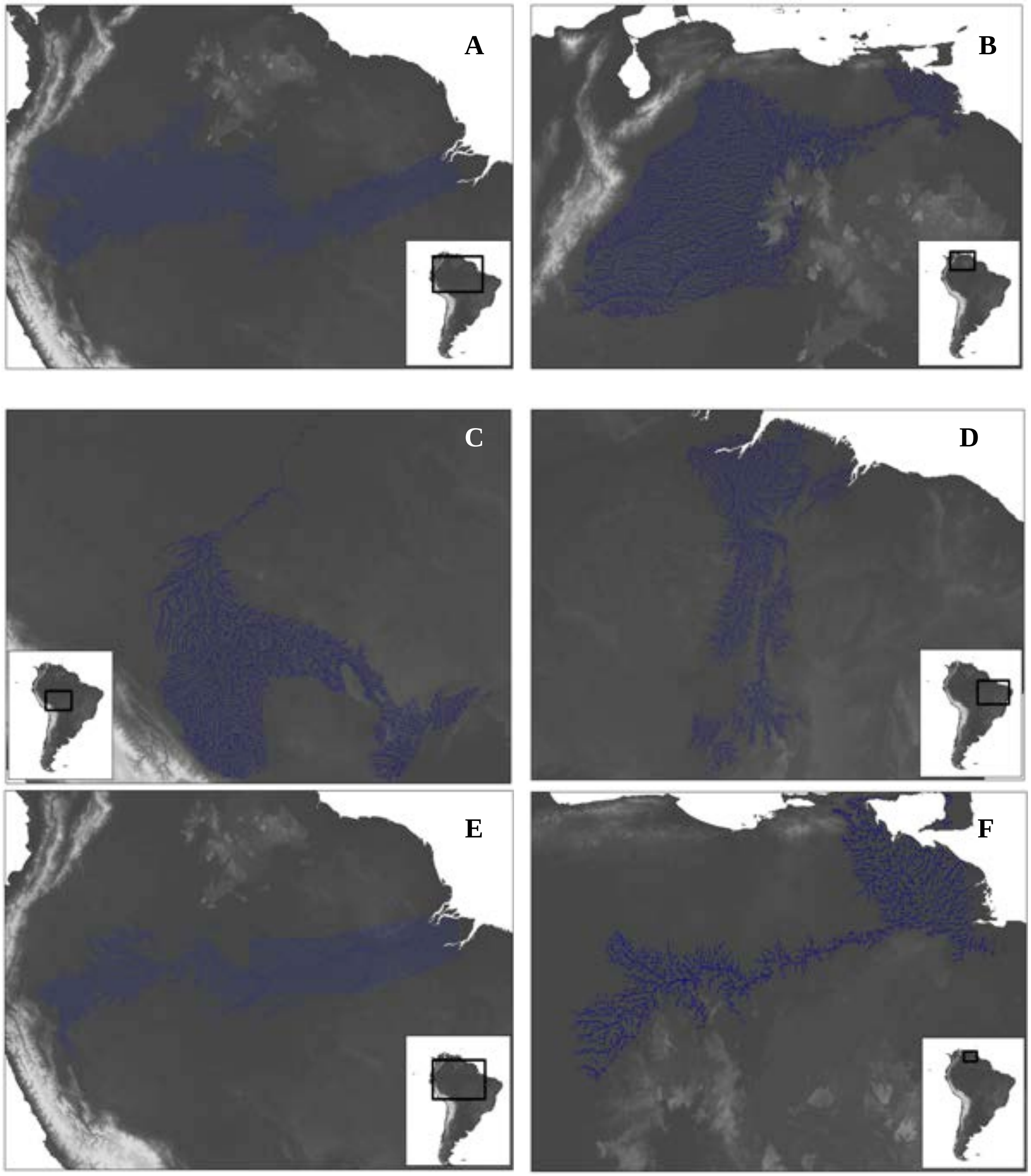

Figure 3. Modelled potential distrubution of the South American river dolphins (species and subspecies) *Inia* and *Sotalia*, derived from the algoritm MaxEnt. **A.** *I.g. geoffrensis.* **B.** *I.g. humboldtiana.* **C.** *I.g.boliviensis.* **D.** *I. araguaiaensis.* **E.** *Sotalia fluviatilis.* **F.** *S. guianensis.*

Representation of protected and transformed areas in the potential distribution of river dolphins (*Inia and Sotalia*)

Potential distribution areas for the South American river dolphins (*Inia* and *Sotalia*) and their representation in the aquatic ecosystems in Amazon protected areas were calculated in order to establish their representativeness for each taxa. (Table 3). In the category of protected areas, strict figures were included, such as National Parks and regional parks, and other figures such as sustainable reserves and Ramsar sites were included.

Table 3. Representativeness of protected areas in the distribution of South American river dolphins (*Inia* and *Sotalia*).

Species	Total area potential distribution	Areas of aquatic ecosystems in conservation km^2						Total area in Conservation km²
		Brasil	Bolivia	Colombia	Ecuador	Peru	Venezuela	
I.g.geoffrensis	468.717	69.324		5.839	2.900	11.455	397	89.915 (19,2%)
I.g.humboldtiana	114.962			2.151			10.634	12.785 (11,1%)
I.g.boliviensis	76.597	5.892	12.494					18.386 (24,0%)
I. araguaiaensis	76.182	11.503						11.503 (15,1%)
S. fluviatilis	356.716	54.892		2.637	2.900	7.726		68.155 (19,1%)
S. guianensis	17.473						4.630	4.630 (26.5%)

