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Abundance, Distribution, and Habitat Suitability Prediction of the Guiana Dolphin and Common Bottlenose Dolphin in the Gulf of Urabá, Colombian Caribbean

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Abstract

Studying the abundance, distribution, and habitat use of dolphins can provide essential information for preserving marine biodiversity, managing coastal ecosystems, and enhancing our understanding of aquatic life. Herein, we investigated the abundance, distribution, and habitat use of two dolphin populations—Guiana dolphins (*Sotalia guianensis*) and common bottlenose dolphins (*Tursiops truncatus*)—in the Gulf of Urabá, Colombian Caribbean. Between 2017 and 2020, 34 non-systematic surveys were conducted across the studied region, amounting to an effort of 176.69 hours and covering 3,658.33 km, with a dolphin encounter probability rate of 8.65%. The Guiana dolphin population was estimated at 63 (95% CI = 53 to 76) individuals, whereas the common bottlenose dolphin population was estimated at 50 (95% CI = 43 to 58) individuals. The dolphins were mainly found in the central region of the Gulf, particularly around the Atrato River mouth and the east side of the estuary. Both species showed a preference for coastal areas with maximum depths of 20 m, and the Guiana dolphins showed a permanent presence in the Gulf of Urabá region. These findings indicate that the Gulf of Urabá acts as a crucial habitat and feeding ground for both Guiana and common bottlenose dolphins. Therefore, systematic monitoring programmes aiming to protect dolphin populations and their ecosystems from threats posed by coastal development, which currently endanger both species in the area, should be implemented.

Key Words: cetaceans, coastal populations, conservation, maximum-entropy analysis, population parameters, Colombia

Introduction

The Gulf of Urabá, located in the southwest of the Colombian Caribbean and bordering Panama, is a unique and biodiverse region. The Gulf boasts over 5,000 km^2 of mangrove forests and is largely influenced by the Atrato River, the country's second largest river flowing into the Caribbean (Blanco-Libreros & Londoño-Mesa, 2016). More than eight species of cetaceans have been recorded in this marine environment, including killer whales (*Orcinus orca*), false killer whales (*Pseudorca crassidens*), Atlantic spotted dolphins (*Stenella frontalis*), pantropical spotted dolphins (*Stenella attenuata*), sperm whales (*Physeter macrocephalus*), whales from the Balaenopteridae family, Guiana dolphins

(*Sotalia guianensis*), and common bottlenose dolphins (*Tursiops truncatus*). The Guiana dolphin and the common bottlenose dolphin are the two most frequent species found in the Gulf of Urabá (Fundación Omacha & CORPOURABÁ, 2016).

Both Guiana and common bottlenose dolphins exhibit a long lifespan, slow reproduction rate, and high mobility (Walpole & Leader-Williams, 2002; Bossart, 2006; Moore, 2008). Moreover, they inhabit coastal ecosystems where human activities occur and where they are exposed to multiple stressors (Chivers, 2009; Halpern et al., 2015; Avila et al., 2020).

The Guiana dolphin is present from Honduras in Central America to southern Brazil, inhabits coastal regions, and is frequently found in proximity to river mouths and estuarine waters, where they feed on several fish species (Borobia et al., 1991; da Silva & Best, 1994; Flores & da Silva 2009; da Silva et al., 2010; Lobo et al., 2021). The Guiana dolphin holds an international conservation status of "Near Threatened" (Sechii et al., 2018) and a national status of "Vulnerable" (Trujillo et al., 2006), mainly due to fishing activities, habitat degradation, pollution, and marine traffic (Avila et al., 2020). Conversely, the common bottlenose dolphin, an opportunistic predator, is distributed worldwide, including tropical, subtropical, and temperate marine and coastal waters (Wells et al., 2019). Its conservation status is classified as "Least Concern" globally (Wells et al., 2019) and as "Near Threatened" nationally (Capella et al., 2006), mainly due to several multiple-anthropogenic threats, including fisheries interactions (e.g., bycatch), habitat degradation, environmental pollution, and direct capture (Avila et al., 2020).

Currently, the Gulf of Urabá is one of the most human-impacted and dangerous regions for marine mammals in Colombia, given the documented threats (Leal Flórez et al., 2017; Dirección General Marítima [DIMAR], 2018; Avila & Giraldo, 2022). The imminent construction of three mega-ports in Urabá would exacerbate environmental pressures on these dolphin populations (Bailey et al., 2010; Marley et al., 2017; Graham et al., 2019). While environmental licences have been granted for port construction and operation (Autoridad Nacional de Licencias Ambientales [ANLA], 2016, 2017a, 2017b), only one of them incorporates a management plan for dolphin protection.

Beyond Urabá, in Cispatá Bay (a coastal ecosystem of the Colombian Caribbean situated 200 km from the Gulf of Morrosquillo), a previous study highlighted the impact of anthropogenic stressors, including high-speed boat traffic, accidental mortality in fishing gear, and indirect pressure from fisheries depleting marine resources and causing habitat degradation, on the Guiana dolphin population (Garcia & Trujillo, 2004). In Cispatá Bay, a population of 144 Guiana dolphins with a density of 6.3 dolphins per square kilometre was reported in 1995 (Avila, 1995). Between 1996 and 1997, studies on habitat use revealed variations between climatic seasons and distribution associated with resource availability (Garcia & Trujillo, 2004). Subsequently, in 2010, a population of 225 individuals in the dry season and 232 in the rainy season, with a density of 0.74 dolphins per square kilometre, was estimated (Dussan-Duque, 2013). The areas and methodologies used to estimate density and population size in the studies were different. In all cases, it was observed that Guiana dolphins coexisted with common bottlenose dolphins.

In comparison, the available information on cetaceans in the Gulf of Urabá is limited. Interdisciplinary expeditions have been conducted in the Gulf of Urabá (Blanco-Libreros & Londoño-Mesa, 2016), but cetaceans are not mentioned. Notably, a baseline study reported the population of Guiana dolphins in the Gulf of Urabá, focusing on a specific area known as "El Roto" and recorded groups ranging from two to 22 individuals. It reported that this area was primarily used for travelling, resting, and foraging activities. In addition, this study identified a correlation between the behaviour of dolphin groups and tidal variation ($X^2 = 311.83$, $df = 9$, $p < 0.001$; Patiño, 2011).

