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First Range-Wide Aerial Survey off South Brazilian and Uruguayan Waters for Density and Abundance Estimates of the Threatened Franciscana Dolphin

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FIRST RANGE-WIDE AERIAL SURVEY OFF SOUTH BRAZILIAN AND URUGUAYAN WATERS FOR DENSITY AND ABUNDANCE ESTIMATES OF THE THREATENED FRANCISCANA DOLPHIN

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ABSTRACT

The franciscana (*Pontoporia blainvillei*) is endemic to coastal waters from Brazil to Argentina. The species is regarded as one of the most threatened cetaceans in the South Atlantic Ocean due to high bycatch levels. Four management units "FMAs" were defined throughout the species' range. FMA III includes states along southern Brazil and the whole Uruguayan coast. Aerial surveys to estimate density and abundance of franciscanas throughout the whole latitudinal range of FMA III were conducted in two periods: from February 20th to March 14th 2021 (Brazilian sector of FMA III) and from March 01th to April 04th 2023 (Uruguayan sector). A total of 5,312 km of tracklines were surveyed over a total area of 80,342 km^2, and a total of 96 franciscana groups (199 individuals) was recorded on effort by front observers with an average group size of 2.07 (SE = 1.09, median = 2, range = 1-5). Overall density and abundance corrected for visibility bias and group size bias were estimated at 0.54 individuals/km^2 (CV=0.3) and 43,148 individuals (CV = 0.3, 95% CI = 23,786 – 78,271). Because aerial surveys were carried out in 2021 in Brazil and in 2023 in Uruguay, the present density and abundance estimates could be regarded as a 2022 estimate. This is the first study to estimate abundance of franciscana dolphins in the whole of FMA III. The results suggest that this is the most abundant franciscana stock. Available bycatch estimates (from the early 2000s) for this management area correspond to 2-4% of the estimated stock size, suggesting the possibility that bycatch is unsustainable. Continued population monitoring is essential to assess the long-term viability of franciscana dolphins inhabiting southern Brazilian and Uruguayan waters.

INTRODUCTION

The franciscana (*Pontoporia blainvillei*) is a small cetacean endemic to the western South Atlantic Ocean, ranging from Espírito Santo State (ES), Brazil, to Golfo Nuevo, Chubut Province, Argentina (Crespo et al. 1998, Siciliano et al. 2002). Franciscanas are primarily coastal, inhabiting waters beyond the surf zone up to 50 m of depth (Danilewicz et al. 2009, Crespo et al. 2010, Amaral et al. 2018) with occurrences in some bays and estuaries (Cremer and Simões-Lopes 2008, Santos et al. 2009). The species is regarded as one of the most threatened small cetaceans in the

South Atlantic Ocean due to high, and possibly unsustainable, bycatch levels as well as increasing habitat degradation (Secchi et al. 2003, Secchi 2010). The franciscana is currently listed as "Vulnerable" in the IUCN Red List of Threatened Species (Zerbini et al. 2017), as "Critically Endangered" by the Brazilian Government (MMA 2014) and as a Priority Species for Conservation to the National System of Protected Natural Areas (SNAP) in Uruguay (Soutullo et al. 2013).

In order to guide conservation and management actions, 11 Franciscana Management Areas (FMAs) have been proposed (Cunha et al. 2020) and recognized as appropriate units for assessment of the species by the IWC Scientific Committee (SC) (IWC, this meeting). FMA III is the unique FMA shared between two countries, encompassing southern Brazil and Uruguay, and bycatch estimates have been the highest among all FMAs. Franciscana were killed in relatively large numbers historically in Uruguay (nearly 4,000 animals between 1974 and 1993, Praderi 1997) and more recently in both Uruguay and Brazil (annual mortality reaching about 1,000-2,000 individuals, Ott et al. 2002, Secchi et al. 2003, Szephegyi 2012, Prado et al. 2013, Franco-Trecu et al. 2019). Estimating abundance in this region therefore is important to assess the potential impact of this high fishing-related mortality to the stock. For this reason, the IWC Scientific Committee, the Franciscana Conservation Management Plan, and the IUCN have regarded surveys in this area as a priority (Reeves et al., 2003, IWC, 2005, 2016, Anonymous, 2015).

