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ARTICLE

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Distribution, habitat use, and abundance of the endangered franciscana in southeastern and southern Brazil

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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 South America due to high bycatch levels. Four management units (FMAs) were defined throughout the species' range. FMA II includes states along southeastern and southern Brazil, and represents one of the least known units. Recently, genetic analysis proposed that FMA II comprises two distinct populations and its range should be divided into FMA IIa and IIb. In December 2008 and January 2009 aerial surveys were conducted to assess the distribution and to estimate abundance of franciscanas off FMA II. A total of 54 groups were seen (average group size = 2.76, *SE* = 0.17) in shallow (mean depth = 7.15 m, *SE* = 7.08) coastal habitats (average distance from the shore = 6.48 km, *SE* = 6.28). Abundance corrected for perception and availability bias was estimated at 6,827 (*CV* = 0.26) franciscanas in FMA II, and at 1,915 (*CV* = 0.32) and 4,353 (*CV* = 0.24) franciscanas in FMA IIa and FMA IIb, respectively. This study indicates that, at least during the summer, franciscanas aggregate in shallow coastal habitats. Current estimates of incidental mortality in FMA II correspond to 4.4%–7.3% of the estimated stock size, suggesting high, likely unsustainable bycatch.

KEYWORDS
abundance, aerial surveys, cetaceans, conservation, distribution, mark-recapture distance sampling methods, strip transect estimates, threatened species

1 | INTRODUCTION

Assessing distribution and abundance of rare and threatened species is naturally difficult, yet this information is fundamental to properly evaluate their conservation status and to plan effective management actions (Taylor & Gerrodette, 1993; Williams, Nichols, & Conroy, 2001). Aircraft are useful platforms to conduct biological surveys. These platforms provide the opportunity to search large and/or inaccessible areas of the ocean in a short period of time (Andriolo, Kinas, Engel, Martins, & Rufino, 2010; Crespo, Pedraza, Grandi, Dans, & Garaffo, 2010; Hiby & Hammond, 1989; McLellan et al., 2018). In addition, the perspective from an aerial platform can provide better visibility under water and provide robust data to assess many aspects on the ecology of marine species (e.g., Mayo et al., 2018; Smultea et al., 2017; Sucunza et al., 2015). For many marine species (e.g., cetaceans and marine turtles) line transect aerial surveys constitute one of the most common methods to estimate abundance (Andriolo et al., 2010; Fuentes et al., 2015; Secchi et al., 2001; Slooten, Dawson, & Rayment, 2004; Thomas et al., 2010). In order to compute unbiased estimates, line transect methods assume that detection on the survey trackline is certain, i.e., $g(0) = 1$ (Buckland et al., 2001). However, this assumption is rarely met when abundance is estimated using aerial platforms, i.e., $g(0) < 1$, requiring the development of correction factors to compute robust estimates (Laake & Borchers, 2004; Laake, Calambokidis, Osmek, & Rugh, 1997; Sucunza, Danilewicz, Cremer, Andriolo, & Zerbini, 2018). Marsh and Sinclair (1989) coined the terms perception and availability bias to differentiate two forms of visibility bias during aerial surveys. Perception bias occurs when animals are available to be seen but are not detected by the observers while availability bias occurs when animals are missed because they are submerged and unavailable to be detected.

The franciscana, *Pontoporia blainvillei*, is a small dolphin endemic to coastal waters of Brazil, Uruguay, and Argentina (Crespo, 2009). Franciscanas occur in waters typically shallower than 30 m (Danilewicz et al., 2009) and present a discontinuous distribution from Itaúnas, Brazil (18°25′S) to Golfo San Matías, Argentina (42°10′S) (Crespo, Harris, & González, 1998; Siciliano, Di Beneditto & Ramos, 2002). The species is considered one of the most threatened small cetacean in South America due to high, and possibly unsustainable, bycatch levels as well as increasing habitat degradation (Secchi, 2010; Secchi, Ott & Danilewicz, 2003a). Incidental catches in fishing gear, especially gill nets and trammel nets, have been reported along most of the species' range since at least the 1940s (Ott et al., 2002; Secchi et al., 2003a; Van Erp, 1969). The franciscana is currently listed as "Vulnerable" in the IUCN Red List of Threatened Species (Zerbini, Secchi, Crespo, Danilewicz, & Reeves., 2017) and "Critically Endangered" by the Brazilian Government (Ministério do Meio Ambiente [MMA], 2014).

