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Study and conservation of the Guiana dolphin (*Sotalia guianensis*) (Van Bénéden, 1864) in French Guiana

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Abstract

The Guiana dolphin (*Sotalia guianensis*) occurs in warm and shallow waters of the Atlantic Ocean and the Caribbean Sea, from southern Brazil to Honduras, including estuarine and freshwater habitats such as Maracaibo Lake (Venezuela), and the Orinoco River. In 2018, the Guiana dolphin was reclassified from Data Deficient to Near Threatened on the global IUCN Red List. Nevertheless, the conservation status identified by national and regional Red Lists is even more alarming. In French Guiana, for example, the species is classified as Endangered based on strong pressures such as bycatch. In this region, the Guiana dolphin inhabits river mouths and coastal waters where most anthropogenic activities occur. Better knowledge of the biology and ecology is needed in French Guiana to help inform effective conservation actions. Here, we present ongoing studies to map the distribution of Guiana dolphins along the French Guiana coast and estimate abundance in a hotspot area. Aerial survey campaigns were conducted during the dry season in 2013, 2014, 2015, and 2019. Eight flights were conducted and 146 dolphins belonging to 39 groups were observed. Boat-based line-transect surveys were also conducted in the coastal waters of Cayenne in 2017 and 2018. Twenty-one survey trips were conducted covering 999.06 km. Three hundred and eighty-two dolphins belonging to 63 groups were observed. The total abundance in the Cayenne area was estimated at 128 dolphins (% CV = 30.92; CI (95%) = 70-235) with a density of 0.80 ind./km² (% CV = 30.92; CI (95%) = 0.44-1.47). Additionally, a descriptive analysis was performed on stranding data collected in French Guiana between 2014 and 2020 to identify the major cause of death and seasonality in the stranding events. In total, 43 dolphins were found, especially on the beaches of Rémire-Montjoly, Cayenne, and Kourou: bycatch was the major identifiable cause of death. We recommend a local conservation strategy and actions to be undertaken in the short- and medium-term to address different issues: knowledge, threats, conservation, and cooperation.

Keywords:
Line-transects, aerial surveys, boat-based surveys, distribution, abundance, bycatch, conservation issues

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Introduction

The Guiana dolphin (*Sotalia guianensis*) (Van Bénéden, 1864) is a small Neotropical delphinid endemic to the eastern coast of South and Central America (Rice, 2002; Secchi *et al.*, 2018). It occurs in warm and shallow waters in open bays, estuaries, and river mouths from Florianópolis, Santa Catarina state, southern Brazil (27°35' S, 48°35' W), with a continuous distribution northwards in the Caribbean Sea and along the coast of Central America, to central Honduras (15°58' N, 79°54' W) (Carr and Bonde, 2000; Edwards and Schnell, 2001; da Silva *et al.* 2010; Secchi *et al.*, 2018). Within populations, Guiana dolphins usually form small groups (Borobia *et al.*, 1991; Flores and da Silva, 2009; da Silva *et al.*, 2010) and have small home ranges (Flores and Bazzalo, 2004; Santos and Rosso, 2007; Oshima and Santos, 2016). Genetic population structure studies conducted along the coast of South America show strong differentiation between populations. However, genetic information is still lacking for Central America (Caballero *et al.*, 2017; 2018) and the Guiana Shield region (Domit *et al.*, 2021).

In French Guiana, the Guiana dolphin is observed along the entire coast, mainly on rocky sites and in the largest river mouths, such as the Maroni, Kourou, Cayenne, Mahury, Approuague, and Oyapock. The species is not observed beyond 36 km offshore (Mannocci *et al.*, 2013) and 18 km upriver (two sightings recorded in the Cayenne and Mahury rivers in 2014, A. Bordin, pers. obs.). The main sites of species occurrence are close to areas with large human populations, estimated at about 270,000 inhabitants, most of whom live in the coastal zone (INSEE, 2019). Anthropogenic activities generate direct and indirect threats and pressures on dolphins. Every year, legal and illegal fishing causes several dolphin deaths as a result of bycatch (Van Waerebeek, 1990; French Guiana Stranding Network, 2020). The species may also be impacted by the degradation of coastal and marine environments caused by land-based sources of pollution, such as insufficiently purified wastewater, macro and micro-waste disposal, and gold panning associated chemical pollution (Brichet, 2009).

Locally, the National Nature Reserve of Grand-Connétable Island (created in 1992) and the Amana Nature Reserve (created in 1998) help protect part of the French Guianese waters, including the Guiana dolphin, which is present in their marine ecosystem. Local protection for marine mammals is reinforced by the Ministerial Decree as of 1 July 2011 that protects all marine mammals in national territory. Since 1982, Guiana dolphins have been listed on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and listed on Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) since 1985 (Crespo *et al.*, 2010). This species is also included in Annex 2 of the Specially Protected Areas and Wildlife Protocol (SPAW) of the Cartagena Convention for Protected Species in the Wider Caribbean Region.

For many years, the International Union for Conservation of Nature (IUCN) listed the Guiana dolphin as Data Deficient. However, recently, the IUCN conservation status was reclassified as Near Threatened (Secchi *et al.*, 2018) and several national and regional Red Lists have been assessed which have resulted in alarming conservation status assessments: Vulnerable in Brazil (ICMBio/MMA, 2018), Colombia (Rodríguez-Mahecha *et al.*, 2006) and Venezuela (Barrios-Garrido *et al.*, 2015), and Endangered in French Guiana (UICN France *et al.*, 2017). In the latter, the main criteria for listing the species as Endangered was based on the high degree of pressure exerted on the species, from bycatch and habitat degradation, and the species assumed limited exchanges (due to sedentary groups and movements over short distances) with dolphin populations from neighboring countries (UICN France *et al.*, 2017).