To date, reliable estimates of the whole FMA III stock size have never been computed because abundance estimates have only been carried out along the Brazilian portion of the range of the stock (Secchi et al. 2001, Danilewicz et al. 2010, Sucunza et al. 2020). The IWC Scientific Committee in partnership with Yaqu Pacha, Instituto Aqualie, and GEMARS sponsored an aerial survey in Uruguay to estimate abundance of franciscanas. In this study, information from this survey is pooled with surveys conducted in southern Brazil to compute an estimate of the size of the franciscana population inhabiting FMA III.

METHODS

Study Area and Survey Design

Aerial surveys were carried from Santa Catarina, southern Brazil, (27º51'S, 48º34'W) to the southern border of Uruguay (36°3'S, 54º40'W) (Fig. 1). This area includes the whole latitudinal range of FMA III (Cunha et al. 2014). The survey occurred in two periods: from February 20th to March 14th 2021 off the Brazilian sector of FMA III and from March 01th to April 04th 2023 off the Uruguayan sector (Fig. 1). Four survey strata were proposed: *i*) southern Brazilian coast (Brazil stratum), *ii*) Uruguayan offshore (30-50m) waters (UY-offshore stratum), *iii*) Uruguayan inshore (0-30m) waters (UY-inshore stratum), *iv*) Uruguayan Río de la Plata estuary area (UY-Río de la Plata stratum) (Fig. 1).

The survey tracklines followed design-based line transect methods, which assume that the estimated density of animals in the sampled area is on average equal to the density in the study area if transect placement results in uniform coverage probability (Buckland et al. 2001). In the Brazil stratum, a set of 101 equally-spaced (Table 1), parallel transect lines was placed perpendicular from the coastline up to the isobath of 50 m. Transect lines ranged from 7.24 to 89.09 km in length, with a 7 km spacing in between (Fig. 1). In Uruguay, 30 parallel equally-spaced transect lines were placed perpendicular from the coastline up to the isobath of 30 m (UY-inshore stratum), 14 between the isobaths of 30 and 50 m (UY-offshore stratum) in the Atlantic

Ocean portion of the Uruguayan waters, and 15 from the coastline up to the National airspace border between Uruguay and Argentina in the UY-Río de la Plata stratum (Table 1). Transect lines ranged from 7.3 to 102.9 km in length, with a 9.73 km spacing in between in the UY-inshore and UY-Río de la Plata strata and 19.5 km in the UY-offshore stratum (Fig. 1). Coverage probability in the UY-offshore stratum was ~50% of the coverage in the UY-inshore and UY-Río de la Plata strata. This survey design makes no assumption about the spatial distribution of the animals and ensures an equal sampling probability. Total planned effort was 7,230 km, corresponding to 4,140 km and 3,086 km off Brazilian and Uruguayan waters, respectively (Fig. 1, Table 1).