In order to guide conservation and management actions on a regional basis, the franciscana range was divided in the early 2000s into four zones known as "Franciscana Management Areas" (FMAs) (Secchi, Danilewicz, & Ott, 2003b). FMA I includes Espírito Santo (ES) and northern Rio de Janeiro (RJ) States in southeastern Brazil; FMA II corresponds to southern RJ, São Paulo (SP), Paraná (PR), and northern Santa Catarina (SC) States; FMA III encompasses southern SC, Rio Grande do Sul (RS) States in Brazil and Uruguay; and FMA IV corresponds to the coast of Argentina (Anonymous, 2015; Secchi et al., 2003b). Absence of stranded or incidentally killed animals indicated a gap of approximately 320 km in the franciscana distribution between northern and southern RJ (Siciliano et al., 2002). This gap separates the southern border of FMA I and the northern border of FMA II.

FMA II is one of the least known franciscana stocks. A recent reevaluation of the franciscana population structure based on the analysis of mtDNA control region sequences proposed that individuals from FMA II comprise two distinct populations, one including the southern area of RJ and northern SP (referred to as FMA IIa) and the other extending from the central coast of SP to the central coast of SC (referred to as FMA IIb) (Cunha et al., 2014). In addition, franciscanas in Babitonga Bay, a small estuarine area in SC, are thought to be isolated from open ocean dolphins in FMAs IIa and IIb (Cremer & Simões-Lopes, 2008). Demographic isolation within FMA II may represent an additional challenge for the conservation of the franciscana, especially if anthropogenic threats are greater for smaller units within more restricted habitats.

Estimating abundance of franciscanas and assessing their potential occurrence in distributional gaps along the species range have been recommended as a priority by local and international organizations including the governments of Brazil and Argentina, the International Union for Conservation of Nature (IUCN), and the International Whaling Commission (Anonymous, 2015; Instituto Chico Mendes de Conservação da Biodiversidade [ICMBio], 2011; International Whaling Commission [IWC], 2005, 2016; Reeves, Smith, Crespo & Di Sciara, 2003). In late 2008 and early 2009, aerial surveys were conducted along the range of FMA II to assess distribution and abundance within FMA II and to assess whether franciscanas occurred in the distributional gap between FMA I and FMA II. Preliminary results of these surveys were presented in Zerbini et al. (2010). Since then, the limits of FMA II have been reviewed, evidence of population substructure has been reported and new estimates of correction factors for availability bias have been computed (Anonymous, 2015; Cunha et al., 2014; Sucunza et al., 2018). The main goal of this study was to revise the estimates presented in Zerbini et al. (2010) in light of this new information. Specifically, a more detailed description of the distribution and new estimates of abundance, including the whole range of FMA II and areas for which potential substructure has been identified (FMA IIa and IIb) are provided here.

2 | METHODS

2.1 | Study area and survey design

Aerial surveys were conducted on 11–22 December 2008 and 11–18 January 2009 between Arraial do Cabo, RJ (22°56′S, 42°09′W) and the southern border of the state of SC (27°37′S, 48°25′W) (Zerbini et al., 2010) (Figure 1). The survey tracklines followed design-based line transect methods, which assume that the 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). A set of 97 parallel transect lines ranging from 1.68 km to 47.96 km in length and equally spaced by ~11 km was placed perpendicular to the coast line. This design makes no assumption about the spatial distribution of the animals, ensures an equal sampling probability, and thus, allows for poststratification of the study area.

When originally designed, the survey region encompassed the latitudinal range of the hiatus in the distribution of the franciscana between FMA I and FMA II as well as the whole of FMA II as defined by Secchi et al. (2003b). Due to a recent review of the latitudinal ranges of the FMAs and a change in the boundary between FMA II and FMA III, these surveys