Knowledge on the biology, ecology, and behavior of *S. guianensis* in French Guiana is still very limited, but several initiatives have been carried out recently or are in progress. Here, we present current efforts to map the species distribution along the Guianese coast and to estimate its abundance and density in the coastal waters of Cayenne. We also present a preliminary and descriptive analysis of stranding data collected between 2014 and 2020 by the French Guiana Stranding Network, to identify the main areas where strandings occur, the major cause of death, and possible seasonal variations. Finally, we recommend a local conservation strategy and actions to be undertaken in the short- and medium-term under the framework provided by the International Whaling Commission (IWC) report of the *Sotalia guianensis* pre-assessment workshop (Domit *et al.*, 2019; 2021), the United Nations Environment Programme's Marine Mammal Action Plan (UNEP/MMAP) (UNEP, 2008), and the Action Plan for South American River Dolphins (Trujillo *et al.*, 2010).

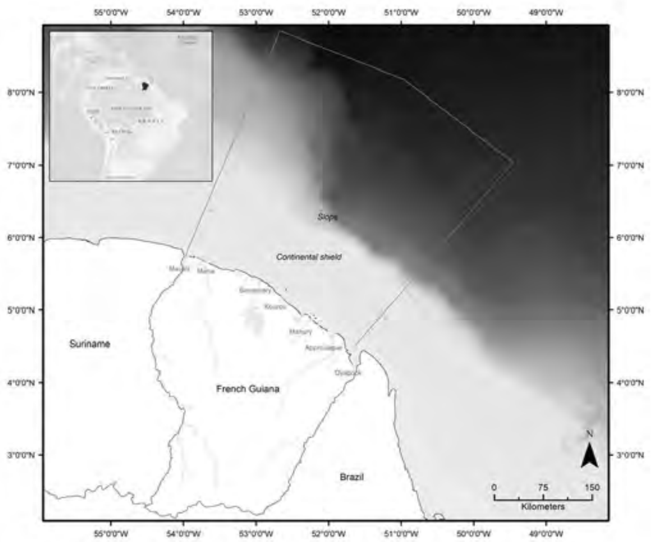

Figure 1. Exclusive Economic Zone and rivers of French Guiana (Base map: ESRI, www.gebco.net).

Materials and method

French Guiana

French Guiana is a French overseas territory located in the Equatorial zone of the Northern Hemisphere between 2° and 7° N, and 51° and 54° W (Fig. 1). It is part of the Guiana Shield region bordering the Atlantic Ocean, including five other countries (Venezuela, Guyana, Suriname, as well as parts of Colombia and Brazil). French Guiana has an area of 86,504 km² with a coastline of about 300 km. Its Exclusive Economic Zone (EEZ) is almost 140,000 km² in area (Barret, 2001).

Coastal and marine habitats of French Guiana are characterized by shallow depths with a gently declining continental shelf extending up to 150 km offshore (Boyé *et al.*, 1979). Littoral and coastal environments are influenced by large rivers - Oyapock, Approuague, Mahury, Kourou, Sinnamary, Mana, Maroni - running from south to north, which discharge sediments and fresh water into the Atlantic Ocean. Eastward, the Amazon River in Brazil, through its massive, suspended sediment discharge, plays an important role in the composition of the estuarine, coastal, and shelf marine ecosystems (Artigas *et al.*, 2003; Anthony *et al.*, 2013). Under the combined influence of the Amazon River and Guiana Current, sediments produce huge mudflats that move westward and extend up to 60 km long, 30 km wide, and 5 m thick (Gensac, 2012). The coastal waters of French Guiana are thus subject to strong seasonal and inter-annual variations in turbidity and salinity.

The shoreline of French Guiana is mostly bordered by mangrove forests of *Avicennia nitida* along the coast and *Rhizophora mangle* in the estuaries (Battistini, 2003). French Guiana has around 10-30 km of beaches, which corresponds to less than 10% of the coastline, and hosts the only rocky habitats found between the Amazon and Orinoco rivers. These habitats are frequented by many top marine predators that use these areas as feeding and nursery grounds, such as Goliath groupers (*Epinephelus itajara*) (Artero *et al.*, 2015), Atlantic tarpons (*Megalops atlanticus*) (Rohtla *et al.*, 2016), Guiana dolphins (Mannocci *et al.*, 2013), and other charismatic vertebrates including green turtles (Chambault *et al.*, 2018) and Antillean manatees (Castelblanco-Martinez *et al.*, 2018). The intense coastal dynamics create specific challenges for the long-term monitoring of marine turtles (Kelle *et al.*, 2007) and potentially for all the megafauna species, like the Guiana dolphin, associated with this rapidly evolving ecosystem.

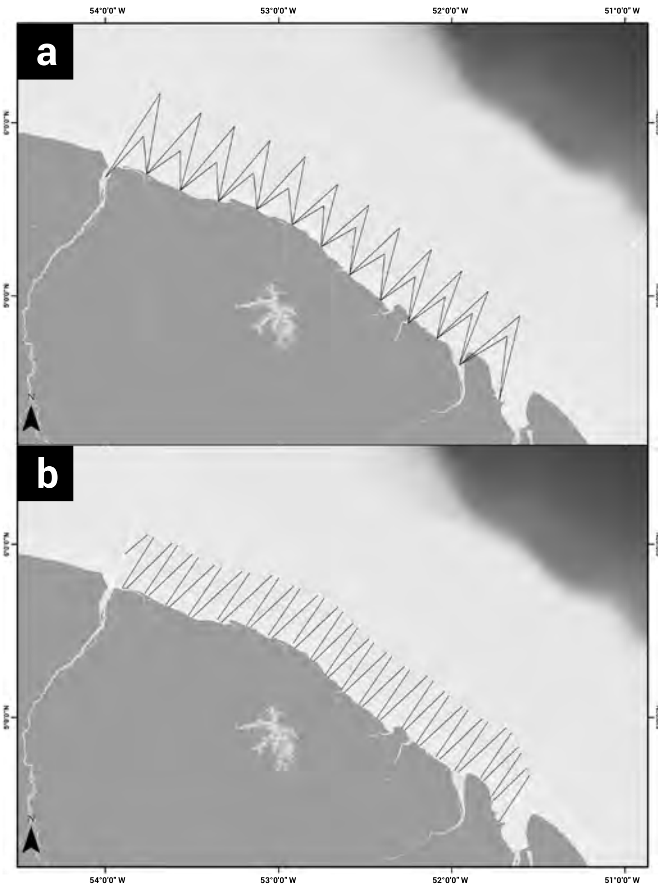

Figure 2. Survey transects from aerial surveys conducted between 2013 and 2019 along the French Guiana coast **(a)** by WWF/campaign 1 and **(b)** GEPOG/campaign 2 to assess Guiana dolphin abundance.