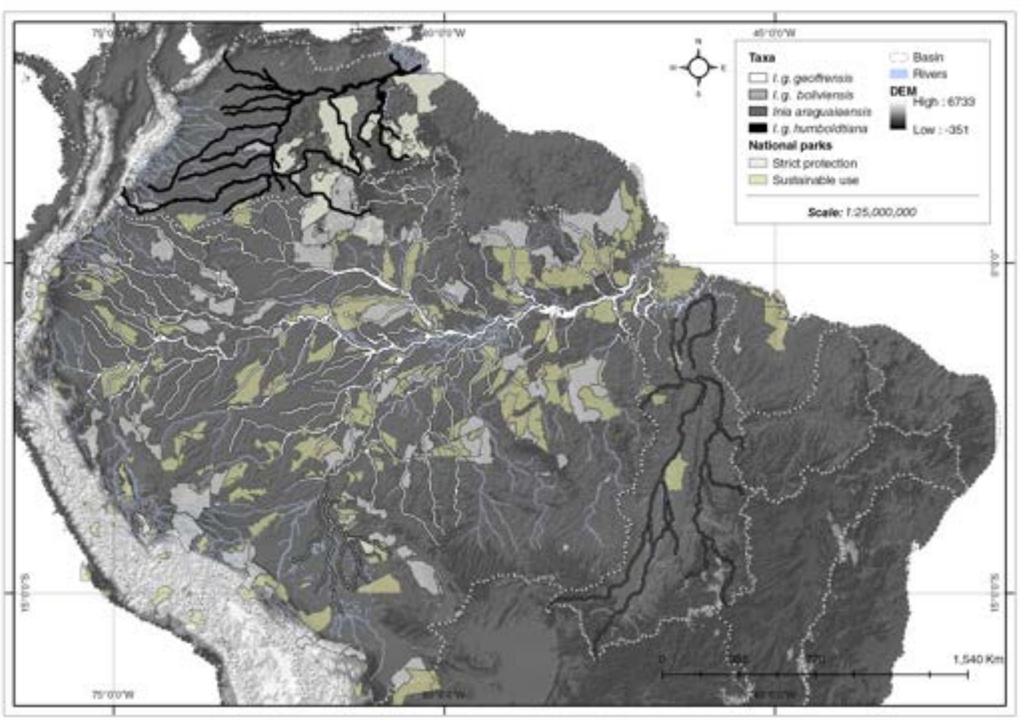

Figure 4. Distribution of the genus *Inia* in Amazon protected areas

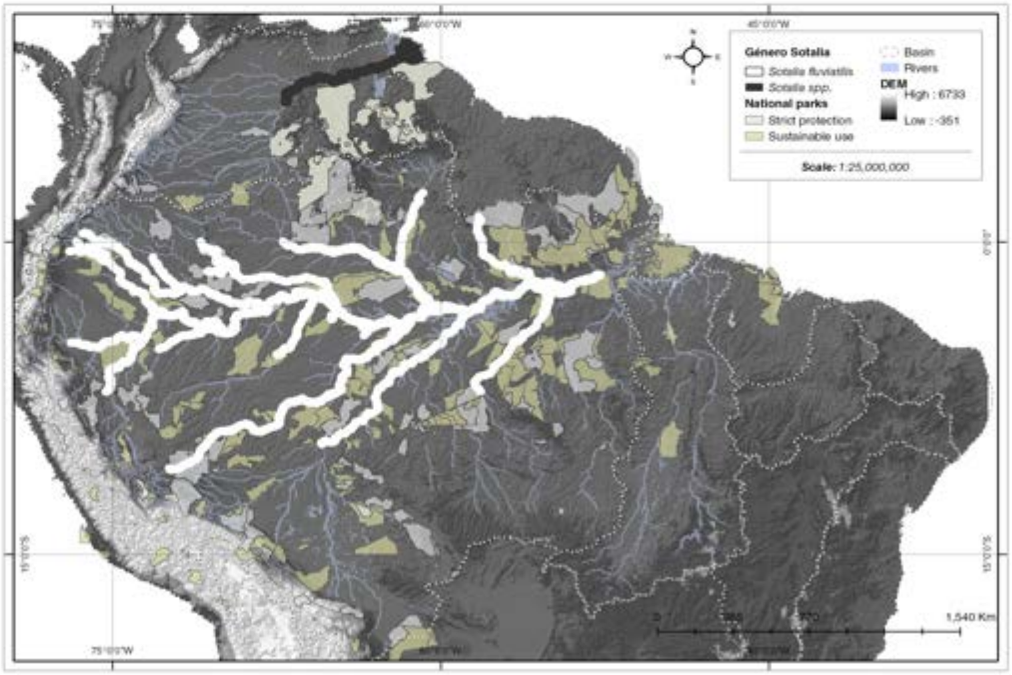

Figure 5. Distribution of of the genus *Sotalia* in Amazon protected areas.

The areas transformed by hydroelectric plants were calculated in phases of planning, construction and operation, and the representation of these in the potential distribution areas of the South American river dolphins (Table 4).

Table 4. Representativeness of transformed areas by hydroelectric plants in the distribution of South American river dolphins (*Inia* and *Sotalia*).

Species	**Total area potential distribution km²**	**Areas transformed by hydroelectric plants in different phases km²**		
		Operation	**Constrution**	**Planning**
I. g. geoffrensis	468.717	77.077 (16.4%)	68.995 (14.7%)	139.981 (29.9%)
I. g. humboldtiana	114.962	26.348 (22.9%)	6.302 (5.5%)	
I.g. boliviensis	76.597			1.482 (1.9%)
I. araguaiaensis	76.182	41.853 (54.9%)	16.005 (21%)	36.281 (47.6%)
Sotalia fluviatilis	356.716	77.077 (21.6%)	68.995 (19.3%)	139.981 (39.2%)
Sotalia guianensis	17.473	2.704 (15.5%)	2.555 (14.6%)	

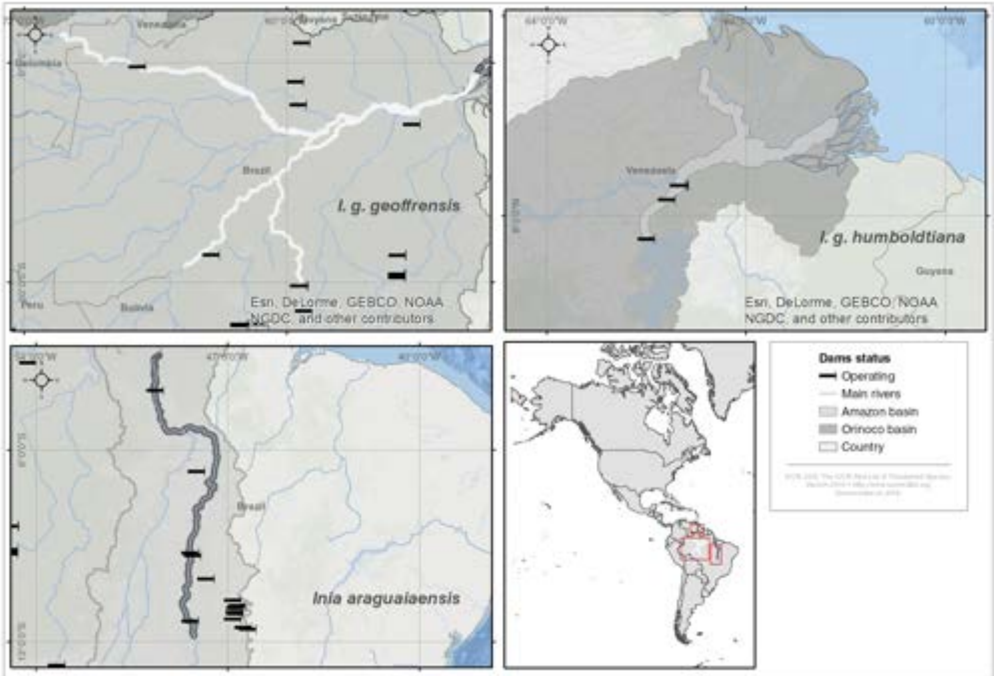

Figure 6. Spatialisation of habitats transformed by hydroelectics in the operation phase for the genus *Inia*.