Conversely, ecological information on dolphin populations in the Gulf of Urabá, including their abundance, survival, density, and habitat use, is lacking, thereby posing challenges for their conservation. The absence of comprehensive data impedes the ability to accurately assess population dynamics, to understand habitat preferences, and to discern potential anthropogenic impacts on dolphin species in this region. This knowledge gap hinders the formulation and implementation of effective conservation strategies, thereby limiting our capacity to mitigate threats such as habitat degradation, pollution, and human disturbances. Furthermore, the lack of scientific insight into dolphin populations precludes a thorough understanding of their ecological roles and interactions within the marine ecosystem of the Gulf of Urabá. Population parameters, such as abundance and survival, are crucial for risk assessments and conservation initiatives (Hammond, 2010; Azevedo et al., 2017). Thus, it is recommended to investigate ecological and anthropological factors influencing dolphin distribution and movement patterns to provide baseline information for developing conservation strategies such as creating protected areas or establishing periods of exclusion from impacting activities (Jefferson et al., 2009). This study aimed to (1) investigate key population parameters for Guiana and common bottlenose dolphins such as abundance and survival, (2) estimate the distribution and density of these dolphin species, and (3) predict suitable habitat for these dolphins. The findings of this study are expected to guide coastal planning and management actions to conserve these dolphin species in the Gulf of Urabá.

Methods

Study Area

The Gulf of Urabá, situated in the Colombian Caribbean Sea to the east of the border with Panama (N 8° 17.674', W 76° 53.133'), encompasses Bahía Colombia (Figure 1). It lies within the Gulf of Darien and extends southward between Tiburon Cape and Caribaná Point. The Gulf spans 80 km in length, with a width ranging from 5.9 to 48.5 km. It covers a total water surface area of 2,980 km^2. The area reaches maximum depths of 80 m and maintains an average temperature of 28.5°C (Garcia-Valencia, 2007). Because of its hydrodynamic characteristics, it is categorised as a stratified estuary (Pritchard, 1967; Odum, 1972; Montoya Jaramillo, 2010).

This region features two climatic seasons: (1) the dry season, which occurs between December and April and is influenced by trade winds from the north and northeast; and (2) the rainy season, which occurs between May and December and is characterised predominantly by southern winds of low speed (Aguilera, 1988; Chavillot et al., 1992). Within the estuary, several critical ecosystems thrive, including mangrove forests, coral reefs, seagrasses, and soft bottoms (Garcia-Valencia, 2007).

The seascape of the Gulf of Urabá is used for various economic activities, including artisanal fishing, tourism, hydrocarbon exploration, domestic travel (small to medium boats), and transportation of bananas (prevalent in the area) and occasionally other commodities (larger shipping boats) (Fundación Humedales & Incoder, 2006; Garcia-Valencia, 2007; Zamora et al., 2008; Barreto et al., 2013). Over the past few decades, three major development infrastructures have sought licences for construction and operation, raising local and regional concerns (Figure 1). Puerto Antioquia, located south of the Gulf at the León River mouth, started being constructed in 2023 and is designed with a capacity of 6,696,991 tons. The other two infrastructures have been licensed but not yet started. One is located at the north of Necoclí and aims to handle 6,786,641 tons of cargo annually, and the other is located in the locality of Turbo, near the mouth of the Atrato River, with a planned capacity of 1,800,000 tons per year (ANLA, 2016, 2017a, 2017b).

Data Collection

Data were collected between 2017 and 2020. In 2017-2018, platforms of opportunity were used and included commercial routes between Turbo and Capurgana and between Necoclí and Capurgana, zigzag routes on vessels of the Colombian national navy, and fishing routes in the southern Gulf. To ensure efficient data collection on platforms of opportunity, captains were instructed to stop the vessel to record dolphin sightings and collect photographic records. In 2019-2020, systematic surveys were conducted throughout the Gulf using a 10-m-long boat with a width of 1.1 m, powered by an 80-hp outboard motor capable of reaching a maximum speed of 8 kts (average trip duration = 5.2 h; Figure 2).

When groups of dolphins were sighted during the systematic survey trips, the boat was decelerated and carefully moved towards the group to ensure prolonged observation, employing focal-group sampling techniques described by Lehner (1996). At each dolphin sighting, a comprehensive set of data, including the geographical location of the group (obtained through a Garmin handheld global positioning system [GPS]); numerical count of individuals constituting the group; demographic composition in terms of presence of adults and calves; detailed catalogue of their primary behaviours, including feeding, travelling, socialising, resting, and milling; and photographic records of the dolphins, primarily those of their dorsal fins, was systematically gathered. During data collection, a researcher photographed as many individuals as possible until the dolphins either disappeared or all individuals had been photographed. Individual photographs were captured following the photo-identification protocol established by Würsig & Jefferson (1990).

Behaviour and Group Structure

The fundamental social unit under consideration in this study was the group, which was defined as an assembly of dolphins exhibiting apparent association within a 100-m radius distance and engaging in similar behaviours (Altmann, 1974; Wedekin et al., 2007). The primary activity of the group was determined based on the behaviour of the majority of individuals within the first 5 min of observation (Mann, 1999). For determining the group composition, individuals were categorised as adults and calves based on their size and colour (Randi et al., 2008). Calves were identified