Spatial distribution along the French Guiana coast

- ***Aerial surveys***

Between 2013 and 2015, the World Wide Fund for Nature (WWF) implemented the first aerial survey campaign (Campaign 1) dedicated to the census of the Guiana dolphin and its distribution along the French Guiana coast. The surveys occurred over three days in November 2013 and one day each in May 2014 and July 2015 (Table 1). The survey track covered 2,307 km (an area of approximately 2,500 km²) and the total survey effort was about 18 hours, including search, observation, and transit time (Fig. 2a). Transects of the neritic stratum were carried out once while those of the coastal stratum were replicated between one and three times, with more survey effort in the western part of the study area. In 2019, the Groupe d'Etude et de Protection des Oiseaux en Guyane - GEPOG (Study and Protection Group of Birds in French Guiana) and the National Marine Reserve of the Grand-Connétable Island also conducted aerial surveys under the framework of the European project CARI'MAM (Campaign 2) (Table 1). These surveys took place on three days in October 2019 during the dry season when the conditions were most favorable. The survey covered 2,198 km (approximately 2,500 km²) over about 12 hours (Fig. 2b). Transects were sampled one or two times. All surveys were carried out early in the morning to limit sun glare and when the sea state was equal to 3 or below on the Beaufort wind scale.

Table 1. Effort and groups of Guiana dolphins observed during aerial campaigns 1 and 2 conducted in 2013, 2014, 2015 and 2019 in French Guiana.

Date	Campaign	Number of lines	Km travelled	Stratum	Number of groups (inds)
14 Nov 2013	1	8	390	Neritic (east)	3 (5)
15 Nov 2013	1	8	418	Neritic (west)	7 (11)
16 Nov 2013	1	16	462	Coastal (west + east)	9 (27)
		8	349	Neritic (east)	
23 May 2014	1	12	316	Coastal (west)	3 (7)
21 Jul 2015	1	14	372	Neritic (east)	10 (24)
03 Oct 2019	2	20	727	Neritic (east)	2 (4)
05 Oct 2019	2	20	744	Neritic (west)	1 (9)
06 Oct 2019	2	20	727	Neritic (east)	4 (59)
			4,869		39 (146)

The transect design followed a zigzag profile that cut perpendicularly across the isobaths to sample different depths, allowing rapid coverage of a large area and optimizing flight time by limiting transits between transects. The Campaign 1 sampling included 48 transects for a total length of 1,837 km. The sampling design consisted of a peri-coastal stratum with 24 transects extending to 20 km offshore (effort = 680 km) and a neritic stratum with 24 transects extending to about 45 km above the 40 m depths (effort = 1,157 km). The sampling design of Campaign 2 was slightly different with a single neritic stratum, including 40 transects closer together and extending to 40 km above depths of 30 m, with a total length of 1,471 km.

For both campaigns, the aircraft used was a twin-engine Britten Norman 2 (BN2) with high wings and equipped with two bubble windows so that observers could look below the aircraft. Its maximum flight time was approximately six hours. The aircraft maintained an altitude of 182 m (600 feet) above the water's surface and flew at a speed of 167 km/h (90 knots). The crew was composed of five people, including a pilot, a navigator, a co-navigator, and two experienced observers. The navigator oversaw entering the data on a laptop computer equipped with SAMMOA software , specially developed for aerial surveys by the

PELAGIS Observatory of La Rochelle University, and a GPS unit. A strip of about 1,000 m width was covered by the observers (500 m on each side of the plane). For each observation, the observer recorded the number of individuals, surface behavior, and swimming direction. Records related to human activities (boats, nets, macro-waste, and pollution) were also reported. The resulting distribution map was made with ArcGIS 10.8 ESRI software (ESRI, 2021).

Abundance and density estimates in the coastal waters of Cayenne

- ***Boat-based line-transect surveys***

Boat-based line-transect surveys using the Distance Sampling method (Buckland *et al.*, 1993; Thomas *et al.*, 2010) were conducted to estimate the abundance and density of Guiana dolphins in the coastal and estuarine waters of Cayenne. The study area was bordered by two estuaries, the Cayenne River in the west and the Mahury River in the east (Fig. 3). It extended up to 10 km offshore and included a variety of habitats such as estuaries, mangroves, islands, and beachfronts over an area of 160 km².

In total, 21 survey trips were carried out during the dry season (August, October, and November 2017; July and August 2018) (Table 2). The trips were conducted between 07:00 h and 14:00 h when conditions were most favorable, prior to increased afternoon wind activity (Beaufort sea state less than or equal to 3, no rain). The sampling plan included 26 transects with an average length of 6 km (min. = 4.6 km; max. = 10.5 km) covering 999.06 km (Fig. 4). The transects were distributed throughout the study area and covered different habitats: estuaries, navigation channels, and rocky and muddy zones. The aircraft was oriented according to the direction of the swell and the geographical constraints of the study area (submerged rocks, islets, mudflats, etc.). The transects were carried out in succession to limit transit times. Each survey lasted approximately 4.5 hours, for a total of 100 hours, including search, observation, and transit time. The transects were replicated between 4 and 11 times (mean = 6), with more effort in the eastern part of the study area.