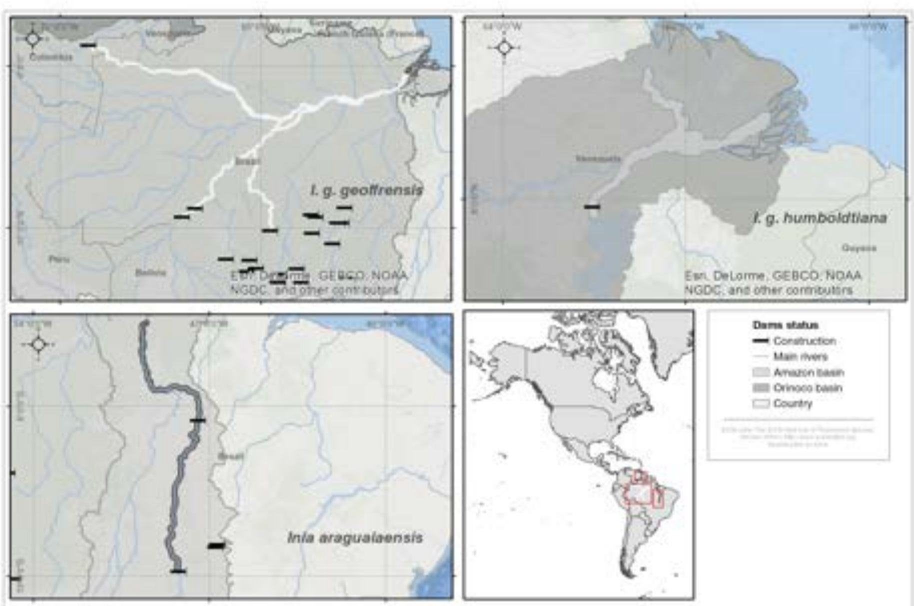

Figure 7. Spatialisation of habitats transformed by hydroelectics in the constrution phase for the genus *Inia*.

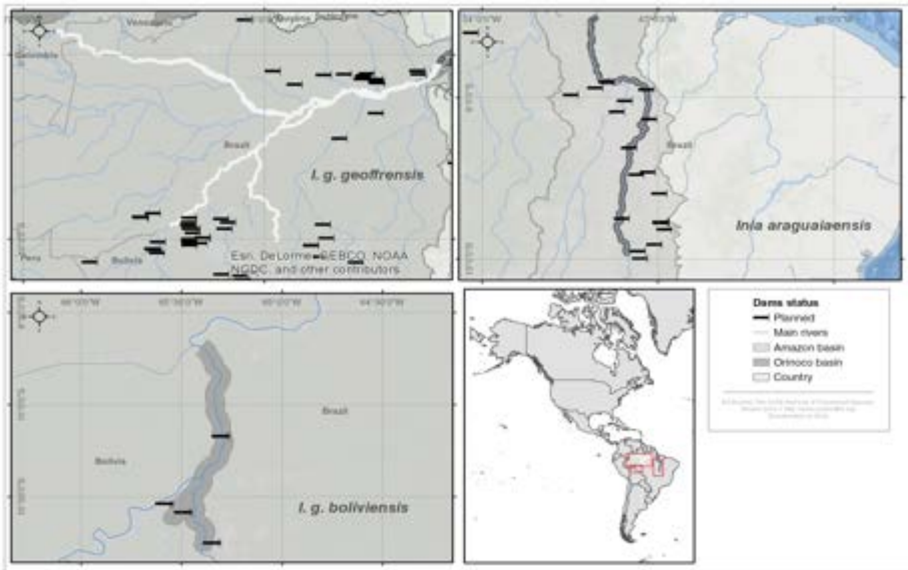

Figure 8. Spatialisation of habitats transformed by hydroelectics in the planning phase for the genus *Inia*.

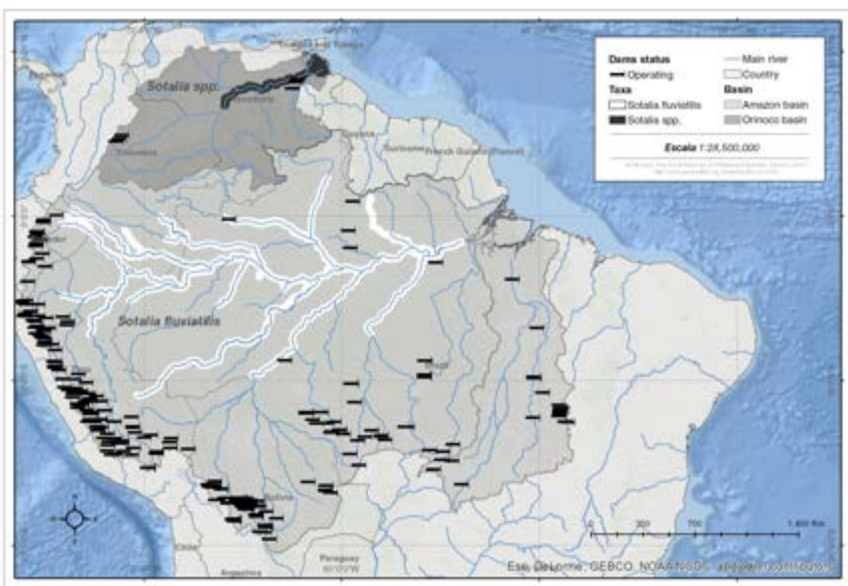

Figure 9. Spatialisation of habitats transformed by hydroelectics in the operation phase for the genus *Sotalia*.