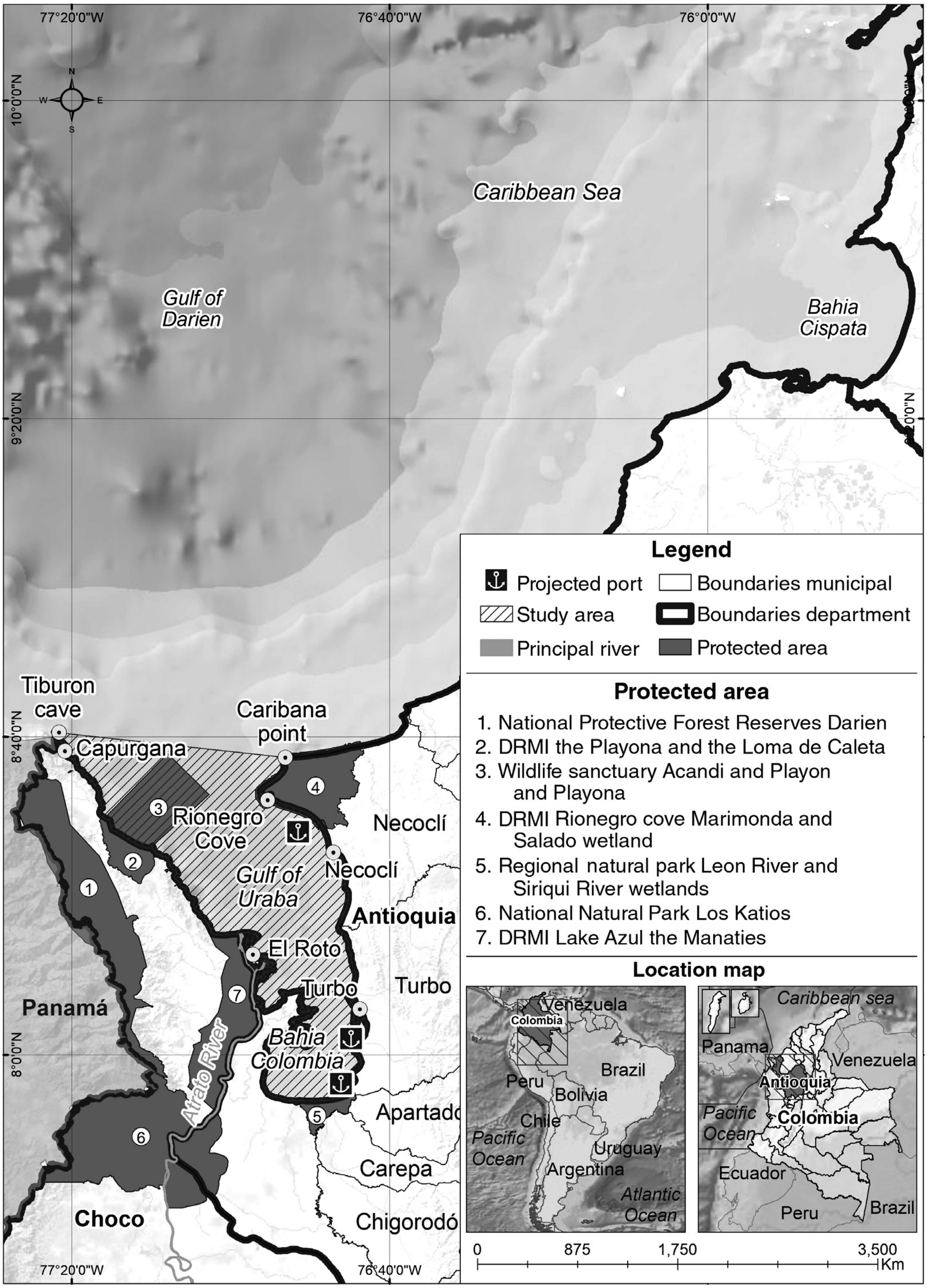

Figure 1. Gulf of Urabá, western Colombian Caribbean. The map highlights the political division; main cities; and protected areas such as National Natural Park, DRMI (Regional Integrated Management District), national protective reserve, regional natural park, and wildlife sanctuary. Squares with anchors indicate the locations earmarked for the development of major port infrastructure projects.

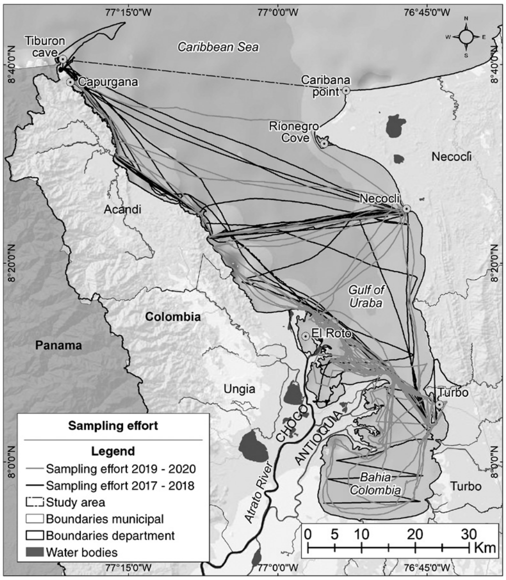

Figure 2. Sampling effort within the Gulf of Urabá discriminated per year and in distance. Gray track indicates the years 2019-2020. Black track indicates the years 2017-2018.

as individuals measuring approximately one half of the adult's size and typically accompanied by an adult animal (Geise et al., 1999; Lodi, 2003). Behaviours were classified into the following categories:

- *Feeding* – Asynchronous swimming marked by repeated, rapid, and arched dives with swift changes in direction, often concentrating in one place. Occasionally, the group travelled a short distance and resumed feeding. Fish could be observed on the surface or in the mouths of the animals (Azevedo et al., 2005; Flach et al., 2008). The presence of birds feeding with or following the dolphins served as a reliable indicator of feeding behaviour (Garaffo et al., 2007).

- *Travelling* – Consistent movements in one direction at a constant speed, with short distances between individuals in the group. Occasional jumps might occur (Flach et al., 2008).

- *Socialising* – Behaviours encompassing body contact, jumping, chasing other dolphins, tail slapping, high-speed movements, frequent directional changes, and leaps (Garaffo et al., 2007). This category included sexual behaviour and play (Domit et al., 2016).

- *Resting* – This behaviour was characterised by a low level of activity, with dolphins floating on the surface and showing occasional smooth movements (Azevedo et al., 2005).

- *Milling* – Low-speed movements with frequent changes in direction (Garaffo et al., 2007). Evasive behaviour was also observed in the presence of fast boats and independently recorded for future analysis.

Photo-Identification Analysis

Individual dolphins were distinguished based on the distinctive natural markings on their dorsal fins (Würsig & Jefferson, 1990). The photographic quality of dorsal fin images was assessed and classified as bad, good, or excellent based on factors such as focus, angle, clarity, sharpness, contrast, and proximity. Only good and excellent images were considered for individual identification, aligning with the criteria established by O'Brien et al. (2009). The cataloguing process involved verifying the positions and types of natural marks on the dorsal fin. Positions were categorised as upper, middle, and lower, while marks included cuts, notches, and shapes on the dorsal fin (Sarasota Dolphin Research Programme [SDRP], 2006). Each marked individual received a unique identification code, and the contour of its dorsal fin was categorised using the categories suggested by Darwin®. Matches were determined by comparing each new photograph with dorsal fins from the existing catalogue. If no match was found, the individual was considered new (Urian et al., 2015). To minimise subjectivity in the pairing process, photograph comparisons were performed by experienced researchers, and Darwin® was used for verification of manual comparisons (Wilkin & Debure, 1999). To assess the cumulative proportion of the population sampled, curves for all identified dolphins were plotted (Wilson et al., 1999).

Population Parameters

A binary matrix was created with the capture-recapture history of marked individuals on each sampling day (Hammond, 2010). This matrix was used for population modelling using the open population POPAN model in the *MARK* software (Cooch & White, 2019) to determine the abundance (N), apparent survival (Φ), and capture probabilities (p) of individuals as well as the probability of entry of individuals from the general population into the sampled population between sampling events (pent). The POPAN model for open populations is an extension of the Jolly–Seber model and is based on several assumptions:

(1) marks are not lost during the study; (2) marks are recognisable in recaptures; (3) individuals are released immediately after tagging; (4) intervals between samplings are large compared with the time required for taking samples, allowing samples to be treated as instantaneous; (5) homogeneity in captures means all individuals collected in a sample have the same probability of survival until the next data collection; and (6) the study area remains constant. This model allows for the calculation of relative survival, capture probability, abundance, and recruitment rates (Schwarz & Arnason, 2019). Considering the irregularity of data sampling and the absence of prior information about the populations, an open population model that included factors such as births, immigration, emigration, and deaths was used.