Motorized boats (< 7 m long) equipped with a GPS unit and depth sounder were used. The boat speed ranged between 14 and 22 km/h, faster than the swimming speed of dolphins (7 km/h;

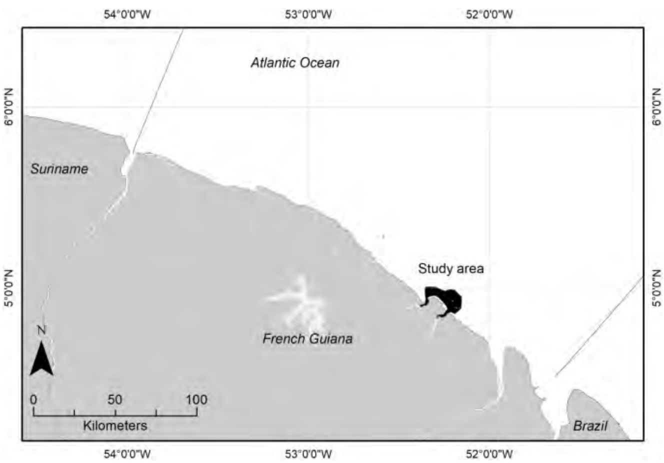

Figure 3. Study area of the boat-based line-transect surveys of Guiana dolphins in French Guiana, 2017-2018.

Table 2. Effort and groups of Guiana dolphins observed in line-transect surveys in 2017 and 2018 in the coastal waters of Cayenne, French Guiana.

Year	Trips	Km travelled	Nbr groups (inds)
2017	9	341.03	22 (146)
2018	12	658.03	37 (225)
Total	21	999.06	59 (371)

Cremer *et al.*, 2000). Two trained observers were placed at the front of the boat and surveyed 90° each, for a 180° total forward observation, over a band of 500 m. Geographic coordinates of the observations were collected using a Garmin GPS unit. Starting in July 2018, a cellular iPad touchscreen tablet equipped with the OBSenMER application's expert component was used to record the tracks, observations, and conditions.

When a dolphin was detected, its geographic position was recorded when it was perpendicular to the boat and the animal's distance from the vessel was estimated by naked eye.

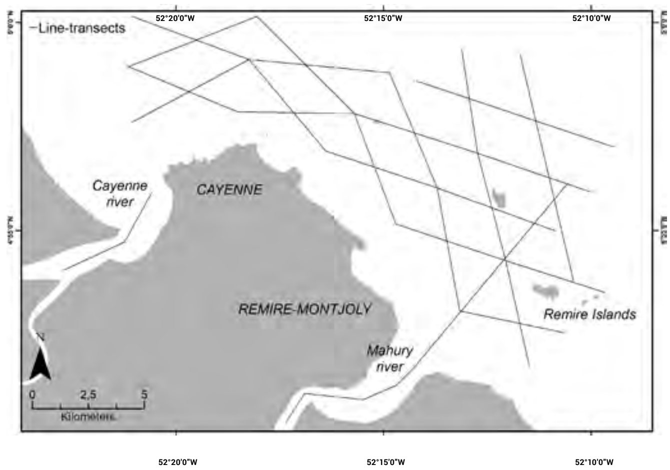

Figure 4. Boat-based line-transect surveys conducted between 2017 and 2018 in the coastal waters of Cayenne, French Guiana, to assess Guiana dolphin abundance.

The observers were previously trained to estimate distances using buoys and GPS. The information recorded which side of the vessel the observation occurred (right or left) and group size.

Data were spatially displayed using ArcGIS 10.8 (ESRI, 2021), and abundance and density analyses were performed using Distance 7.3 Release 1 (Thomas *et al.*, 2010). Observations were grouped into distance intervals (0-100 m, 100-200 m, 200-300 m, 300-500 m) and those greater than 500 m were excluded from the analysis to refine the detection function per the recommendations of Buckland *et al.* (2001). The probability of detection was estimated using a Conventional Distance Sampling (CDS) approach. This method considers that the probability of detection decreases with greater distances between the g(0) line and the observation. It is based on three assumptions, which can lead to potential bias if not considered: (1) all animals on the line are detected and the detection probability is assumed to be equal to 1 (g(0) = 1), (2) animals do not flee or be attracted by the survey platform, and (3) the distances are measured accurately (Buckland *et al.*, 2001). Three key functions were tested (half-normal, hazard-rate, and uniform), both without adjustment and with Cosine adjustment. The detection function model was selected according to the minimum Akaike Information Criterion (AIC) (Akaike, 1985; Laake *et al.*, 1993), and the fit of the detection function to the observed data was estimated with a Goodness-Of-Fit (GOF) test available in Distance software.

Strandings

A local branch of the French Stranding Network was created in 2014 to train and empower approximately 20 volunteers to respond to stranded animals in French Guiana. Between 2014 and 2020, the network responded to 43 strandings of Guiana dolphins, mainly on the beaches of Remire-Montjoly, Cayenne, and Kourou (86% of stranding records).

For each stranding event, geographic coordinates, species, sex, state of decomposition, number of teeth per jaw, and body measurements (length of the body, fins, rostrum, circumference, etc.) (Jauniaux *et al.,* 2002) were recorded. Photos were taken, and an external examination followed. If the state of decomposition was not too advanced, a necropsy was performed to identify the cause of death. Banding marks, clear cuts, and antemortem haematomas usually indicate capture in a net. A descriptive analysis of the eight years of stranding data allowed us to identify spatial and temporal trends in stranding events and highlighted the main causes of death. An ANOVA test was run to determine whether the number of strandings varied by months (at a 5% significance level).