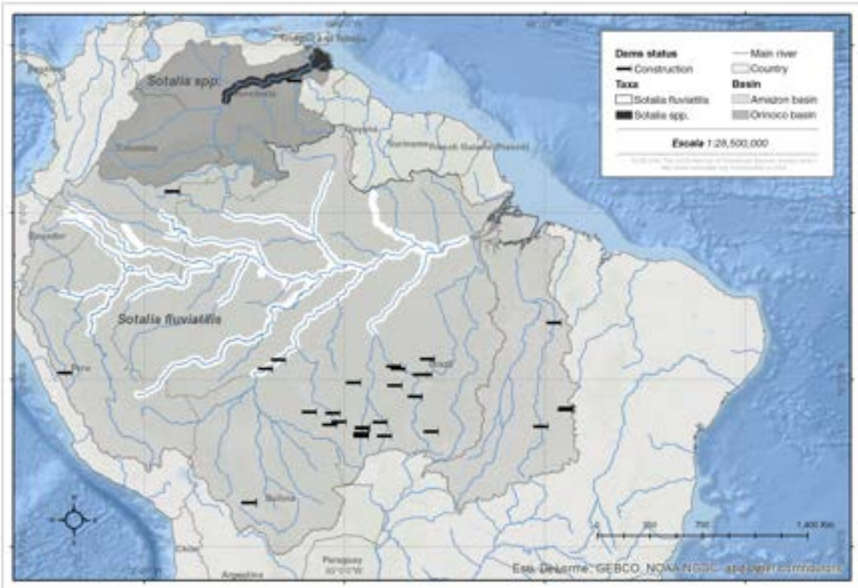

Figure 10. Spatialisation of habitats transformed by hydroelectics in the constrution phase for the genus *Sotalia*.

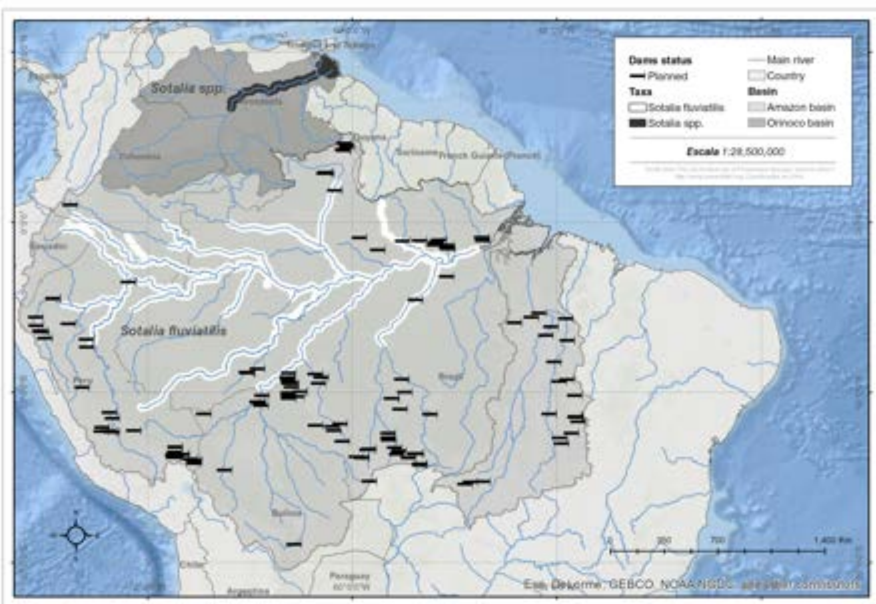

Figure 11. Spatialisation of habitats transformed by hydroelectics in the planning phase for the genus *Sotalia*.

Discussion

Potential distribution models

River dolphins (*Inia* and *Sotalia*) occur in the Amazon and Orinoco river basins, from the deltas upstream, to where impassable rapids, waterfalls, lack of water and possibly low temperatures block their movement (Best and da Silva 1989a, b). For the genus *Inia* three geographic populations have been recognised as subspecies: *I. g. geoffrensis* in the Amazon basin, except for the Madeira basin in Bolivia upstream, from the Teotonio rapids, *I. g. boliviensis* in the upper Madeira basin, and *I. g. humboldltiana* in the Orinoco basin (Rice 1998, Reeves et al. 2011). Genetic studies reveal the relevance of these geographical barriers in the generation of vicariant speciation processes, as is the case with *Inia araguaiaensis,* a species recently described, whose populations are isolated by the Araguaia-Tocantins hydrographic complex (Hrbek et al. 2014).

For *I. g. geoffrensis*, the distribution generated by the model coincide with the distribution presented by de Best and da Silva (1989a), (1989b) and Leatherwood (1996), who place its occurence in the rivers Xingu, Tapajós, Madeira (downstream from the rapids of Teotonio), Purus, Juruá, Ucayali and Marañón (and Samiria tributary) that flow generally towards the north, and the Negro river with itstributaries Caquetá (Japurá), Apaporis, Putumayo (Iça) and Napo.

In relation to the distribution of *I. g. humboldtiana,* the model outcome matches what was reported by Pilleri y Gihr (1977); Best y da Silva (1989a), (1989b); Meade and Koehnken (1991); Velásquez-Roa et al. (2015), identifying the subspecies' presence in the Apuré tributaries (Portuguesa and Guanmar), Capanaparo, Cinaruco, Meta, Bita, Vichada, Tomo, Tuparro, Guaviare (tributary Guayabero), Inírida and Atabapo (and Temi tributary) that flow to the south and east, and the tributaries Aro, Caura, Parquaza, Ventauri (San Juan tributary) that flow to the north and west, as well as the Casiquiare Canal, which connects the Orinoco with the Negro river (a tributary of the Amazon), above and below the two series of rapids in Puerto Ayacucho, which are the main barriers that are expected to separate the dolphin populations of the Amazon and the Orinoco (Reeves et al. 2011). Nevertheless, river dolphins have been seen crossing the first group of rapids in Puerto Ayacucho (Atures) during the high tide (Fernando Trujillo, personal communication with B.D. Smith).

The modelled distribution generated for *Inia boliviensis* coincides with what is stated by Pilleri and Gihr (1977); Best and da Silva (1993); Aliaga-Rossel et al. (2006); Da Silva (2009); Aliaga-Rossel (2010); Tavera et al. (2010); Cella-Ribeiro et al. (2013), and Gravena et al. (2014), that this unique aquatic mammal is present in the sub-basins of the rivers Abuna, Guaporé, Iténez or Guaporé basin (including Verde and Iporuporé tributaries), Mamoré basin and its primary and secondary tributaries: Pirai, Grande, Ichilo, Chapare, Ibaré, Tijamuchi, Apere, Yacuma and Yata, Beni (and Orton tributary); on the Madeira river, its distribution is considered below the Tetonio rapids located upstream from Porto Velho. According to Cella-Ribeiro et al. (2013), the Bolivian river dolphin presents an estimated evolutionary divergence of 3.1 million years of genetic isolation generated by the geographic barrier formed by a series of 18 rapids along a stretch of 290 kilometers on the Madeira river. These rapids are thought to act as a barrier to the movement of dolphins and thus restrict the distribution of *I.g.boliviensis* upstream of the rapids, and *I.g.geoffrensis* downstream of the rapids.