The POPAN models did not differentiate between sex or age groups and were fitted to the dataset, with parameters set as constant (.) or allowed to vary with time (t). Eight models were tested for each species, considering all possible combinations of pent, p, and ϕ, with options for these parameters to be constant or variable over time. Given that the sum for the probability of entry must be 1, a parameter-specific link function was employed. To specify that a set of parameters must sum to 1 and considering only one group, the Multinomial Logit Link Function One (Mlogit 1) was used for pent, the sin function for ϕ and p, and the Logit function for N.

The selection of the most parsimonious model was based on the Akaike's Information Criterion (AIC), AIC delta value, and AIC weight (Anderson et al., 1994; Burnham & Anderson, 2002). To validate model assumptions, GOF tests were conducted, employing TEST 2 and TEST 3 to assess the assumptions of equal capture probabilities and survival. The analysis was conducted using the RELEASE programme included in *MARK* (Cooch & White, 2019).

The abundance estimates derived from the design models only represented the segment of the population with identifiable individuals. The total population size (corrected population size) was determined by dividing the population estimate generated by these models by the proportion of identifiable individuals (θ) within the observed groups. The proportion of identifiable individuals was calculated as the number of individuals with discernible marks from good and excellent images divided by the total number of individuals observed in each encounter, averaged across all encounters (Silva et al., 2009). The variance of this corrected estimate was computed using the θ formula (Wilson et al., 1999):

$$Var(\hat{N}_{total}) = \hat{N}^2_{total}(var\hat{N}.\hat{N}^{-2} + ((1-\hat{\theta})n\hat{\theta}^{-1}))$$

Herein, ($\hat{N}_{total}$) is the estimated total population size, $\hat{N}$ is the mark-recapture estimate of the number of animals with unique natural markings, and $\hat{\theta}$ is the estimated proportion of animals with long-lasting marks in the population.

Distribution

The geographical coordinates of each dolphin sighting were plotted to conduct a spatial analysis of their distribution using geographic information system tools. For this purpose, the 'Kernel Density' tool in *ArcGIS PRO*, Version 2.7.1, was employed. This tool calculates a magnitude area per unit of point features or polyline (ArcGis, 2012). Kernel analysis involves a continuous density, unimodality, and symmetric function around 0 (Salazar Buelvas, 2011). When applying this spatial analysis tool to the data, the weighted sum of these functions results in a function representing population density (Worton, 1989). This sum is a continuous function that smoothens the distribution profile by capturing the influence of nearby data (Zucchini, 2003).

Suitable Habitat Prediction

The selection of predictor variables for inclusion in the models was based on their potential biological relevance as described in studies focusing on Guiana and common bottlenose dolphins, along with available data for the specific area (Azevedo et al., 2007; Rossi-Santos et al., 2010; van der Roest, 2019; Tardin et al., 2020). The chosen variables comprised depth, slope, distance from the coast, and prey availability (Grigg & Markowitz, 1997; Barros & Wells, 1998; Azevedo et al., 2007; Bazzalo et al., 2008; Pitchford et al., 2016; Zanardo et al., 2017; Lobo et al., 2021; see Supplemental Material [the supplemental material for this article are available on the *Aquatic Mammals* website]). Bathymetry data (see Figure S1A) were sourced from the Ocean Numerical Modelling Research Group of the University of Antioquia and were derived from Nautical Chart 412 of the Centre for Oceanographic and Hydrographic Research of Colombia (CIOH), with a resolution of 0.06 minutes of arc. These data were modelled in raster format using the 'Kriging' interpolation tool in *ArcGIS PRO*, Version 2.7.1, facilitating the estimation of variable values in unsampled areas based on information from sampled areas (Porras Velázquez, 2017). Using the raster modelling result of bathymetry, the slope was calculated with the 'Surface Raster' tool in the same software. The slope (see Figure S1B) was determined as the maximum gradient of depth change for each grid cell from 0 to 90°.

For the distance to shore (see Figure S1C), the Euclidean distance spatial analysis tool was employed to ascertain the distance of each cell from the nearest point on the coastal boundary. Ten categories were established, separated by a distance of approximately 1,600 m for modelling purposes (Esri, 2013).

A fishing ground map was used as a reference to determine areas with a high concentration of food for the dolphins; data available in Colombia's Marine Environmental Information System (SIAM) geographical viewer (https://siam.invemar.org.co/informacion-geografica) were used. Subsequently, the kernel spatial density analysis tool was employed to model areas with the highest concentration of food (see Figure S1D).

Maximum-entropy modelling was employed to establish the relationship between selected variables and the presence of dolphins. This technique, a habitat modelling approach, relies on predictions of where an animal is present and does not require absence data (Phillips et al., 2006). The model maximises the dispersion of data in geographic space, estimating the probability distribution of occurrence closest to maximum entropy (i.e., as close as possible to a uniform distribution). This model uses an algorithm to assess the relationship between occurrence species in terms of presence and environmental variables in the study area, conceptualised as the probable area of sample distribution. Employing a logistic output, it evaluates the suitability of each grid, assigning values from 0 (inadequate habitat) to 1 (optimal habitat). Given the spatial bias in occurrence data affecting the model, replication was conducted using a cross-validation method. This method divides the random occurrence data into a specified number of groups, running the model while skipping one group at a time. An average model is derived from ten potential models for each dataset through an interactive process (Phillips et al., 2006). This analysis was performed using *Maxent*, Version 3.3.1 (www.cs.princeton.edu/~schapire/maxent).

Model evaluation employed the area under the curve (AUC), with values ranging from 0 (lacking predictive ability) to 1 (perfect predictive ability) (Pearson et al., 2007), and assessed sensitivity vs 1-specificity, indicating the proportion of correctly predicted observed occurrences vs the proportion of correctly predicted absences or pseudo-absences. To elucidate species distribution, Jackknife analysis was conducted with the training and test datasets, yielding average percentage contribution values for each parameter (Phillips & Dudík, 2008).

Results

The 34 surveys conducted in the Gulf of Urabá covered a total distance of 3,658.33 km, involving 176.69 h of total effort (Figure 2; Table 1), of which 15.4 h were dedicated to effective sightings, resulting in an encounter rate of 8.71%. Overall, 32 dolphin groups were recorded (Table 2).

For the Guiana dolphin sightings, one to four groups with a range of two to 26 individuals ($\bar{X}$ = 12.30 ± 6.95) were observed. Group composition analysis revealed that 80% (n = 16) were calves in the groups, with up to six calves. The predominant behaviours observed among the dolphins were travelling (60%) and feeding (35%), whereas socialising was observed in only 5% of the recorded individuals. Resting and milling were not observed in any individuals. For common bottlenose dolphin sightings, groups ranging from one to 35 individuals were recorded ($\bar{X}$ = 13.00 ± 8.25). In 80% of these groups (n = 8), up to three calves were present. The observed behaviours primarily included travelling (80%) and feeding (20%). On one occasion, both species were sighted simultaneously, but no interactions between them were observed. All sightings of Guiana and common bottlenose dolphins were considered for the analysis of distribution and habitat use (Table 2). However, only 20 sightings were used to estimate population parameters due to the lack of or the low quality of images.