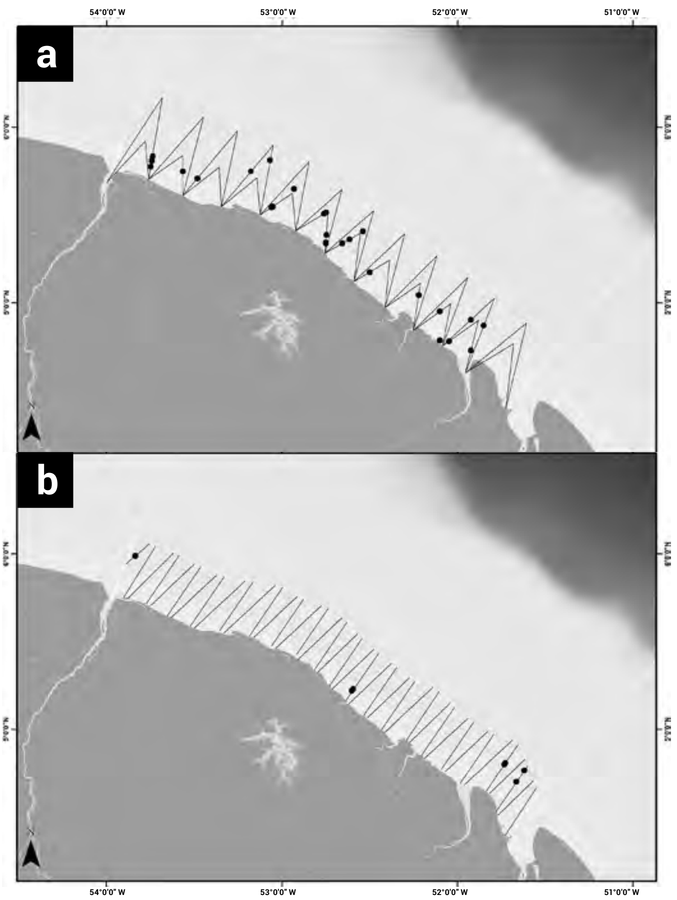

Figure 5. Location of the Guiana dolphin groups (n = 39) observed during **(a)** aerial campaign 1 and **(b)** aerial campaign 2 along the French Guiana coast, 2013-2019.

Results

Spatial distribution

A total of 74 Guiana dolphins belonging to 32 groups were observed during aerial campaign 1 (Fig. 5a) and 72 Guiana dolphins (7 groups) during Campaign 2 (Fig. 5b) (Table 1). Encounter rates were 3.21 individuals per 100 km travelled during Campaign 1 and 3.27 individuals per 100 km travelled for Campaign 2. Group sizes varied from 1 to 6 individuals (mean = 2.31, Campaign 1) and from 2 to 50 individuals (mean = 10.28, Campaign 2). It should be noted that the Campaign 2 mean is equal to 4 when we remove the outlier group of 50 individuals due to the infrequency of groups of that size. The groups were observed in water depths from 2 to 28 m, with a mean depth of 11 m for Campaign 1 and 14 m for Campaign 2 (Fig. 6). Most of the groups were located between 10 km and 23 km offshore. The group observed at the 28 m isobath was located 34 km offshore.

Abundance and density estimates

In total, 382 individual Guiana dolphins belonging to 63 groups were recorded during our line-transect surveys (Fig. 7). The encounter rate was 0.038 ind./100 km. Sightings of 371 individuals from 59 observations were used for abundance and density analyses after truncating the data to exclude sightings beyond 500 m (5% of the dataset) (Table 2). Distance intervals of 0-100 m, 100-200 m, 200-300 m, and 300-500 m included 25, 18, 9, and 7 observations respectively. The model used for the detection function as determined by the lowest AIC was the Hazard-Rate model (AIC = 153.38), with a Cosine fit based on the better GOF (GOF = 0.90).

The abundance of dolphins using the waters of Cayenne was estimated to be 128 individuals (% CV = 30.92; CI (95%) = 70-235) with a density of 0.80 ind./km² (% CV = 30.92; CI (95%) = 0.44-1.47).

Group sizes varied from 2 to 50 individuals. The average group size for the entire study area was 6.28 individuals (CV = 16.34; CI (95%) = 4.58-8.70). The effective detection width was estimated at 236.01 m (Fig. 8).

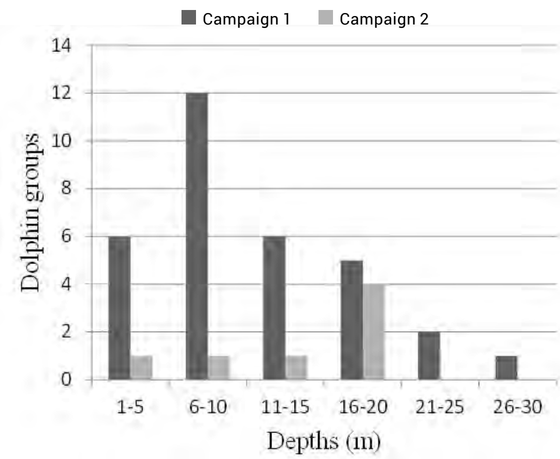

Figure 6. Depths (m) of the Guiana dolphin observations recorded during aerial campaign 1 (depth mean = 11) and aerial campaign 2 (depth mean = 14) along the French Guiana coast, 2013-2019.

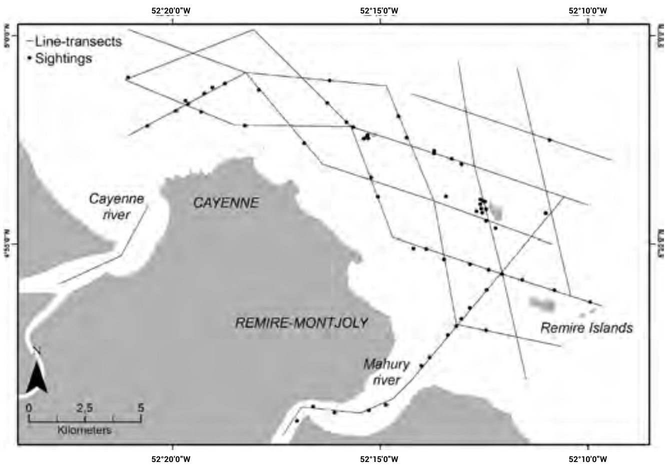

Figure 7. Location of the Guiana dolphin groups (n = 63) observed during the boat-based line-transect surveys in 2017 and 2018 in the coastal waters of Cayenne, French Guiana.