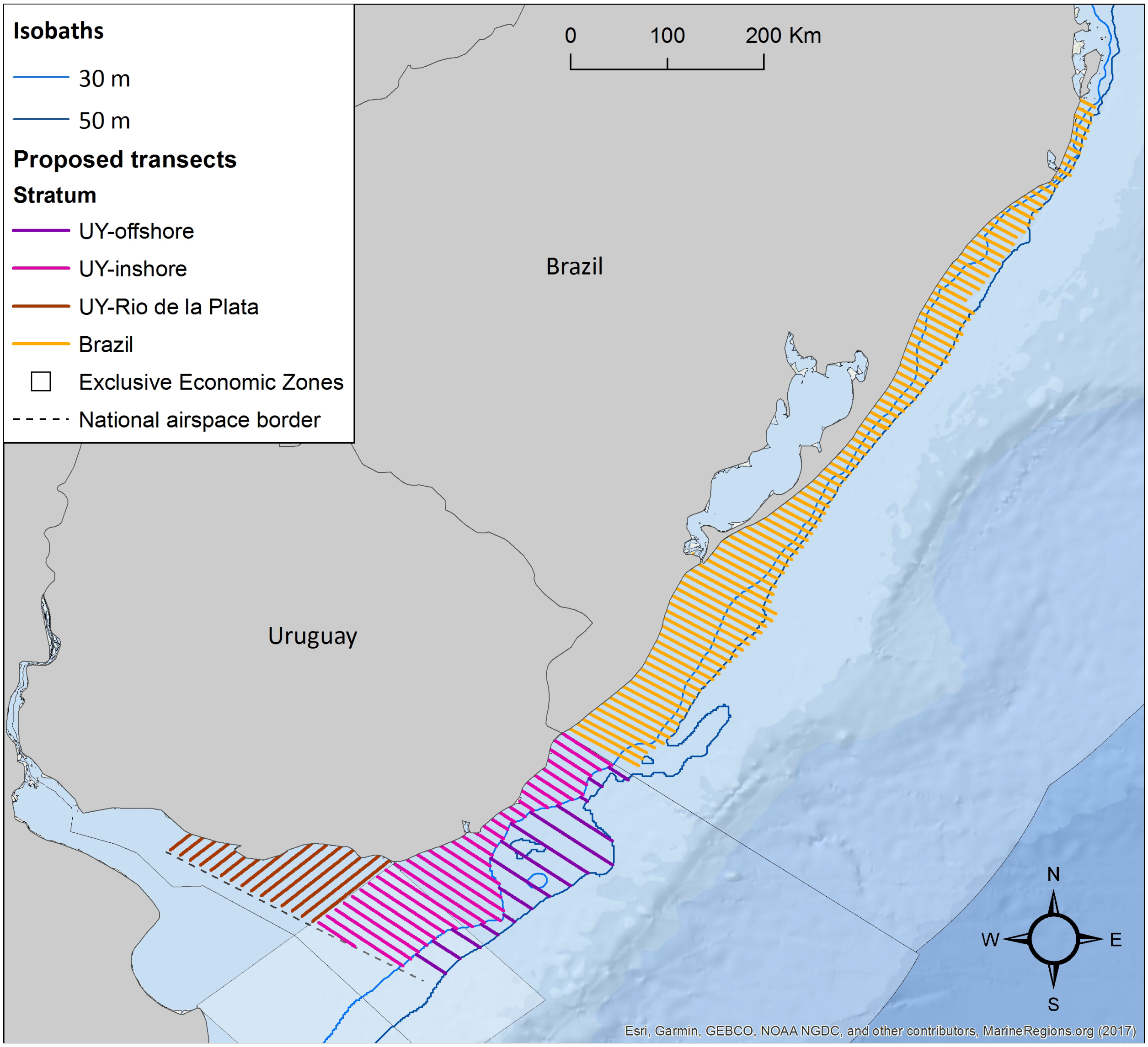

Figure 1. Proposed transect lines for aerial surveys to estimate franciscana abundance in FMA III. Four strata are indicated with different colors as shown in the legend: UY-offshore (oceanic waters, 30-50m depth); UY-inshore (oceanic water, 0-30m depth); UY- Río de la Plata (uruguayan estuarine area, from shore up to the National airspace border); and Brazil (0-50 m depth).

Table 1. Survey strata, covered area, number of transects, planned effort and realized effort from aerial surveys designed to estimate franciscana abundance in FMA III.

Stratum	Proposed Area (km^2)	# Proposed Transects	Proposed Effort (km)	# Realized Transects	Realized Effort (km)
Brazil	30,859	101	4,140	79	2,683
UY offshore	13,581	14	569	7	323
UY inshore	19,911	30	1,681	28	1,560
UY Río de la Plata	15,991	15	836	14	745
Uruguay	49,483	59	3,086	49	2,628
Total (FMA III)	80,342	160	7,226	128	5,311

Searching for franciscana groups was conducted from a high-wing, twin-engine *Aerocommander500B* aircraft at an approximately constant altitude of 150 m (500 ft) and a speed of 170-200 km/h (~90-110 knots). The aircraft had four observation positions (two on each side of the plane), with bubble and flat windows available for front and rear observers, respectively. Flights were generally conducted under relatively good weather and visibility conditions (Beaufort sea state <= 4). The searching team consisted of four observers, who recorded environmental data (*i.e.*, Beaufort sea state, glare, water color and turbidity) at the beginning of each transect and whenever the conditions changed. The beginning and the end of the transect lines were informed to the observers by the pilot. All observers were independent as they were visually and acoustically isolated and did not communicate with each other during the flights over transect lines. When a group of franciscana dolphins was detected, the declination angle between the horizontal and the group was obtained using an inclinometer when the group passed abeam of the plane. In addition, the size of the group was estimated and additional information such as presence of calves in the groups and the conditions of the sea surface in Beaufort sea state were recorded. Data were entered on audio digital recorders. Every record was time-referenced based on a digital watch synchronized to the GPS. This allowed observations to be geo-referenced.