Individual Identification

In this study, 2,126 photographs of dolphins were captured, of which 835 (38.8%) were considered for individual identification based on their superior quality. On average, identified individuals constituted 37% of the total sightings (see Table S1). In total, 44 individuals were successfully identified during the surveys. For Guiana dolphins, 26 individuals were identified from 1,449 photographs, with 46% of them captured more than three times. For common bottlenose dolphins, 18 individuals were identified from 667 photographs, with 22% of these individuals captured more than three times. In general, recapture events were less frequent for common bottlenose dolphins compared with Guiana dolphins. The discovery curve did not exhibit signs of saturation, indicating a consistent rate of discovery throughout the observation period.

Population Parameters

The most parsimonious model for Guiana dolphins was the one in which the encounter probability and the probability of entering the superpopulation varied over time while survival remained constant (Tables 3 & 5). The survival probability was 1.00, the probability of encounter was highly variable

Table 1. Sampling effort per year in terms of distance and effective sampling time

Year	Effective effort (h)	Effective effort (km)	Sightings/h	Sightings/km
2017	35.97	977.46	0.11	0.004
2018	20.87	700.62	0.05	0.0014
2019	121.86	2,056.25	0.20	0.011
2020	11.13	117.8	0.27	0.25
Total general	189.83	3,852.13	0.17	0.008

Table 2. Number of dolphin sightings discriminated by species and year during the sampling period

	2017	2018	2019	2020	Total
Guiana dolphins	--	1	17	2	20
Common bottlenose dolphins	4	--	5	1	10
Atlantic spotted dolphins	--	--	1	--	1
Unidentified delphinid species	--	--	1	--	1
Total	4	1	24	3	32

Table 3. Model selection details for *Sotalia guianensis*. Details of candidate models for survival probabilities (ϕ), capture probabilities (p), and population entry probabilities (pent) have been listed. Models are listed in the descending order of the quasi Akaike information criterion (QAICc).

Sotalia guianensis						
Models	AICc	Delta AICc	AICc weights	Model likelihood	No. parameters	Deviance
{ϕ(t)p(.)pent(t)}	155.78	0.00	0.98	1.0000	13	–15.09
{ϕ(.)p.(t)pent(t)}	164.48	8.70	0.01	0.0129	12	–3.27
{ϕ(t)p.(t)pent(t)}	166.78	10.99	0.00	0.0041	17	–17.84
{ϕ(.)p(t)pent(.)}	172.38	16.59	0.00	0.0002	8	15.97
{ϕ(.)p(.)pent(.)}	1,7096.33	1,6940.55	0.00	0.0000	13	1,6925.4
{ϕ(t)p.(t) pent(.)}	1,7114.17	1,6958. 38	0.00	0.0000	9	1,6955.08
{ϕ(t)p(.)pent(.)}	1,7123.37	1,6967.58	0.00	0.0000	8	1,696.96
{ϕ(.)p(.)pent(t)}	1,7125.03	1,6969.25	0.00	0.0000	4	1,6978.50

between 0.08 and 0.7, and the probability of entry ranged from 0.39×10^{-390} to 0.39. The estimated abundance was 26.18 (SE = 1.05; 95% CI = 26 to 33) individuals, and the corrected abundance was 63 (95% CI = 53 to 76; CV = 9.42%) individuals (Table 6). GOF test results showed that assumptions of equal probability of capture and survival were not violated, and the $\hat{c}$ value confirmed that there was no overdispersion of data.

The most parsimonious model for common bottlenose dolphins was the one in which survival, the probability of entry into the superpopulation, and the probability of encounter were constant (Tables 4 & 5). The estimated survival rate was 0.98, the probability of encounter was 0.37, the probability of entry was 0.47, and the abundance was 19 individuals (Table 6). The corrected abundance for

Table 4. Model selection details for *Tursiops truncatus*. Details of candidate models for survival probabilities (ϕ), capture probabilities (p), and population entry probabilities (pent) have been listed. Models are listed in the descending order of the quasi Akaike information criterion (QAICc).

Tursiops truncatus						
Models	AICc	Delta AICc	AICc weight	Model likelihood	No. parameters	Deviance
{ϕ(.)p(.)pent(.)}	89.9606	0.00	0.9743	1.0000	4	9.0172
{ϕ(.)p(.)pent(t)}	98.3140	8.35	0.0150	0.0154	11	–8.3479
{ϕ(.)p(.)pent(t}	99.1458	9.18	0.0099	0.0101	7	9.0172
{ϕ(t)p(.)pent(t}	104.0597	14.09	0.0009	0.0009	10	2.1217
{ϕ(t)p(t)pent(t)}	115.2550	25.29	0.0000	0.0000	14	–8.9128
{ϕ(t)p(.)pent(.)}	14,232.12	14,142.16	0.0000	0.0000	7	1,4141.99
{ϕ(t)p(t)pent(.)}	14,234.22	1,444.26	0.0000	0.0000	11	1,4127.56
{ϕ(.)p(t)pent(.)}	14,239.08	14,149.13	0.0000	0.0000	11	1,4145.36

Table 5. Results of goodness-of-fit (GOF) tests for Guiana (*Sotalia guianensis*) and common bottlenose (*Tursiops truncatus*) dolphins in the Gulf of Urabá (Colombian Caribbean) examining the assumptions of equal capture probabilities and survival using the RELEASE programme

Species	Model chosen	Chi-square	df	p level	AIC	$\hat{c}$
S. guianensis	{ϕ(.)p(t)pent(t)}	4.70	9	0.86	118.07	0.522
T. truncatus	{ϕ(.)p(.)pent(.)}	3.82	3	0.28	53.84	1.270

Table 6. Corrected abundance values for Guiana and common bottlenose dolphins. This table presents corrected abundance values for the above-mentioned two dolphin species, accounting for the percentage of individuals not tagged during sightings. *Key Metrics:* Theta = the average percentage of individuals without marks registered in the groups, N = population size according to the most adjusted population model, SE = standard deviation of the model, CV(n) = coefficient of variation of the model data, CV(Theta) = coefficient of variation of unmarked individuals among sightings, $\widehat{N}$ = corrected population size, CV($\widehat{N}$) = coefficient of variation of corrected abundance, and CI = confidence interval.

Species	N	SE	CV(n)	Theta	CV(Theta)	$\widehat{N}$	CV($\widehat{N}$)	CI
S. guianensis	26	1.05	0.04	0.41	0.08	63	0.08	53-76
T. truncatus	19	0.00	0.00	0.38	0.08	50	0.08	43-58

common bottlenose dolphins was 50 (95% CI = 43 to 58; CV = 7.87%) individuals (Table 6). Notably, the results of GOF tests indicated that the assumption of equal probability of capture and survival was not violated, and the $\hat{c}$ value indicated overdispersion of data.