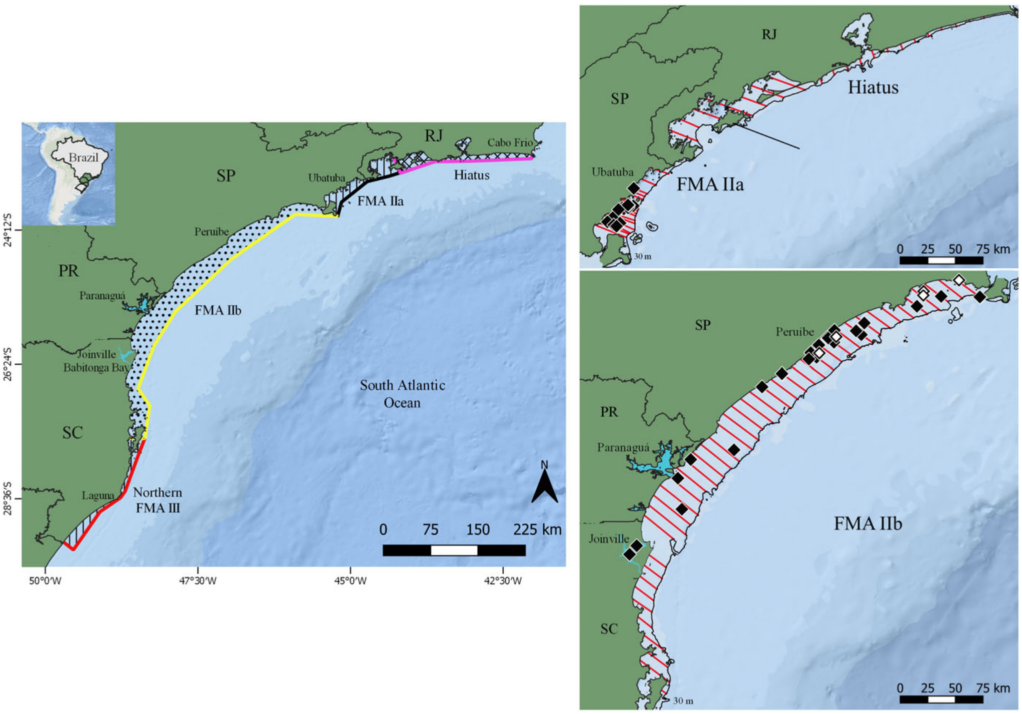

FIGURE 1 (Left) Study area of franciscana aerial survey conducted between 11–22 December 2008 and 11–18 January 2009 off southern and southeastern Brazil. This area encompasses the northern region of the Franciscana Management Area (FMA) III (red line), the whole FMA II (with FMA IIb shown by the yellow line, and FMA IIa shown by the black line), and a hiatus that separates the southern border of FMA I and the northern border of FMA II (pink line). (Right) Survey strata and realized effort (red lines) used to compute abundance estimates, and franciscana sightings (on effort = black diamond, off effort = white diamond). Sightings that appear on land (near Joinville) have been recorded inside an estuary (Babitonga Bay) where franciscanas are regularly documented. SC = Santa Catarina State, PR = Paraná State, SP = São Paulo State and RJ = Rio de Janeiro State.

TABLE 1 Survey strata, covered area, number of transects, and achieved survey effort in the inshore stratum (waters within 30 m of depth) for franciscana aerial surveys in southeastern and southern Brazil.

Stratum	Area (km^2)	# Transects	Effort (km)
(1) Hiatus	623	17	174
(2) FMA IIa	3,246	23	433
(3) FMA IIb	17,198	45	1,372
Total	21,067	85	1,979

now also include the northern portion of the latter management area (Anonymous, 2015) (Figure 1). For the analysis presented here, three survey strata were established (Table 1): (1) distributional gap in southern RJ or "Hiatus stratum" (22°58′S–22°56′S); (2) southern RJ-northern SP or "FMA IIa stratum" (22°56′S–13°48′S); and (3) central and southern SP, PR, and northern SC or "FMA IIb stratum" (23°48′S–27°36′S) (Figure 1). Survey lines were designed to cover an inshore (waters within 30 m of depth) and an offshore stratum depth ranging from 30 to 50 m (Zerbini et al., 2010). However, due to the complete absence of sightings in the offshore stratum, only tracklines allocated to the inshore area are considered in this study. Total planned effort within the three survey strata corresponded to 1,916 km.

2.2 | Sampling methods

Searching for franciscana groups was conducted from a high-wing, twin-engine *Aerocommander 500B* aircraft at an altitude of approximately 150 m (500 ft) and a speed of 170–200 km/hr (~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. Different window configuration resulted in a partial overlap in the front and rear observer's field of view (beyond 80 m from the trackline). Flights were generally conducted under relatively good weather and visibility conditions (Beaufort sea state ≤3). The searching team consisted of four observers, who recorded environmental data (e.g., Beaufort sea state, water transparency) at the beginning of each transect and whenever conditions changed. The observers were informed of the beginning and end of the transects by the pilot. All observers were independent as they did not communicate with each other during the flights. Data were recorded on audio digital recorders. Every record was time-referenced based on a digital watch synchronized to the GPS. This allowed observations to be georeferenced.