This example is similar to the recent description of the species *Inia araguaiaensis* (Hrbek et al. 2014) distributed in the Araguaia-Tocantins river hydrographic complex, currently isolated from the Amazon river basin (Rossetti and Valeriano 2007; Goulding et al. 2003). The two basins have been disconnected, although not completely isolated from each other in the transition from Pliocene to Pleistocene (Rossetti and Valeriano 2007). Currently, only a narrow channel west of the island of Marajo joins the delta of the Amazon river with the Para river, which drains the Araguaia-Tocantins river. The connectivity between the Araguaia-Tocantins and Amazon basins is restricted by a series of important rapids in the lower Tocantins river, becoming an important biogeographical element to generate speciation processes (Hrbek et al. 2014).

The results obtained in relation to the distribution of *S. fluviatilis* coincide with the reports generated by Layne (1958); Obregón et al. (1988); Borobia et al. (1991); Trujillo (1992), (1994a), (2000); Vidal et al. (1997); McGuiere and Henningsen (2007); Gómez-Salazar et al. (2010); Carvajal-Castro et al. (2015) and Caballero et al. (2017). All report its presence in the Amazon basin as far inland as southern Peru, eastern Ecuador and southeastern Colombia. This presents a sympatric distribution with *I. g.geoffrensis* (Secchi 2012), although *S. fluviatilis* does not occur in the Beni/ Mamoré river basin ,in Bolivia nor in the upper part of the Negro river (Flores y da Silva 2009). The results obtained by modeling identy limitations for the distribution of *S. fluviatilis* in the Caqueta/Japura river basin, determined by the rapid of Cordoba and reported by Trujillo (1994b); Trujillo (1995), Galindo (1997); Trujillo et al. (2006); Gómez-Salazar et al. (2010); Pavanato et al. (2014) and Caballero et al. (2017); in the Apaporis river, its distribution is limitated by the rapids of Estrella and Puerco (Gómez-Salazar et al. 2010).

In relation to *S. guianensis*, the presence of the species in the Colombian Orinoco is not corroborated, which suggests that its distribution is restricted to the middle basin and delta of the Orinoco. This can be explained by the rapids of Maipures, Atures and the Dead between the Ayacucho and Samariapo Ports in the Venezuelan Orinoco, probably restricting the species' distribution (Gómez-Salazar et al. 2010; Herrera-Trujillo 2012).

Representation of protected and transformed areas in the potential distribution of river dolphins (*Inia and Sotalia*)

In the Amazon and Orinoco basins there are important areas under conservation management, such as national natural parks and Ramsar sites. Among these, there are areas of distribution of river dolphins (Trujillo et al. 2014). However, the remoteness of these areas, the limited resources for their control and surveillance, the constant threat of extractive economies such as gold mining, deforestation of riparian forest, commercial fishing and directed catches, as well as the terrestrial approach of the initiatives of conservation initiatives, make the management of aquatic ecosystems within protected areas still limited (Mosquera-Guerra et al. 2015).

The transformation of the heterogeneous and complex aquatic ecosystems in the Amazon through the construction of more than one hundred hydroelectric plants causes the ecological homogenisation of these systems, changes in the flood pulses downstream of the dams and the retention of limiting nutrients for primary productivity in aquatic food webs such as the N and P (Forsberg et al. 2017; Latrubesse et al. 2017; Anderson et al. 2018). It also causes significant losses in fluvial connectivity exactly where the greatest diversity of river dolphins and fish on the planet are found (Mosquera-Guerra et al. 2015; Anderson et al. 2018). These tensors have caused the transformation of extensive areas occupied by river dolphins in South America. Arauho and Wang (2014), report the effects on populations of *I. araguaiaensis* due to the presence of seven hydroelectric projects constructed in their distribution area and for *I.g. boliviensis*, *I.g. geoffrensis* and *Sotalia fluviatilis* are reported a total of three new ones.

These effects are not only limited to the fragmentation of complex and heterogeneous aquatic systems such as the Araguaia, Tocantins and Madeira rivers. These ecosystems are made up of habitats types essential for feeding, reproduction and refuge of dolphins such as confluences, tributaries, lakes and main rivers and tributaries with different origins, Andean in the case of white waters, jungle in the black and clear rivers influenced by the Brazil shield

Another type of cumulative negative effect at the macrobasin scale is reported by Forsberg et al. (2017), which predicts that upon entry into operation of the Rositas dams, Angosto Del Bala, Inambari, Tam 40, Pongo De Aguierre and Pongo De Monseriche, will reduce the supply of sediment by 69%, phosphorus by 67% and nitrogen by 57% in the Andean region and in the entire Amazon basin by 64, 51 and 23%, respectively. These large reductions in the supply of sediments and nutrients will have a great impact on the geomorphology of the channels, the fertility of the floodplains and the aquatic productivity (Latrubesse et al. 2017).

These effects will be greater near the dams and will extend to the lowland flood plains (Latrubesse et al. 2017). It is expected that the attenuation of the downstream flood pulse will alter the survival, phenology and growth of the floodplain vegetation and reduce the primary and secondary productivity of the floodplain food source for fish in its different phases. This reduction in the biomass of these systems could potentially exacerbate the conflicts between the river dolphins and the artisanal and commercial fisheries due to the decrease of fishing resource in the Amazon.

When analyzing the representativeness of protected areas, it is evident that in the case of *Inia boliviensis* and *Inia araguiaensis* it is relatively low. That is why it is advisable to encourage the creation of aquatic ecosystem conservation figures that generate protection mechanisms for these species. Ramsar sites with implemented management plans can be efficient and suitable for river dolphins.

Acknowledgments

This research was conducted as part of the South America River Dolphins Conservation Programme sponsored by Whitley Found for Nature, Foundation Segre, WWF, Nature Serve and Colciencias. The authors thank the researchers and local and national authorities who participated in the 28 expeditions carried out in South America and satellite telemetry project to study the ecology of the movement of river dolphins in the Amazon and Orinoco.