Bycatch

The French Guiana Stranding Network recorded 43 stranded Guiana dolphins between 2014 and 2020 (mean = 6/year), including one live-stranded neonate that did not survive. Twenty animals (46%) were fresh with little decomposition, which allowed for external examinations and necropsy to facilitate determination of the cause of death. From 2014 to 2020, 26 individuals were killed from entanglement in fishing gear, representing 60.5% of strandings (annual mean = 3.7) (Table 3). The catches were made either in the nets of the coastal artisanal fisheries or illegal foreign fisheries. The animals were mostly found on the beaches of Rémire-Montjoly, Cayenne, and Kourou (Table 4, Figs 1 and 4). The number of strandings averaged 3.6 per month, with very few individuals reported in July (n = 0) and August (n = 1), and higher numbers of individuals reported in March (n = 6), September (n = 6), and December (n = 7) (Fig. 9). The ANOVA test showed that the differences in the number of strandings by month were not significant (F ANOVA = 1.392; p = 0.257).

Discussion

Aerial surveys have been used in several areas to study small delphinids (Slooten *et al.,* 2004; Lambert *et al.,* 2019), but sparingly for Guiana dolphins. In Nicaragua, Carr and Bonde (2000) and Edwards and Schnell (2001) conducted aerial surveys, coupled with boat surveys, to assess the distribution of the species and its abundance. However, protocols of those studies (aircraft, speed, altitude, sampling designs) differed from those implemented in French Guiana, precluding further comparisons. Furthermore, standardized methods for estimating ecological parameters of populations are essential to compare results, monitor trends, and to establish conservation actions (Gomez-Salazar *et al.,* 2012; Domit *et al.,* 2019).

During the 2008 dry season in French Guiana, La Rochelle University carried out the EXOCET aerial campaign, which provided the first snapshot of the distribution and abundance of marine mammals and other megafauna species within the EEZ (Mannocci *et al.,* 2013). During those surveys, 22 groups of Guiana dolphins

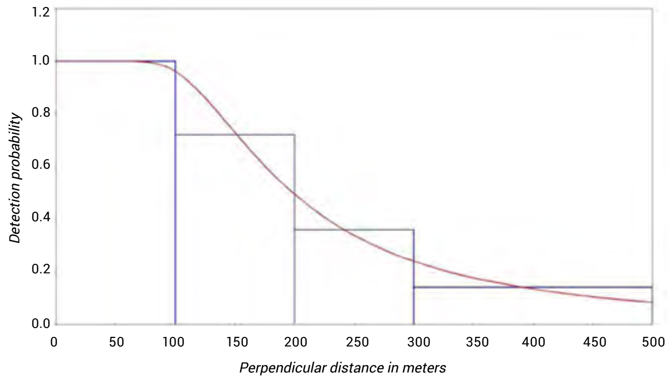

Figure 8. Detection probability of Guiana dolphin according to distance from the g(0) line during survey effort. The curve represents the best detection function model.

(n = 59) were observed during three flights with an average group size of 2.6 (min = 1; max = 8).

Despite a similar survey effort (around 750 km covered in the coastal strip), the number of groups observed was higher during the EXOCET campaign and Campaign 1 than in Campaign 2; the encounter rates changed from 7.8 inds/100 km in 2008 to 3.27 inds/100 km in 2019. The average group sizes remained consistent (if we exclude the observation of the group of 50 individuals in 2019, which is not common). Observations were more concentrated in shallow depths during the EXOCET campaign.

These changes over time could be explained partly by the variations in some of the environmental parameters such as bathymetry. Since 2014, a large westward-moving mudflat increased the sediment deposition rate in that area. Thus, animals could be forced to move towards the open water, especially during low tide. The land-based surveys conducted in 2014 and 2018 in French Guiana also confirmed a decrease in number of observations in the shallow waters (< 5 m) (A. Bordin, unpub. data). The lower encounter rates could also be explained by the higher level of turbidity generated by the suspended sediments, which decreases the detection rate of individuals. Moreover, water temperature, salinity, prey distribution, and prey abundance can also influence the distribution of marine mammals (Vidal *et al.,* 1997; Garcia and Trujillo, 2004; de Godoy *et al.,* 2015; Tardin *et al.,* 2020). In Nicaragua, the distribution and behavior of Guiana dolphins appear to be influenced by similar environmental

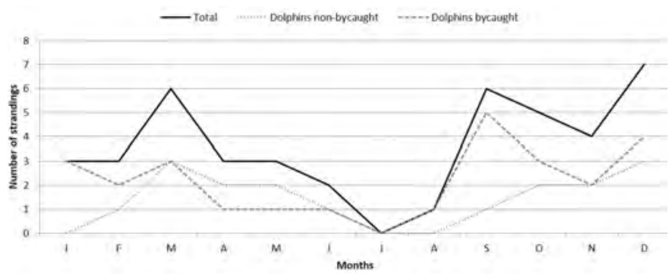

Figure 9. Number of strandings and number of bycaught Guiana dolphins per month between 2014 and 2020 along the French Guiana coast.

Table 3. Number of bycaught and non-bycaught Guiana dolphins between 2014 and 2020 along the French Guiana coast.

	Bycatch	No sign of bycatch	Unknown	Total
2014	2	-	-	2
2015	8	-	2	10
2016	5	-	2	7
2017	2	-	2	4
2018	1	-	3	3
2019	3	1	6	10
2020	5	-	2	7
Total	26	1	17	43

variables (Edwards and Schnell, 2001). A final hypothesis could be linked to a declining demographic trend. However, to confirm this, further surveys should be conducted over a longer time-period, including surveys to obtain abundance estimates.