Line transect analysis methods

Detection probability was estimated using Conventional (CDS) and Multiple Covariate Distance Sampling (MCDS) methods (Buckland et al. 2001, Marques & Buckland 2003). Sighting data from another franciscana survey (Sucunza et al. 2020) conducted in Brazil in 2014 by the same observers were combined with 2021/Brazil and 2023/Uruguay surveys data to increase sample size and better estimate detection probability in this study (sightings from the 2014 survey were not used to estimate density or abundance). Exploratory analyses indicated that adequate fits were obtained by modeling ungrouped and untruncated distance data. Only the half-normal and the hazard-rate key functions were proposed to fit distance data. Beaufort sea state (factor covariate with two levels: "low", Beaufort sea state between 0-2, and "high", 3 and 4), glare (factor covariate with two levels: “Yes” and “No”), turbidity (factor covariate with two levels: “murky” and “clear”), water color (factor covariate with three levels: “brown”, “green” and “blue”), survey (factor covariate with three levels: “Brazil 2014”, “Brazil 2021”, “Uruguay 2023”), and group size (numerical covariate) were considered as covariates to model distance data.

A set of detection function models were fitted following standard combinations and models with acceptable fit based on visual assessment, covariate effect and on goodness-of-fit statistics where ordered based on the Akaike Information Criterion (AIC) values. Most supported models (ΔAIC <= 2) were selected, and model averaging were performed to incorporate unconditional model selection variance in the estimates and confidence intervals (Burnham & Anderson 2002). Analyses were performed using a set of customized functions (mrds v.2.2.6, Laake et al. 2022) in R version 4.1.1 (R Development Core Team 2021). Detection probability was computed only using sightings recorded by front observers (bubble windows) from the three surveys (n = 139 sightings) because of the field of view between front and rear observers only partially overlapped.

Abundance Estimation

Uncorrected density (D_u) and abundance (N_u) were estimated using the Horvitz-Thompson-like estimator (Borchers et al. 1998, Borchers & Burnham 2004). Expected mean group size was obtained as suggested by Innes et al. (2002) and Marques and Buckland (2003). Variance was estimated using the analytical estimator of Innes et al. (2002) and log-normal 95% confidence intervals (Buckland et al. 2001) were computed after unconditional variance was derived (Zerbini et al. 2006).

A correction factor for visibility (perception and availability bias, Marsh and Sinclair 1989) and groups size bias computed to correct abundance estimates of franciscana dolphins from aerial survey data (CF = 4.76, CV = 0.25; Sucunza et al. 2022) was multiplied to the uncorrected (D_u) estimate of density to compute a corrected density estimate (D_c). Corrected abundance (N_c) was then estimated as the product of the corrected density and the total area. Variance of D_c was computed by the Delta method (Seber 1982).

RESULTS AND DISCUSSION

A total of 5,312 km of on effort survey was used for density and abundance estimation (Table 1). This is the first study to carry out a full aerial survey in FMA III and compute a stock-wide abundance estimate as well as provide hitherto unknown density and abundance values for Uruguayan waters. A total of 96 franciscana groups (199 individuals) (Fig. 2) were recorded on effort by front observers with an average group size of 2.07 (SE = 1.09, median = 2, range = 1-5). The most supported detection probability model is illustrated in Fig. 3 and the set of candidate detection probability models (AIC <= 2) are provided in Table 2. Model averaged detection probability was estimated at 0.64 (CV = 0.08). Overall density and abundance corrected for visibility bias and group size bias were estimated at 0.54 individuals/km^2 (CV = 0.311) and 43,148 individuals (CV = 0.311, 95% CI = 23,786 – 78,271) for the whole FMA III. Stratum-specific estimates of both density and abundance for the proposed survey areas are provided in Table 3. Because aerial surveys were carried out in 2021 in Brazil and in 2023 in Uruguay, the present density and abundance estimates could be regarded as a 2022 estimate.