References

Aliaga-Rossel, E., McGuire, T. L. and Hamilton, H. 2006. Distribution and encounter rates of the river dolphin (*Inia geoffrensis boliviensis*) in the central Bolivian Amazon. Journal of Cetacean Research Management 8(1): 87–92.

Aliaga-Rossel, E. and T. L. McGuire. 2010. Iniidae. pp. 535-549. In: Wallace, R.B., H. Gómez, Z.R. Porcel & D.I. Rumiz (eds.) Distribución, Ecología y Conservación de los Mamíferos Medianos y Grandes de Bolivia. Centro de Ecología y Difusión Simón I. Patiño, Santa Cruz.

Anderson, E. P., Jenkins, C. N., Heilpern, S., Maldonado-Ocampo, J. A., Carvajal-Vallejos, F. M., Encalada, A. C., Rivadeneira, J. F., Hidalgo, M., Cañas, C. M., Ortega, H., Salcedo, N., Maldonado, M. 2018. Tedesco, Fragmentation of Andes-to-Amazon connectivity by hydropower dams. Sci. Adv. 4, eaao1642.

Arauho, C and Wang, J. 2014. The dammed river dolphins of Brazil: impacts and conservation. Fauna & Flora International, Oryx, 49(1), 17–24 doi:10.1017/S0030605314000362

Araujo, MB, New M. 2007. Ensemble forecasting of species distributions. Trends Ecol. Evol. 22: 42–47.

Banguera-Hinestroza, E., Cárdenas, H., Ruiz- García, M., Marmontel, M., Gaitán, E., Vázquez, R., and García-Vallejo, F. 2002. Molecular identification of evolutionarily significant un its in the Amazon River dolphin *Inia* sp. (Cetacea:Iniidae). Journal of Heredity 93:312–322.

Best, R.C, da Silva VMF (1993). *Inia geoffrensis*. Mamm Species 426:1–8.

Best, R. C. and da Silva, V. M. F. 1989a. Amazon River dolphin, boto *Inia geoffrensis* (de Blainville, 1817). In: S. H. Ridgway and R. Harrison (eds), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales, pp. 1-24. Academic Press.

Best, R. C. and Da Silva, V. M. F. 1989b. Biology, status and conservation of *Inia* geoffrensis in the Amazon and Orinoco river basins. In: W. F. Perrin, R. L. Brownell, K. Zhou and Lu Jiankang (eds), Biology and conservation of the river dolphins, pp. 23-34. IUCN Species Survival Commission.

Borobia, M., Siciliano, S., Lodi, L., and Hoek, W.1991. Distribution of the South American dolphin *Sotalia*. Canadian Journal of Zoology 69 (4): 1025-1039 pp. http: / / dx.doi.org/10.1139/z

Bivand R, Rundel C. 2014. rgeos: Interface to Geometry Engine–Open Source (GEOS). R Package.

Caballero, S., Trujillo, F., Vianna, J.A., Barrios-Garrido, H., Montiel, M.G., Beltran-Pedreros, S., Marmontel, M., Santos, M.C.O., Rossi-Santos, M.R., Santos, F.R. and Baker, C.S. 2007.Taxonomic status of the genus *Sotalia*: species level ranking for 'tucuxi' (*Sotalia fluviatilis)* and 'costero' (*Sotalia guianensis*) dolphins. Marine Mammal Science 23(2): 358-386. http://dx.doi.org/10.1111/j.1748-7692.2007.00110.x

Caballero, S., Trujillo, F., Vianna, J.A., Barrios-Garrido, H., Montiel, M.G., Beltrán Pedreros, S., Marmontel, M., Santos, M.C.O., Rossi-Santos, M.R., Santos, F.R and Baker, C.S. 2010. Mitochondrial DNA diversity, differentiation and phylogeography of the South American riverine and coastal dolphins *Sotalia fluviatilis* and *Sotalia guianensis*. Latin American Journal of Aquatic Mammals 8(1-2): 69-79. http://dx.doi.org/10.5597/lajam00155

Caballero, S., Trujillo, F., Del Risco, A., Herrera, O., and Ferrer, A. 2017. Genetic identity of *Sotalia* dolphins from the Orinoco River. Marine Mammal Science 33(4): 1214-1223. http://dx.doi.org/10.1111/mms.12422

Carvajal-Castro, J.D., Velásquez-Roa, T., Mantilla-Meluk, H., Trujillo, F. and Mosquera-Guerra, F. 2015. Modelación de nicho y aspectos biogeográfícos del género *Sotalia* (Cetartiodactyla: Delphinidae) en los ríos Amazonas y Orinoco, Colombia. Momentos de Ciencia. 12 (2). 121-125.

Cella-Ribeiro, A., G. Torrente-Vilara., D.B. Hungria., Oliveira M de. 2013. As corredeiras do Rio Madeira. Peixes do Rio Madeira. pp 47–53.

Cunha, H.A., Da Silva, V.M.F., Laílson-Brito, J.J., Santos M.C.O., Flores, P.A.C., Martin, A.R., Azevedo, A.F., Fragoso A.B.L., Zanelatto, R.C. and Solé-Cava, A.M. 2005. Riverine and marine ecotypes of *Sotalia fluviatilis* are different species Marine Biology 148(2): 449-457.http://dx.doi.org/10.1007/s00227- 005-0078-2

Da Silva V.M.F. 2009. Amazon River Dolphin (*Inia geoffrensis*). In: Perrin WF, Wursig B, Thewissen JGM (eds) Encycl. Mar. Mamm. Academic Press, London, UK, pp 18–20.

Da Silva V. and A.R. Martin. 2000. The status of the boto or Amazon River dolphin *Inia geoffrensis* (de Blainville, 1817): a review of available information. Paper submitted at the meeting of the IWC Scientific Committee, 2000. IWC, Cambridge, UK.

Da Silva, V. M. F. and Best, R. C. 1994. Tucuxi *Sotalia fluviatilis* (Gervais, 1853). In: S. H. Ridgway and R. Harrison (eds), Handbook of marine mammals, Volume 5 The first book of dolphins. 43-69. Academic Press, London, UK.

Edmond J.M., Palmer, M.R., Measures, C.I., Brown, E.T. and Huh, Y. 1996. Fluvial geochemistry of the eastern slope of the northeastern Andes and its foredeep in the drainage of the Orinoco in Colombia and Venezuela. Geochimica et Cosmochimica Acta 60: 2949–2976.

Fick, S.E., Hijmans, R.J. 2017. WorldClim 2: new 1‐km spatial resolution climate surfaces for global land areas. International Journal of Climatology, 37(12), 4302-4315.