An analysis of EXOCET data included a first estimate of the Guiana dolphin population as 1,968 individuals (IC 95% = 938 - 4063) (Mannocci *et al.,* 2013), but with a high standard deviation, meaning that this result should be taken with caution. Aerial surveys have several limitations for the census of small and coastal cetaceans in French Guiana. The size of the animals, their cryptic behavior at the water surface, and turbidity make them difficult to detect. Moreover, to obtain statistically sound results for abundance and density, the surveys must be replicated over a long time-period, requiring a considerable budget. In our case, and for these different reasons, we consider that the abundance estimate of Guiana dolphins by aerial surveys does not allow to obtain significant results and that other means should be considered. Aerial surveys using ultralight aircraft have been tested and could be an adequate solution to study the species distribution and abundance in its preferential habitats (A. Bordin, unpub. data). This aircraft is less expensive than a plane and can fly at a low altitude and speed, which facilitates the detection of animals. An ultralight aircraft was previously used for surveying marine turtle populations along the west coast of Reunion Island, Indian Ocean (Jean *et al.,* 2010) and monitoring dugongs (*Dugong dugon*) in Mayotte, western Indian Ocean (Kiszka *et al.,* 2007). In addition, the use of environmental data (bathymetry, salinity, temperature, distance to shore, etc.) and observation data would allow the realization of Ecological Niche Modeling (ENMs) in order to identify the favorable sites, or not, to the species along the coastline. Several studies have used this method, in particular to identify areas of interaction between animals and human activities, but also future marine protected areas (Tardin *et al.,* 2020; Lobo *et al.,* 2021).

The Distance Sampling method is the most used technique to estimate the abundance and density of the Guiana dolphin (Santos *et al.* 2010), even if the studies remain scarce along the range of the species. Thirty-six studies have been compiled between 2000 and 2019 (Domit *et al.* 2019), most of which were conducted in small areas in Brazil. The results obtained for the surveyed area in French Guiana (160 km²) show a density of 0.80 ind./km² (% CV = 30.92; CI (95%) = 0.44-1.47). By comparing these results with those obtained in other areas, the density is quite low (Table 5). Data on Guiana dolphin ecology in French Guiana are limited, therefore data on abundance, a key factor in evaluating the conservation status and defining a management plan, are also limited. The only published abundance estimate for the entire population in French Guiana was that obtained from the EXOCET aerial surveys. In those surveys, the abundance estimate only considered a specific area or hotspot and the estimate was quite low (128 individuals (% CV = 30.92; CI (95%) = 70-235) compared to other sectors (Table 5).

The reasons for the low density and abundance estimated in this study could be related to sampling bias because we did not respect all Conventional Distance Sampling assumptions. Accurate estimates of marine mammal densities and abundance are particularly difficult to obtain. Sampling biases can lead to inaccurate estimates because dolphins respond to the platform, therefore group size estimates are imprecise and affected by the detection rate (Buckland *et al.,* 1993; Edwards and Schnell, 2001). In our research, the detection probability along the g(0) line was assumed to be equal to 1, because of the slow speed of the vessel, the favorable survey conditions, estimated dive time of 30 seconds for this species (Cremer *et al.,* 2000; 2011), and shallow depth of the habitat. The animals were not attracted to the boat and those with an avoidance response were quickly detected. However, perpendicular distance estimation by naked eye can generate biases in abundance and density estimates, and can also lead to fitting an inappropriate detection function. In our study, distance estimation and measurement methods requiring the horizon were not possible since we were in a restricted area (Williams *et al.,* 2007) and we used low platforms (Williams *et al.,* 2017). Williams *et al.* (2007) compared different distance estimation methods in four experiments, including a study on dolphins in the Amazon River. The latter compares visual estimates and laser rangefinder measurements, and shows that

Table 4. Location of strandings of Guiana dolphins between 2014 and 2020 on the beaches of French Guiana and at sea.

	Awala-Yalimapo	Kourou	Macouria	Cayenne	Rémire-Montjoly	At sea	Total
2014	-	-	-	-	2	-	2
2015	1	5	-	1	3	-	10
2016	-	1	-	1	3	2	7
2017	-	3	-	-	1	-	4
2018	-	2	-	1	-	-	3
2019	-	2	2	1	5	-	10
2020	-	2	1	1	3	-	7
Total (%)	1 (2%)	15 (35%)	3 (7%)	5 (12%)	17 (39%)	2 (5%)	43 (100%)

errors could bias distance estimates downward by as much as 14% with naked eye estimation. Thus, measurements in future line-transect surveys must be made using laser rangefinders.

The confidence interval obtained for the abundance estimate is particularly large, which underlines a certain fragility of the dataset. The reasons are certainly related to an insufficient number of observations, and also due to methodological weaknesses. To reduce this confidence interval, additional survey trips should be conducted including a better coverage of the western part of the study area which was under-sampled. Indeed, the sampling design was extended beyond the Remire islands in 2018 to respond to a project of the French Guiana commercial harbor about the presence of the Guiana dolphin in the site. This project was a good funding opportunity, but increased the effort in the eastern part. A higher platform and the use of laser rangefinders should help limit bias in future estimates.

In addition to line-transect surveys, mark-recapture methods are regularly used to estimate the abundance of many marine mammal species and have largely demonstrated their effectiveness (Nery *et al.* 2008; Cantor *et al.,* 2012; Coimbra *et al.,* 2016; de Mello *et al.,* 2019). A long-term photo-identification monitoring program in Sepetiba Bay in Brazil provided unbiased and more precise estimates of population size than those derived from line-transect surveys (Nery *et al.,* 2008). Daura-Jorge and Simões-Lopes (2016) compared both approaches and showed that mark-recapture methods were twice as effective in terms of precision.