A relatively large portion of the southern area of the Brazil stratum was not surveyed (proposed area = 30,859 *versus* covered area = 21,517 km^2, Fig. 2). Therefore, extrapolating density and abundance estimates computed in the covered area to the whole area of the Brazil stratum could potentially lead to bias (e.g., IWC, 2007). Therefore, we provide here the abundance for the covered area of the Brazil stratum, which is estimated at 9,160 individuals (CV=0.327). However, we propose the extrapolation may be warranted in this case because there is evidence that abundance in the covered and uncovered areas are similar. A survey conducted in 2014 to estimate density of franciscanas off the southern coast of Brazil (Sucunza et al. 2020) sampled the whole area of the Brazil stratum as defined in the 2021 survey. The encounter rate of the 2014 survey in the covered and uncovered areas of the 2021 survey were identical (Table 4). This suggests that if the distribution of the franciscana dolphins in 2021 were similar to that in 2014, the extrapolation of the 2021 density from the covered to the uncovered area may be valid.

Table 2. Summary of selected models (ΔAIC <= 2) to fit perpendicular distance data for density and abundance estimation of franciscana dolphins in FMA III. Hn - half-normal key function, Hr - hazard-rate key function, f(glare) - glare covariate, f(survey) - survey covariate, ΔAIC - Akaike's Information Criterion differences between the model in question and the most parsimonious model, *wi* - Akaike weight, $\hat{P}$ - overall probability of detection, CV - Coefficient of variation.

Models	Δ AIC	w_i	P	CV(P)
Hn + f(glare)	0.000	0.247	0.636	0.072
Hn + f(survey)	0.149	0.229	0.632	0.073
Hn	0.279	0.215	0.641	0.073
Hr + f(survey)	1.533	0.115	0.668	0.093
Hr + f(glare)	1.774	0.102	0.678	0.093
Hr	1.980	0.092	0.617	0.127

The present results indicate the greater FMA III stock size among all FMAs, and corroborate with previous studies that indicate Uruguayan waters as one of the primary habitats for franciscana dolphins as well as the area with the highest genetic diversity (Secchi et al. 2010, Cunha et al. 2022). In addition, the high density estimated for the UY-Río de la Plata stratum (Table 3) confirms the high importance of Río de la Plata estuarine waters for franciscana dolphins. In this stratum, franciscana groups were observed from the coast up to the Uruguayan airspace southern limit (Figure 2) and, thus, future studies should investigate how franciscana dolphins are distributed between the coasts of Argentina and Uruguay along the Río de la Plata estuarine area.

In this study, not all survey lines were covered in all survey strata (see red lines in Fig 2). The southernmost portion of the southern portion of the Brazil stratum could not be surveyed, leaving a relatively large portion of that stratum not surveyed. Similarly, nearly half of the lines in the UY offshore stratum. Abundance estimates computed here were extrapolated to the whole area of the stratum, therefore the estimated density in the covered areas were assumed to apply to the non-covered areas.

Mortality due to bycatch is currently the major threat to franciscana dolphins throughout the species range (Ott et al. 2002, Secchi et al. 2003, 2021). Although the high abundance estimated for FMA III in this study could indicate a healthy condition of this stock, bycatch estimates for FMA III have been the highest among all FMAs (Secchi et al. 2003). Current bycatch estimates are not available for the whole FMA III, however estimates from the early 2000s (Secchi et al. 2003) indicate that bycatch mortality represent ca. 2-4% of the estimated abundance, numbers considered unsustainable for small cetaceans. Continued population monitoring through aerial surveys is essential to better understand the impact of bycatch as well as other sources of unaccounted mortality and, consequently, to assess the long-term survival of franciscana dolphins inhabiting southern Brazilian and Uruguayan waters.