Distribution

Both species were found to be distributed at the Atrato River mouth, specifically in areas known as "El Roto" and "El Rotico." Kernel density analysis further revealed that the utilisation of the habitat by dolphins was not uniform. The Guiana dolphins were distributed in 2.18% of the entire study area (65.26 km^2; Figure 3A) and were specifically found at the Atrato River mouth. In contrast, common bottlenose dolphins were concentrated in the central and northern regions of the Gulf, particularly in sectors such as Punta de la Vaca and the Atrato, Acandí, and Capurgana River mouths. Overall, common bottlenose dolphins covered an area of 310.76 km^2 (i.e., 10.43% of the total study area; Figure 3B).

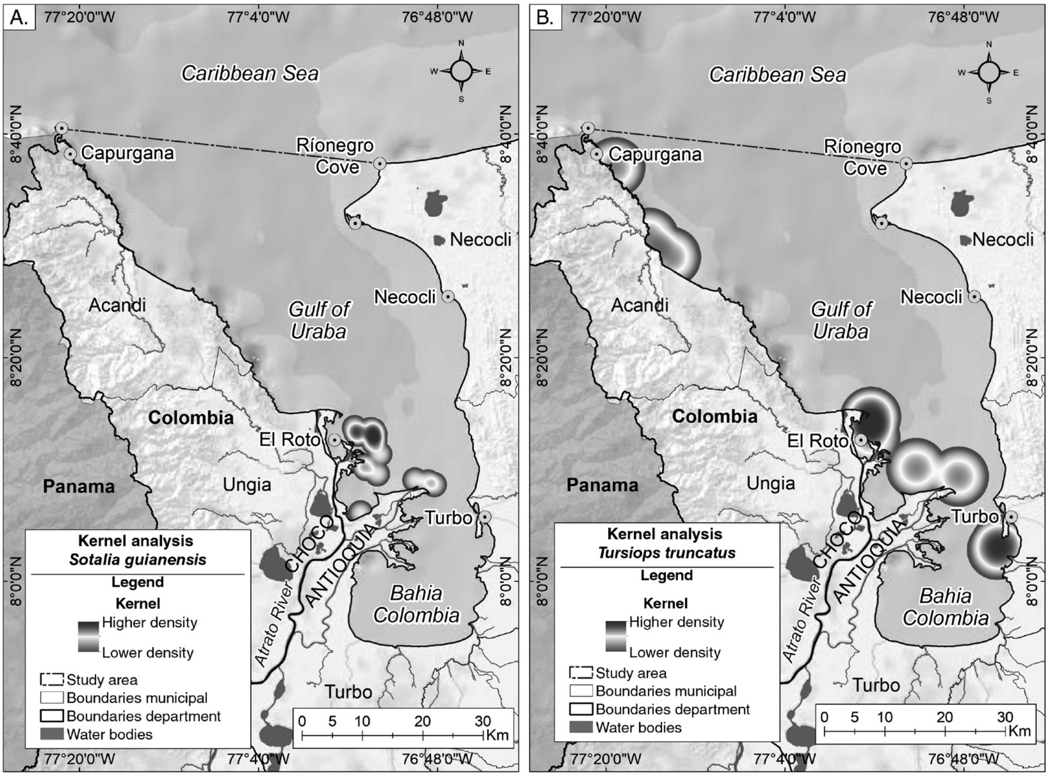

Figure 3. Kernel density analysis results for (A) *Sotalia guianensis* and (B) *Tursiops truncatus* in the Gulf of Urabá, Colombian Caribbean

Suitable Habitat Prediction

The *Maxent* models for both species demonstrated effective performance. For Guiana dolphins, the AUC was 0.96; whereas for common bottlenose dolphins, it was 0.84. In both cases, the distance to the coast was the most significant factor explaining the distribution of populations, contributing over 58%. For Guiana dolphins, the slope was the least significant parameter explaining their habitat use, contributing less than 3.3%. For common bottlenose dolphins, both slope and fishing areas showed no correlation with the species distribution, contributing less than 0.3% (Table 7).

Both dolphin species exhibited a clear preference for coastal habitats, favouring distances between 400 m and 4 km from the shoreline, shallow waters ranging from 2 to 20 m in depth, and areas with marked slopes. For the Guiana dolphins, a noteworthy correlation with fishing areas was identified, constituting a permutated importance of 22.2% (Figure 4). The distribution pattern of Guiana dolphins indicated a strong preference for the central sector of the Gulf, particularly around the Atrato River mouth on the western side and the Rionegro cove on the eastern side to the north. Conversely, common bottlenose dolphins exhibited a broader potential distribution, with predominance in the El Roto sector and in front of the urban area of Necoclí.

Table 7. Permutated importance of environmental variables to model percent contribution to the *Maxent* models for Guiana and common bottlenose dolphin species in the Gulf of Urabá (Colombian Caribbean)

Variables/Species	*S. guianensis*	*T. truncatus*
Depth	16.0	3.4
Fishing grounds	22.2	0.1
Distance to shore	58.5	96.2
Slope	3.2	0.2