When a group of cetaceans was detected, the species and the size of the group were recorded. The declination angle between the horizontal and the sighting was obtained using an inclinometer when the group passed a beam of the plane. Additional information such as presence of calves in the groups, Beaufort sea state, and water transparency were also recorded along with each sighting. Sighting data collection was standardized while surveying the proposed transects as well as during transiting between transects and from and to the survey area to airports. Additional transit lines were proposed in observed areas of high density of franciscanas to increase sample size for the estimation of detection probability. All sightings recorded under such conditions were considered "on effort" and used for the estimation of the detection function but only sightings detected while flying transect lines were used to compute the estimates of density and abundance.

2.3 | Analytical methods

2.3.1 | Distribution

Only sightings recorded in either FMA IIa or IIb strata were used to assess distribution patterns of franciscana in FMA II. Bathymetry data were extracted for each franciscana group from the ETOPO1 1 Arc-Minute Global Relief Model (Amante & Eakins, 2009). Distance from the shore was calculated for each group using *GPS TrackMaker Pro* software. To assess the effect of bathymetry on the occurrence of franciscanas in FMA II, relative density of franciscana groups was compared among the 0–10 m, 11–20 m, and 21–30 m isobaths. Relative density was computed for each interval as the number of groups detected per distance surveyed on effort within each interval of isobaths, and the Fisher-Pitman permutation test (Fisher, 1936; Pitman, 1937) was used to test for statistical difference between intervals.

2.3.2 | Line transect analysis methods

Detection probability was estimated using the point independence approach of Laake and Borchers (2004) and Borchers, Laake, Southwell and Paxton (2006). This approach combines distance sampling and mark-recapture methods to estimate the probability of detecting an object (a group of franciscanas in this study), given their distance from the survey line and other covariates. In simple terms, the shape of the detection function is estimated from perpendicular distance data assuming all animals in the trackline are seen, $g(0) = 1$, and the probability of detection on the trackline, i.e., $P(0)$ is estimated with the mark-recapture component. A detailed description of the statistical procedures to estimate perception bias is found in Borchers et al. (2006) and Burt, Borchers, Jenkins and Marques (2014).

Sighting data and covariates from front and rear observation platforms were used in the mark-recapture models for the estimation of the probability of detection on the trackline. Because observers in these two positions were independent, sightings of the front and rear observers in each side of the plane were compared to identify sightings made by only one, or those made by both observation platforms (Laake & Borchers, 2004). Determination of simultaneous sightings by both platforms was based on coincidence in timing of the sighting, declination angle, group size and, whenever feasible, the presence and number of calves in the group. To ensure data comparability between front and rear observers, only sightings recorded beyond 80 m (left truncation of perpendicular distance data) from the trackline on each side of the plane were used in fitting the detection function. This distance corresponds to the area under the aircraft not available for searching to observers in the flat windows (i.e., rear position). Left truncation of perpendicular distance data caused 11 sightings from front (bubble window) observers to be removed from the line transect analysis.

In order to fit the detection function, 80 m were subtracted from the set of truncated perpendicular distance, resulting in the assumption that $\bar{P}(0) = \bar{P}(80\,\text{m})$. Due to the relatively small sample of sightings available for estimating detection probability (see Results section), perpendicular distance data were not right truncated (Buckland et al., 2001). Only the half-normal and the hazard-rate detection functions were proposed to fit distance data. Exploratory analyses indicated that the distance data should be grouped (grouping intervals: 0–50 m, 51–100 m, 101–150 m, 151–200 m) to achieve better model fits. The effect of covariates such as group size and Beaufort sea state on the shape of the detection function was not investigated due to the small number of sightings remaining after truncation. Environmental and biological covariates were proposed for the mark-recapture component due to possible differences in sighting (capture) probabilities due to distance (numerical covariate), the window configuration for front and rear observers (factor covariate with two levels: bubble and flat windows), the sea state (factor with two levels: high and calm), and the size of the group (numerical covariate). Models were ranked according the Akaike information criterion (AIC), 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.2.2.0; Laake, Borchers, Thomas, Miller & Bishop, 2018) in R (R Core Team, 2018).

2.3.3 | Abundance estimation

Density and abundance were estimated based on line- and strip-transect analysis methods (Buckland et al., 2001). Strip transect estimates were produced with sightings (n = 8) recorded by front observers in the area between 0 m and 80 m of distance from the trackline on each side of the plane. All groups within the strip were assumed to be detected with a probability equal to the estimated probability of detection on the trackline, i.e., $\bar{P}(0)$.