Flores, P.A.C. and Da Silva V.M.F. 2009. Tucuxi and Guiana Dolphin - *Sotalia fluviatilis* and *S. guianensis*. 1188-1191pp. En: Perrin, W.F., Würsig, B. y Thewissen, J.G.M. (Eds) Encyclopedia of Marine Mammals. 2nd ed. Academic Press, Amsterdam, Netherlands.

Forsberg, B.R., Melack, J.M., Dunne, T., Barthem, R.B., Goulding, M., Paiva, R.C.D., et al. 2017. The potential impact of new Andean dams on Amazon fluvial ecosystems. PLoS ONE 12(8): e0182254. https://doi.org/10.1371/journal. pone.0182254

Galindo, A.1997. Ecología y abundancia de los delfines de río *Inia geoffrensis* y *Sotalia fluviatilis* en el río Caquetá, área de influencia de la Pedrera, Colombia. B.Sc.Thesis. Universidad del Valle. Cali. Colombia. 77 pp.

Goulding, M., Barthem, R.B., Ferreira, E.J.G. 2003. The Smithsonian Atlas of the Amazon. Washington, DC: Smithsonian Institution Press.

Gómez Salazar, C., Portocarrero-Aya, M., Caballero, S., Bolaños-Jiménez, J., Utreras, V., McGuire, T., Ferrer-Pérez, A., Pool, M., and Aliaga-Rossel, E. 2010. Update on the freshwater distribution of *Sotalia* in Colombia, Ecuador, Peru, Venezuela and Suriname. LAJAM 8(1-2): 171-178 pp. E-ISSN 2236-1057 / ISSN 1676-7497

Graham, C., Hijmans, R.J. 2006. A comparison of methods for mapping species ranges and species richness. Global Ecology and Biogeography, 578–587.

Gravena, W., Izeni, P.F., Da Silva, M.N.F., Da Silva, V.M.F., and Hrbek, T. 2014. Looking to past and the future: were the Madeira River rapids a geographical barrier to the boto (Cetacea: Iniidae)?. Conserv Genet. 15:619-629 pp. DOI 10.1007/S10592-014-0565-4
Herrera-Trujillo, O. 2012. Estatus de los delfines de río *Sotalia* sp. e *Inia geoffrensis* en la cuenca del Orinoco. Tesis para optar al título de Máster Universitario en Biodiversidad en Áreas Tropicales y su Conservación. Universidad Internacional de Melendéz-Pelayo. Quito (Ecuador). 99 pp.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas.International journal of climatology, 25(15): 1965-1978.

Hijmans R.J. 2015. raster: Geographic Data Analysis and Modeling. R package version 2.4-18. ver http://CRAN.R-project.org/package=raster

Hijmans, R.J., Phillips, S., Leathwick, J., Elith, J. 2015. dismo: Species Distribution Modeling. R package version 1.0-12. ver http://CRAN.R-project.org/package=dismo

Hrbek, T., da Silva, V.M.F., Dutra, N., Gravena, W., Martin, A.R. and Farias, I.P. 2014. A new species of river dolphin from Brazil or: how little do we know our biodiversity. PLoS ONE 9(1): e83623. doi:10.1371/journal.pone.0083623

Latrubesse, E. M., E. Y. Arima, T. Dunne, T., .et al. 2017. Damming the rivers of the Amazon basin. Nature 546(7658):363-369.

Layne, J. 1958. Observations on freshwater dolphins in the upper Amazon. Journal of Mammalogy 39(1): 1-22. http:/ / dx.doi.org/10.2307/ 1376605

Leatherwood, S. 1996. Distributional ecology and conservation status of river dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in portions of the Peruvian Amazon. Thesis, Texas A&M University.

Madeira Di Beneditto, A.P. and Arruda Ramos, R.M. 2004. Biology of the marine tucuxi dolphin (*Sotalia fuviatilis*) in south-eastern Brazil. J. Mar. Biol. Ass. U.K. 84,1245-1250.

Martin, A.R., Da Silva, V.M.F. and Salmon, D.L. 2004. Riverine habitat preferences of botos (*Inia geoffrensis*) and tucuxis (*Sotalia fluviatilis*) in the Central Amazon. Marine Mammal Science 20: 189-200.

Meade, R. H. and Koehnken, L. 1991. Distribution of the river dolphin, tonina *Inia geoffrensis*, in the Orinoco river basin of Venezuela and Colombia. Interciencia 16: 300-312.

McClain M.E. and R.J. Naiman. 2008. Andean Influences on the Biogeochemistry and Ecology of the Amazon River. Oxford Journals. Oxford University Press. BioScience, Vol. 58, No. 4: 325-338.

McGuire, T.L., and Henningsen, T. 2007. Movement Patterns and Site Fidelity of River Dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in the Peruvian Amazon as Determined by Photo-Identification. Aquatics Mammals. 33(3), 359-367 pp. DOI: 10.1578/AM.33.3.2007.359

Mosquera-Guerra, F., Trujillo, F., Diazgranados, M. C. and Mantilla-Meluk, H.. 2015. Conservación de delfines de río (*Inia geoffrensis* y *Sotalia fluviatilis*) en los ecosistemas acuáticos de la Amazonia y Orinoquia en Colombia. Momentos de Ciencia 12(2):77-86.

Obregón, C., Torres, F., and Trujillo, F. 1988. Colombian dolphins. Whalewatcher 22:21 pp.

Pavanato, H.J., Melo-Santos, G., Lima, D.S., Portocarrero-Aya, M., Paschoalini, M., Mosquera, F., Trujillo, F., Meneses, R., Marmontel, M., Maretti, C. 2016. Risks of dam construction for South American river dolphins: a case study of the Tapajós River. Endangered Species Research Endang Species Res. Vol. 31: 47–60, 2016 doi: 10.3354/esr00751

Pilleri, G. and Gihr, M. 1977. Observations on the Bolivian (*Inia geoffrensis* d'Orbigny, 1834) and the Amazonian bufeo (*Inia geoffrensis* de Blainville, 1817), with a description of a new subspecies (*Inia geoffrensis humboldtiana*). Investigations on Cetacea 8: 11-76.

Phillips, S.J., Anderson, R.P., Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling. 190: 231–259.

Phillips, S.J., Dudík, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography. 31(2): 161-175.

Reeves, R.R., Jefferson, T.A., Karczmarski, L., Laidre, K., O'Corry-Crowe, G., Rojas-Bracho, L., Secchi, E.R., Slooten, E., Smith, B.D., Wang, J.Y. and Zhou, K. 2011. *Inia* *geoffrensis*. The IUCN Red List of Threatened Species 2011: e.T10831A3220342. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T10831A3220342.en. Downloaded on 30 March 2018.