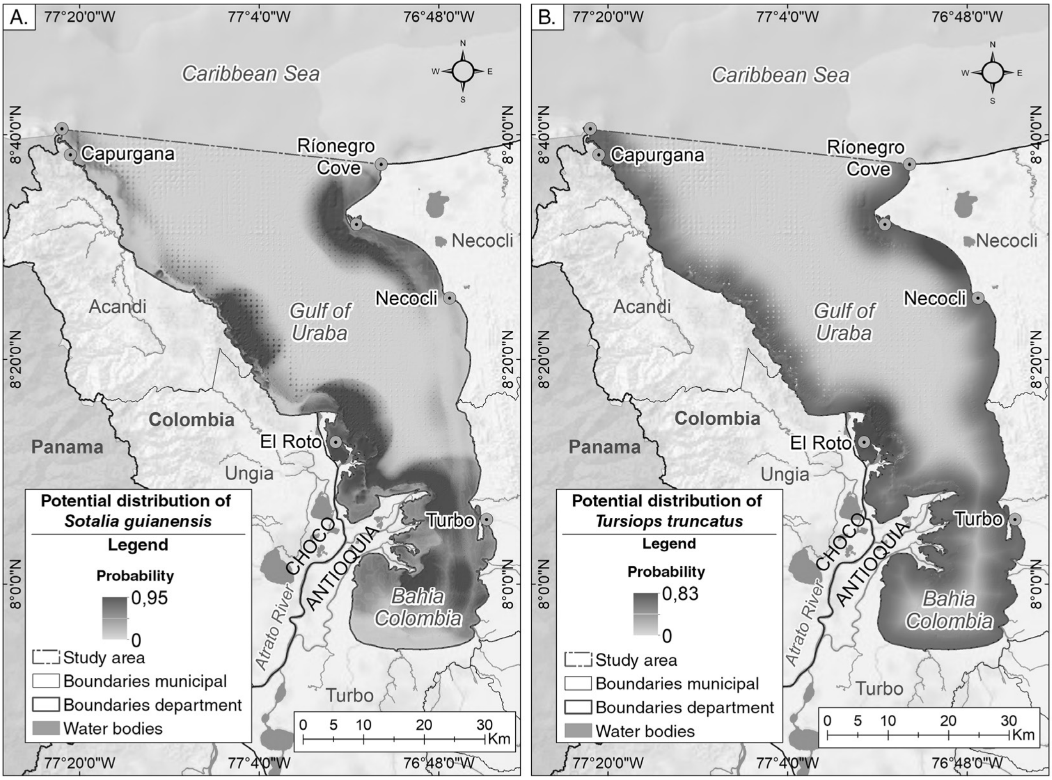

Figure 4. Potential distribution of (A) *Sotalia guianensis* and (B) *Tursiops truncatus* in the Gulf of Urabá, Colombian Caribbean. Black represents the areas with the highest probability of use for the dolphin populations.

Discussion

To the best of our knowledge, this is the first comprehensive study on Guiana and common bottlenose dolphins in the Gulf of Urabá, offering a systematic exploration of their population dynamics, including abundance, distribution, and habitat use. The methods and analyses presented herein are fitted to accommodate the limitations of the available data, particularly the challenges posed by low encounter rates during the surveys.

A crucial factor to consider is the variation in vessels used for data collection. It is well-established that cetaceans alter their behaviour in the presence of speedboats, primarily in response to noise (Koroza & Evans, 2022), leading to a reduced probability of detection due to the speed of such boats. Notably, in 2017 and 2018, boat speeds were not regulated as they were primarily associated with tourist routes or operations conducted by the national navy. The average survey speed exceeded 20 km/h; however, upon spotting dolphins, the boats temporarily halted to conduct group recordings. Notably, dolphin research typically prioritises the use of small vessels, low-powered engines, and reduced speeds to mitigate noise and minimise the risk of collisions with other watercraft (Bejder et al., 2022). Despite these limitations, all records were included in our analyses. This decision was motivated by the cost-effective opportunity they provided to gather data on dolphins in the area, the potential for involving local stakeholders in dolphin conservation efforts, and the accurate and correct recording of data. Consequently, due to the characteristics of the vessels, the encounter rates in 2017 and 2018 were lower than those observed in 2019 and 2020 when systematic sampling was conducted at controlled and reduced speeds.

Population Parameters

The mark-recapture technique is an effective method for estimating population variables, particularly in scenarios with low encounter rates (Wells & Scott, 1990; Acuña, 2002; Azevedo et al., 2003; Fruet et al., 2015; Cooch & White, 2019). The open population model was chosen due to the duration of the data collection, the lifespan of dolphins, and movement patterns of the examined species (de Moura et al., 2023).

In wild populations of less than 100 individuals, as observed in this study, anthropogenic pressures, which cause stress and affect the fitness of individuals, and the occurrence of extreme epizootic or environmental events can lead to a significant decrease in population size or promote population extinction (McCarthy & Thompson, 2001; Traill et al., 2010).

The low encounter rate may be associated with difficulties in detecting dolphins due to oceanographic conditions, evasive behaviour, and dislocation of individuals inside the river or to another area with reproductive intentions or low surface activity (Azevedo et al., 2003). The absence of resting behaviour in both species may be attributed to undetected regions for this activity or challenges in detecting surface activity during resting (Neumann, 2001; Tardin et al., 2014).

In Brazil, abundance estimations of Guiana dolphins using mark-recapture methods have been recorded with values closer to the ones found in this study: 57 to 124 in the Caravelas River estuary, Bahía (Cantor et al., 2012); and 65 to 80 in Benevete Bay, Espírito Santo (dos Santos Mamede, 2015). In Colombia, in Bahía de Cispatá, an abundance of 230 individuals has been estimated (Dussan-Duque, 2013). It is important to note that the areas in which these studies were conducted were smaller than the Gulf of Urabá. Continuous systematic monitoring is essential to ascertain the population trend and implement conservation measures for this species before it reaches a state of endangerment. In Guanabara Bay, Rio de Janeiro, a decline in the population of dolphins was confirmed over 15 y of studies—that is, the population decreased from 62 animals in 2000 to 39 in 2015, a decline of 37% in less than two decades (Azevedo et al., 2003, 2017).

The probability of encounter and entry into the superpopulation for the population of Guiana dolphins showed temporal variability in the model (Table 3), suggesting that individuals may explore different areas based on local conditions such as food availability, socialisation opportunities, and anthropogenic activities. It is also possible that individuals move to other regions for reproduction. In the Morrosquillo Gulf, 228 km north of the Gulf of Urabá, there is a population of Guiana dolphins (Dussan-Duque, 2013; Figure 1). It is possible that dolphins in Urabá may travel through the ocean to reproduce with the northern population, a hypothesis that warrants further investigation. Despite this, the high survival values, indicating the probability of an individual persisting in the population from one capture event to another (Lebreton et al., 1992; de Moura et al., 2023), suggest frequent use of the Gulf of Urabá and also imply that dolphins' lifespans exceed the study period (Zeh et al., 2002; de Moura et al., 2023). This assumption is supported by records of individuals up to 33 y old (Ramos et al., 2008; Lima et al., 2017).

Regarding common bottlenose dolphins, populations associated with protected coastal habitats are commonly small, resident, or semiresident, whereas open water populations show high abundance and distribution (Wells & Scott, 1990; Fruet et al., 2015). In this study, the estimated abundance of common bottlenose dolphins was comparable to that of other coastal populations worldwide, such as 58 individuals in Doubtful Sound, New Zealand (Williams et al., 1993); 83 dolphins in San Antonio Bay, Argentina (Vermeulen & Cammareri, 2009); 50 to 59 individuals in San Antonio Lagoon, Brazil (Daura-Jorge et al., 2013), 78 to 88 individuals in Patos Lagoon, Brazil (Fruet et al., 2015); and 63 to 72 in Uruguay (Laporta et al., 2016). However, the model in our study does not comply with the assumption of homogeneity of the sample, likely due to the distance among sightings, variation in capture rates, and presence of transient individuals (Cooch & White, 2019); therefore, the results need to be interpreted carefully. Additional studies are required to provide more data for model refinement.

The low recapture probability for common bottlenose dolphins (22%) may be linked to their social structure dynamics, characterized by "fission-fusion" societies that promote group division based on individual needs (Wilson et al., 1999). Moreover, it was observed that animals recorded in the northern region were only identified there, and those in the central and southern regions were never recaptured in the northern sector. This indicates potential separation among groups or stocks and contributes to the overdispersion of data for this species. In addition, the high frequency of travelling behaviour could explain the low residency rate and high heterogeneity in the models, suggesting a transient population (Tardin et al., 2014).