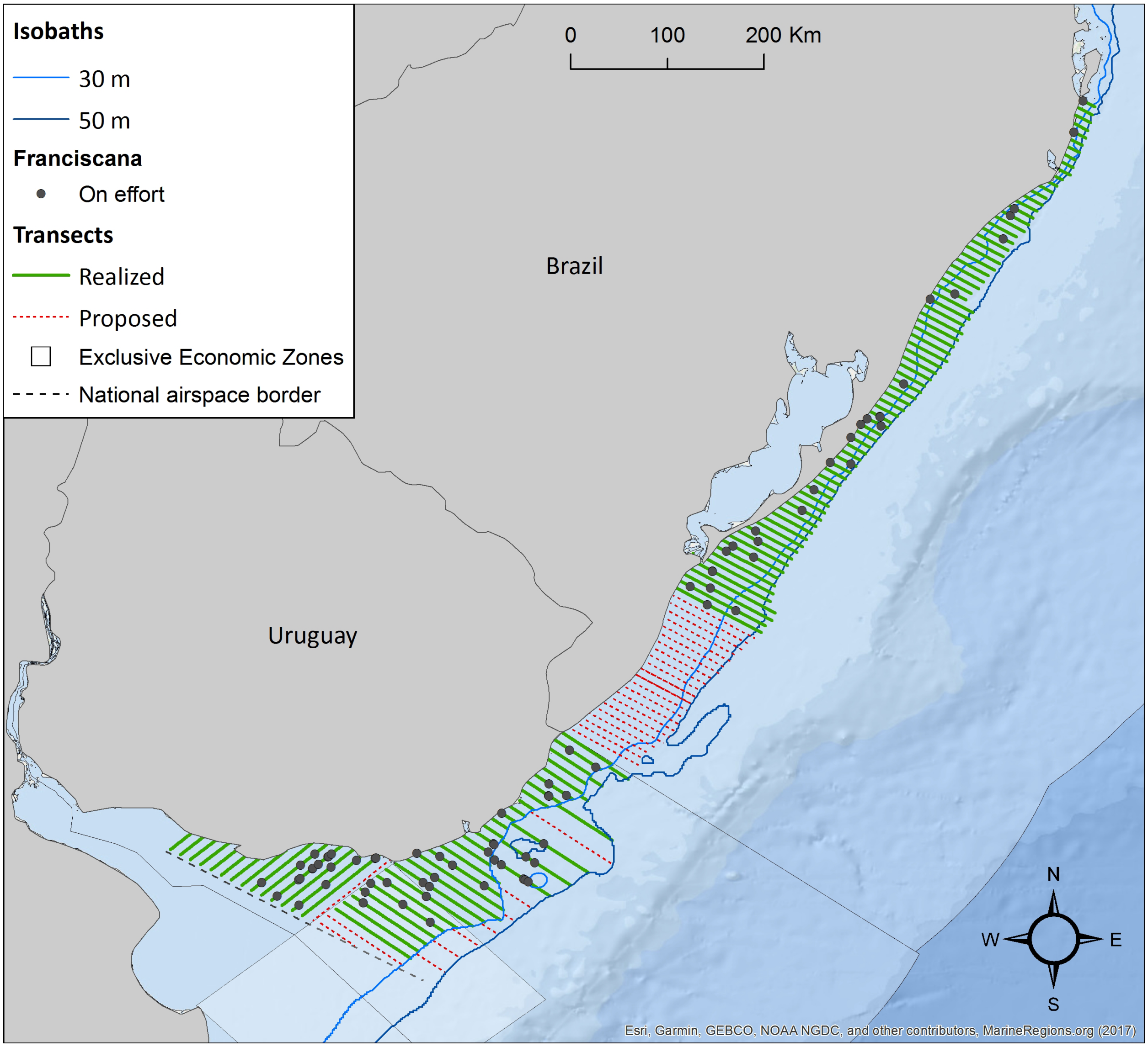

Figure 2. Proposed (all lines) and realized (on-effort, green lines) transect lines from aerial surveys to estimate franciscana abundance in FMA III. On-effort sightings of franciscana are shown as gray circles.

This study was important also in the context of capacity building. Scientists experienced with aerial survey of franciscana dolphins trained colleagues in Uruguay (CD, VFT and CP). The focus of the training was on survey design, survey methods and data analysis, providing the basis for planning and conducting additional aerial surveys in Uruguay in the future.