Reeves, R.R. et al. 2013. *Inia geoffrensis*. The IUCN Red List of Threatened Species 2013: e.T10831A3220342. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T10831A3220342. .en. Downloaded on 30 March 2018.

Rice D.W. 1998. Marine mammals of the world: systematics and distribution. Society for Marine Mammalogy, Special Publication Number 4 (Wartzok D, ed.), Lawrence, KS. USA.

Rossetti D de F, Valeriano M.M .2007. Evolution of the lowest Amazon basin modeled from the integration of geological and SRTM topographic data.Catena 70: 253–265. doi:10.1016/j.catena.2006.08.009.

Ruiz-García M, S. Caballero, M. Martínez- Agüero and J. Shostell. 2008. Molecular differentiation among *Inia geoffrensis* and *Inia boliviensis* (Iniidae, Cetacea) by means of nuclear intron sequences. Pages 177–223 in V.P. Koven, ed. Population genetics research progress. Nova Science Publishers, Inc., Hauppauge, NY.

Ruiz-García, M. 2010. Changes in the demographic trends of Pink River Dolphins (*Inia*) at the microgeographical level in Peruvian and Bolivian rivers and within the Upper Amazon: Microsatellites and mtDNA analyses and insights into Inia's origin. Pages 225–258 in M. Ruiz-García y J. Shostell, eds. Biology, evolution, and conservation of river dolphins within South America and Asia: Unknown dolphins in danger. Nova Science Publishers, Inc., Hauppauge, NY.

Secchi, E. 2012. *Sotalia fluviatilis*. The IUCN Red List of Threatened Species 2012: e.T190871A17583369.http://dx.doi.org/10.2305/IUCN.UK.2012.RLTS.T190871A17583369.en. Downloaded on 30 March 2018.

Tavera, G., ER. Aliaga-Rossel., P.A. Van Damme,, A. Crespo. 2010. Distribution and conservation status of the Bolivian river dolphin Inia boliviensis (d'Orbigny 1832). In: Trujillo F, Crespo E, van Damme PA, Usma JS (eds) Action Plan South Am. River Dolphins 2010-2020. WWF, Fundación Omacha, WDS, WDCS, Solamac, Bogota´, D.C., Colombia, pp 99–122.

Townsend P.A., Papeş, Eaton.M. 2007. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. Ecography, 30, 550– 560.

Tchounwou, P.B., Ayensu, W.K., Ninashivili, N., Sutton, D. 2003. Enviromental exposure to mercury and its toxicopathologic implications for public health. Environ Toxicol. 18:149-175.

Trujillo, F. 1992. Estimación poblacional de las especies dulceacuícolas de delfines de río *Inia geoffrensis* y *Sotalia fluviatilis* en el sistema lacustre de Tarapoto y El Correo, Amazonía Colombiana. Special Report. Vol. 49. Centro de Investigaciones Científicas. Universidad Jorge Tadeo Lozano, Bogotá D.C., Colombia.

Trujillo, F. 1994a. The use of photo-identification to study the Amazon River Dolphin, *Inia geoffrensis*, in the Colombian Amazon. Marine Mammal Science 10 (3): 348-353 pp.

Trujillo, F. 1994b. Informe técnico de la Expedición *Inia* 94. Fundación Omacha. Bogotá, D.C. 154pp.

Trujillo, 1995. Aspectos del comportamiento y la distribución de Inia geoffrensis y Sotalia fluviatilis en el río Caquetá, Colombia. Special Report. Vol. 71. Centro de investigaciones Científicas, Universidad Jorge Tadeo Lozano. Bogotá D.C., Colombia.

Trujillo, F., M.C. Diazgranados and L. Fuentes. 1999. Manual para la identificación de Mamíferos Acuáticos. Fundación Omacha. 161p.

Trujillo, F. 2000. Habitat use and social behaviour of the freshwater dolphin *Inia geoffrensis* (de Blainville 1817) in the Amazon and Orinoco basins. Ph.D. Thesis. Aberdeen University. Scotland. 157 pp.

Trujillo, F., Diazgranados, M.C., Galindo, A and Fuentes, L. 2006. Delfón *gris Sotalia fluviatilis*. Pp 273-278. En: Rodriguez-M.J.V., Alberico, M., Trujillo, F y Jorgenson, J. Eds. 2006. Libro Rojo de los Mamíferos de Colombia Serie Libros Rojos de Especies Amenazadas de Colombia. Conservación Internacional y Ministerio de Ambiente, Vivienda y Desarrollo Territorial. Bogotá D.C. Colombia.

Trujillo, F., Crespo, E., Van Damme, P. and J.S. Usma. 2010. The action plan for south american river dolphins 2010 – 2020. WWF, WCS, Solamac, Fundación Omacha, 1-249.

Trujillo, F., Caicedo, D., and Diazgranados, M.C (Eds.). 2014. Plan de acción nacional para la conservación de los mamíferos acuáticos de Colombia (PAN mamíferos Colombia). Ministerio de Ambiente y Desarrollo Sostenible, Fundación Omacha, Conservación Internacional y WWF. Bogotá D.C. 54 p.

UNEP-WCMC. 2010. Data Standards for the World Database on Protected Areas, UNEP-WCMC.1–9.

VanDerWal J, Falconi L, Januchowski S, Shoo L, Storlie C. 2014. SDMTools: Species Distribution Modelling Tools: Tools for processing data associated with species distribution modelling exercises. R package version 1.1-221. Ver http://CRAN.R-project.org/package=SDMTools

Velásquez-Roa, T., Carvajal-Castro, J.D., Mantilla-Meluk, H., Trujillo, F and Mosquera-Guerra, F. 2015. Caracterización ecológica de cuencas utilizadas por el delfín rosado *Inia geoffrensis* en Colombia, a través de modelamiento de nicho. *Momentos de Ciencia*. 12(2). Pp: 126-130. ISSN 1692-5491

Vidal, O., Barlow, J., Hurtado, L., Torre, J., Cendon, P., and Ojeda, Z. 1997. Distribution and abundance of the Amazon River Dolphin (*Inia geoffrensis*) and the Tucuxi (*Sotalia fluviatilis*) in the upper Amazon River. Marine Mammal Science 13(3) 427:445pp. http:/ / dx.doi.org/10.1111/j.1748-7692.1997.tb00650.x

WCS (Wildlife Conservation Society) . 2017. http://aguasamazonicas.org/la-iniciativa/