In most areas, group size for Guiana dolphin ranges from 2-29 individuals (Geise, 1991; Edwards and Schnell, 2001; Garcia and Trujillo, 2004; Daura-Jorge *et al.,* 2007, Cremer *et al.,* 2011). Here, the group size was estimated from line-transect surveys to be 6.28 individuals, twice as much as during the aerial campaigns. This may be explained by a lower detection of animals during the aerial surveys, and a better detection of large groups by boat (Dawson *et al.,* 2008). Group size can be influenced by physical and environmental parameters, but also by feeding strategies and predation risk in the area (de Meirelles *et al.,* 2020). The large groups (50-400 individuals) observed in the southern limit of the species distribution are explained by high availability of prey owing to the presence of large rivers and estuaries that can support large numbers of species and resources (Edwards and Schnell, 2001; Flores *et al.,* 2018). High numbers of *Sotalia*, as found in some sections of the Amazon or Nicaragua, were the result of different factors such as a high abundance of prey, proximity to the resources, depth, water temperature, and salinity (Vidal *et al.,* 1997; Edwards and Schnell, 2001).

An understanding of the pressures, both natural and anthropogenic, that can affect populations is essential for the conservation of vulnerable species and their habitats. Eleven anthropogenic activities with direct and indirect effects on the Guiana dolphin, including fisheries interactions, coastal infrastructure development, and port activities, have been identified throughout its range (Domit *et al.,* 2019). Several of these pressures have been identified in French Guiana, including impacts from bycatch (Van Waerebeek, 1990; UICN France *et al.,* 2017). Bycatch of dolphins (Guiana and bottlenose dolphins *Tursiops truncatus*) in offshore Guianese waters was first reported after interviews with fishers. These interviews indicated that impacts to the population could be considerable, and a hundred individuals could be taken each year (Van Waerebeek, 1990). Since 2014, the monitoring conducted by the French Guiana Stranding Network has shown that 60.5% of strandings are caused by incidental capture in fishing nets and that the annual numbers do not tend to decrease. The number of strandings could be larger since those found represent only a small proportion of total stranding events. Indeed, the accessible beaches represent around 5% of the coastline, the rest being mangrove swamps or isolated beaches. The high rate of siltation could also block the carcasses on the mudflats and thus limit the number of strandings on the beaches. Moreover, the cause of death was undetermined for 17 animals, partly due to the advanced state of decomposition. In French Guiana, humidity, sun, rain, and black vultures (*Coragyps atratus*) may accelerate the decomposition rate of corpses.

The catches were all accidental; no cases of poaching were noted. In 2019, fishers who captured a Guiana dolphin declared having extracted and used pieces of blubber for bait. Even if this case is anecdotal, the practice was already observed in other stranding cases in French Guiana (Van Waerebeek, 1990).

Peaks of bycatch were noted in March, September, and December, which could be correlated with an increase in fishing activity in the area because of the more favorable sea and weather conditions. A detailed study to overlay the fisheries and distribution data of the dolphins would allow a better understanding of the interactions. Gillnets appear to be the type of gear that generates the most interactions with the Guiana dolphin (Bolaños-Jiménez and Rojas-Bracho, 2005; Domit *et al.,* 2019). Brazilian fishermen operating in the Guianese

Table 5. Density/abundance estimates of Guiana dolphin in areas other than French Guiana.

Study area, country	Technique	Area surface (km²)	Density (ind./km²)	Abundance	Source
Cayos Miskito Reserve, Nicaragua	Boat survey/strip-transect	152.4	0.6	-	Edwards and Schnell, 2001
Gulf of Morrosquillo, Colombia	Boat survey/mark-recapture	310	0.74	118-426	Dussán-Duque, 2013
Southern Gulf of Venezuela, Venezuela	Boat survey/follow-group protocol	6.33	1.34	150-573	Espinoza-Rodríguez *et al* ., 2019
Maracaibo Lake System, Venzuela	Boat survey/mark-recapture	249.2	1.66	-	Delgado-Ortega, 2012 (*in* Barrios-Garrido *et al* ., 2021)
Guanabarra Bay, Brazil	Boat survey/line-transect	70	5.7	-	Geise, 1991
Sepetiba Bay, Brazil	Boat survey/mark-recapture	520	-	588-1004	Flach, 2015 (in Domit *et al* ., 2019)
Paranaguá Bay, Brazil	Boat survey/line-transect	38.84	11.56	1	Filla, 2004
Babitonga Bay, Brazil	Boat survey/line-transect	160	1.3	147-365	Cremer, 2011

waters had reported incidental catches of dolphins in large-mesh multifilament nylon nets (Van Waerebeek, 1990). Although bycatch rates or fishing efforts, particularly for the artisanal fishery, remain poorly known, few initiatives and experiments have been carried out on the Guiana dolphin to limit interactions with fisheries (Domit *et al.,* 2019). From 1996 to 1998, an experimental test with pingers was conducted in Brazil by Monteiro-Neto *et al.* (2004). In 2018 in French Guiana, a project led by WWF and the Regional Committee of Fisheries was conducted to obtain information from fishers on the number of bycatches, frequency and location, and mitigation strategies which could be put in place to limit interactions (André, 2018).

Since the Guiana dolphin has a limited global distribution, France has a special responsibility regarding the study and preservation of this species in the Guianese territory. Consequently, research on *S. guianensis* in French Guiana should continue to help assess the impact of anthropogenic pressures on the local populations and help define the most effective means of protecting the species and its habitat. Efforts should be allocated for strengthening a regional conservation dynamic and the implementation of a National Action Plan that complies with actions promoted by the UNEP's MMAP (UNEP, 2008), the IWC's reports (Domit *et al.,* 2019; 2021; IWC, 2021), and with specific conservation plans such as the Action Plan for South American River Dolphins 2010-2020 (Trujillo *et al.,* 2010). Improving knowledge of abundance and density, spatial and temporal distribution, social parameters, and pressures is essential. Raising the awareness of the local communities and the development of participatory studies are also actions that should be promoted. Conservation actions, such as the development of marine protected areas, which represent less than 1% of the EEZ surface in French Guiana, should be considered to protect habitats favorable to the species, e.g. rocky habitats. These efforts will need to integrate fishers and other stakeholders to reconcile the preservation of marine biodiversity and economic activities. In addition, cooperation with networks in Brazil, the Guianas, Venezuela, Colombia, and Central America should be developed to standardize data collection and strengthen capabilities at local levels.

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