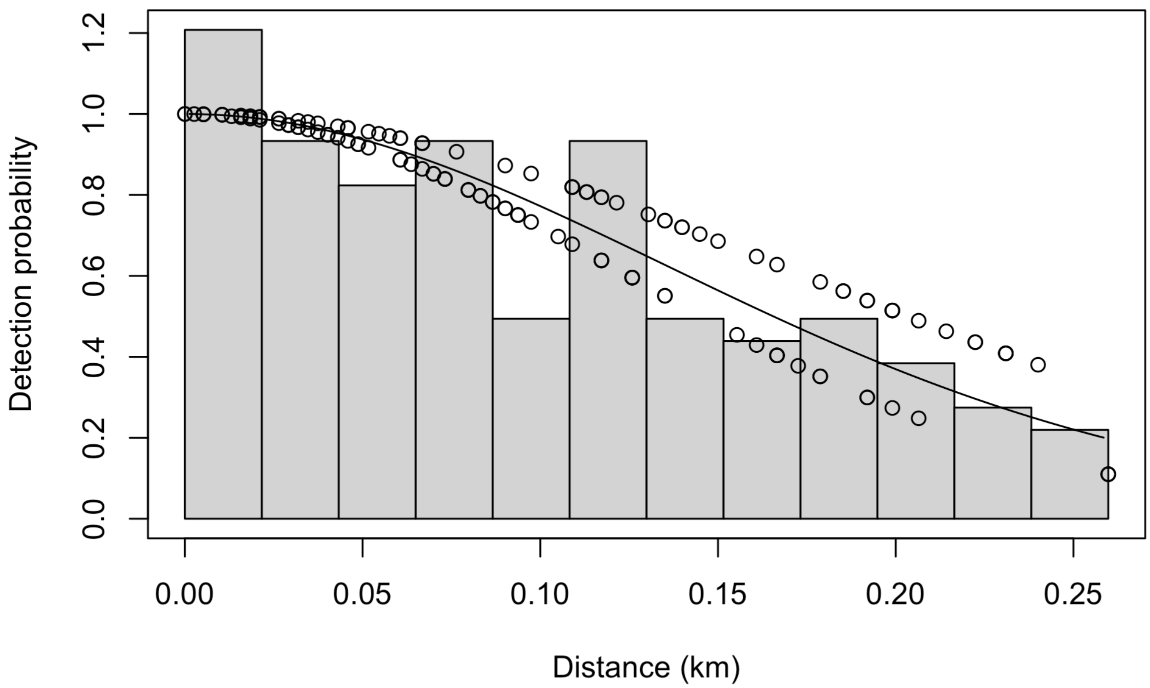

Fig. 3. Half-normal with glare covariate detection function plot with the original distance (km) dataset.

Table 3. Density and abundance estimates of franciscana dolphins in FMA III, southern Brazil and Uruguay, through the study period. “Brazil”, “UY offshore”, “UY inshore” and “UY Río de la Plata” correspond to geographic regions (i.e. strata) used for density estimation. Coefficient of variation (CV). *n* = number of sightings used for density, ER = number of franciscana groups detected/km *on effort* of planned effort, Es = average group, $\widehat{Du}$ = estimated uncorrected density of individuals/km^2, $\widehat{Dc}$ = estimated density of individuals/km^2 corrected for visibility bias and group size bias, $\widehat{Nc}$ = abundance corrected for visibility bias and group size bias, CI = confidence intervals.

Strata	Year	*n*	ER (CV)	Es (CV)	$\widehat{Du}$ (CV)	$\widehat{Dc}$ (CV)	$\widehat{Nc}$ (CV)	95% CI
Brazil	2021	34	0.013 (0.163)	2.525 (0.070)	0.089 (0.211)	0.426 (0.327)	13,137 (0.327)	7,037 – 24,526
UY offshore	2023	8	0.025 (0.531)	2.143 (0.033)	0.170 (0.573)	0.809 (0.625)	10,985 (0.625)	3,558 – 33,917
UY inshore	2023	26	0.017 (0.193)	1.878 (0.116)	0.102 (0.249)	0.484 (0.353)	9,644 (0.353)	4,918 – 18,913
UY Río de la Plata	2023	19	0.025 (0.410)	1.468 (0.131)	0.123 (0.355)	0.587 (0.434)	9,382 (0.434)	4,148 – 21,218
Uruguay	2023	53	0.020 (0.194)	1.818 (0.098)	-	0.606 (0.354)	30,011 (0.354)	15,304 – 58,852
FMA III	*2022**	*87*	*0.016 (0.136)*	*2.090 (0.087)*	-	*0.537 (0.311)*	*43,148 (0.311)*	*23,786 – 78,271*

* The estimate for the whole of FMA III combines a survey conducted in Brazil (in 2021) and another in Uruguay (in 2023), therefore the middle year (2022) is proposed to represent the stock-wide estimate.

Table 4. Survey strata, covered area, number of transect lines, realized effort, franciscana groups detected (*n*) and encounter rate (ER) of aerial surveys designed to estimate franciscana abundance in the Brazilian sector of FMA III in 2014 (Sucunza et al. 2020). Coefficient of variation in parenthesis.

Stratum	Area (km^2)	n of lines	Effort (km)	n	ER (CV)
Covered	21,517	76	2,681	32	0.01194 (0.22)
Uncovered	9,342	18	1,172	14	0.01195 (0.34)

Acknowledgments

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