Distribution and Suitable Habitat Analysis

The distribution areas were interpreted as "vital areas," where animals carry out essential activities such as feeding, calf care, and reproduction (Sampaio Duarte, 2014). These areas differ from use areas, which encompass broader movements for reproduction and feeding, requiring more extensive studies with individual tracking records (Burt, 1943). Furthermore, it is crucial to note that these areas are dynamic and may vary spatially and temporally (Sillero et al., 2021).

The Atrato River mouth served as a vital area for both species, highlighting the ecological importance of this region. The Guiana dolphin populations have high fidelity to specific areas that provide food, shelter, and protection for the care of their offspring (Flach et al., 2008; Flores & da Silva, 2009; da Silva et al., 2010; Domit et al., 2016). Thus, the vital areas calculated in the Gulf are a small percentage of the total area and are smaller than those for *Tursiops truncatus*. The size of the vital areas of Guiana dolphins aligns with calculations in other regions. In the southernmost region of distribution, Bahía Grande, Santa Catarina, Brazil, the species' use area was 62.05 km^2 (Bazzalo et al., 2008); in Babitonga and Santa Catarina, it was 87.01 km^2 (Cremer, 2000); and in Guanabara Bay, Rio de Janeiro, it was 136.9 km^2 (Azevedo et al., 2007).

Comparing the recorded vital area of common bottlenose dolphins with that in other estuarine systems, the vital area of the Gulf of Urabá appears larger. The vital area was 105.7 km^2 in the Sado estuary in Portugal (Sampaio Duarte, 2014); 129.2 km^2 in Veracruz, Mexico (Martinez-Serrano et al., 2011); and 125 km^2 in Sarasota, Florida (Connor et al., 2000). This suggests the possibility that common bottlenose dolphins in the Gulf of Urabá utilise a more extensive area compared with other populations. However, these differences can indicate the presence of two distinct metapopulations with varying vital areas. Due to data limitations, a comprehensive analysis in this regard is currently not feasible.

The Gulf of Urabá, with its diverse ecosystems and unique hydric dynamics, is considered a heterogeneous system (Garcia-Valencia, 2007). Among the seven main mouths of the Atrato River, El Roto contributes approximately 65% of the total river discharge (Aguilera, 1988). This region, with the highest frequency of dolphin records for both species, meets habitat preference requirements for depth, slope, and distance from shore. It also stands out as the area with the largest catch and the highest fish biodiversity in the entire Gulf (Leal Flórez et al., 2017), ensuring wide food availability for the two dolphin species. The sandy bottoms adjacent to the mangrove patches in this sector promote foraging activities, and a sloped bathymetry may facilitate dolphin feeding strategies, including cornering fish while conserving energy (Bonin et al., 2017; Pivari et al., 2020; Pierry et al., 2023). Furthermore, the high percentage of sightings with the presence of calves for both species (80% each) reflects that these shallow coastal areas that are protected from wind and waves, such as El Roto, provide an ideal setting for feeding and parental care activities.

The present study utilised the *Maxent* habitat suitability analysis as it is effective for small sample sizes and has the ability to address limitations (Hernandez et al., 2006), particularly those in the context of the low encounter probability of the animals. Consequently, the analysis relies on the model's performance. However, it is recognised that the interpretation of the data must be done with caution until the incorporation of other environmental factors into the models allows for enhanced robustness of the explanations.

Implications for Conservation

In Colombia, the Guiana and common bottlenose dolphins are considered some of the most vulnerable species. Among the identified threats to their populations, the most prominent are interactions with fishing activities and the effects of marine traffic. The effects of these activities contribute to making the Gulf of Urabá one of the most perilous areas for the survival of aquatic mammals (Avila & Giraldo, 2022). In this regard, the National Action Plan for the Conservation of Aquatic Mammals recognises the threats to cetacean species in Colombia and highlights the lack of information to design effective conservation strategies (Avella Castiblanco et al., 2022).

In addition to fishing activities and marine traffic, the construction and operation of new ports represent significant threats and can lead to habitat disturbance through construction activities such as pile driving and operational activities, including dredging, sediment disposal at sea, and increased marine traffic (David, 2006; Bailey et al., 2010; Rako et al., 2012; Salgado Kent et al., 2012). Moreover, due to the exclusion zones for fishers caused by port operations, it is expected that artisanal fishing areas will become concentrated in El Roto. The displacement of fishers, who previously utilised the Bahía Colombia sector and the León and Suriqui Rivers (the operation area of Puerto Bahía, Colombia), would increase the risk of entanglement in the critical areas for the Guiana dolphin (ANLA, 2016). Finally, the construction of the Darien port in the northeastern region of the Gulf coincides with the suitable distribution areas identified for the two species; and as the licence for this port does not include management plans related to dolphins, the risk to their protection increases substantially (ANLA, 2017a, 2017b).

In this scenario, more robust conservation measures need to be implemented to safeguard the species and their habitats. In addition, the El Roto area has been demonstrated to be a key biodiversity area (Blanco-Libreros & Londoño-Mesa, 2016; Leal Flórez et al., 2017), warranting designation as an area of special environmental interest. Strict regulations controlling marine noise, boat traffic, and water waste and detritus discharges must be enacted and rigorously enforced. Data and information, as presented in this study, should be used; and community participatory decision-making interventions must be incorporated into all coastal development and seascape planning activities to ensure comprehensive and sustainable development of the Gulf of Urabá.

In the future, a systematic monitoring programme should be established in the El Roto and El Rotico areas and on the western side of the Gulf from the mouth of the Atrato River to Sapzurro Bay (border with Panama). This would enhance our understanding of the ecological patterns of the species, their habitats, their role in local economies, and the dependencies between dolphins and local livelihoods. This information is crucial for highlighting the significance of these species in sustainable seascape planning and human development. All these actions must be accompanied and coordinated with tourism operators, fishers, maritime authorities, and other stakeholders who use the Gulf of Urabá. The more stakeholders involved, the more information will be available and the more likely conservation measures for Guiana and common bottlenose dolphins will be effective.

Conclusions

The present study confirms the presence and residence of two cetacean species in the Gulf of Urabá. The abundance estimate data indicate a population of less than 100 individuals for both species, serving as a crucial alert for local, regional, and national stakeholders and decision-makers. It is strongly recommended to establish systematic monitoring programmes to safeguard dolphin populations and their ecosystems. This approach aims to (1) increase the data and information available for decision-making in seascape and land use planning as well as environmental conservation efforts and (2) ensure the involvement of local communities and regional authorities in monitoring the territory and biodiversity of dolphins.

Note: The supplemental materials for this article are available in the "Supplemental Material" section of the *Aquatic Mammals* website: https://www.aquaticmammalsjournal.org/supplemental-material.

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