Density and abundance of franciscanas (N_u, abundance corrected for perception, but not for availability bias) were estimated separately for the FMA IIa and IIb strata using the Horvitz-Thompson-like estimator (Borchers & Burnham, 2004; Borchers et al., 1998). Expected mean group size was obtained as suggested by Innes et al. (2002) and Marques and Buckland (2003). N_u for FMA IIa and FMA IIb strata was obtained as the mean of the line transect and strip transect estimates, weighted by the respective coverage areas. The overall estimate of N_u for the whole FMA II area was obtained as the mean of the stratum-specific estimates, weighted by the respective areas of the strata (Thomas et al., 2010).

Correction for franciscana groups missed because they were submerged during the survey (availability bias) was computed based on helicopter experiments conducted in the survey area with franciscanas (availability AV = 0.39, SE = 0.01, Sucunza et al., 2018). Corrected abundance (N_c) was calculated by multiplying N_u by 1/AV.

Variance of N_u was estimated using the analytical estimator of Innes et al. (2002) and variance of N_c was computed by the Delta method (Seber, 1982) as described in Crespo et al. (2010). Log-normal 95% confidence intervals (Buckland et al., 2001) were calculated after unconditional variance was derived (Zerbini, Waite, Laake & Wade, 2006).

3 | RESULTS

A total of 3,268 km of on effort survey was conducted along the three survey strata, and franciscana groups were recorded in both FMA IIa and IIb, but not in the Hiatus. Realized effort was greater than planned effort because additional lines were placed to obtain sighting data for improving estimates of detection probability. The realized effort used for abundance estimation is reported in Table 1.

3.1 | Distribution

A total of 54 franciscana groups was seen within FMA II (both FMA IIa and IIb strata) during the survey, with 49 sightings observed on effort (Figure 1). Total number of individuals seen was 149 and the average group size for all these sightings combined was 2.76 (*SE* = 0.17, median = 2, range = 1–6). Franciscanas were observed in two main regions: between Joinville/Paranaguá, and from Peruíbe to Ubatuba (Figure 1). Franciscana groups were recorded between 0.64 km and 30.23 km from the shore (median = 4.67, mean = 6.48, *SE* = 6.28), in turbid and clear waters (Table 2, Figure 2). Relative density (encounter rate [ER], defined as groups/km) of franciscana groups off FMA II area was similar between the 0–10 m (ER = 0.03, *SE* = 0.01, 95% CI = 0.02–0.04) and 11–20 m isobaths (ER = 0.03, *SE* = 0.008, 95% CI = 0.02–0.03), and both values were significantly higher than between 21–30 m isobaths (ER = 0.005, *SE* = 0.002, 95% CI = 0.003–0.007) (*p* = .02, *p* = .001, respectively; Table 3).

TABLE 2 Average distance from the shore and depth of franciscana groups recorded during aerial surveys off Franciscana Management Area II (FMA II). FMA IIa and FMA IIb correspond to areas of occurrence of potential distinct franciscana populations within FMA II (Cunha et al., 2014), and treated in this study as FMA IIa and FMA IIb strata. Standard error (*SE*) and total range in parenthesis.

Area	Distance from shore (km)	Depth (m)
FMA IIa	3.57 (*SE* = 2.81, 0.64–8.28)	3.95 (*SE* = 4.12, 1–12.22)
FMA IIb	7.61 (*SE* = 6.90, 0.74–30.23)	8.40 (*SE* = 7.63, 1–21.93)
FMA II	6.48 (*SE* = 6.28, 0.64–30.23)	7.15 (*SE* = 7.08, 1–21)

FIGURE 2 Franciscanas recorded in turbid (left) and clear waters (right).

TABLE 3 Relative density (groups/km) of franciscana groups between three intervals of depth: 0–10 m, 11–20 m, and 21–30 m. *franciscana* management Area II (FMA II). FMA IIa and FMA IIb correspond to areas of occurrence of potential distinct Franciscana populations within FMA II (Cunha et al., 2014), and treated in this study as FMA IIa and FMA IIb strata. Standard error (*SE*) and 95% confidence intervals (CI) in parenthesis.

Area	0–10 m (*SE*, 95% CI)	11–20 m (*SE*, 95% CI)	21–30 m (*SE*, 95% CI)
FMA IIa	0.03 (0.02, 0.01–0.08)	0.07 (0.02, 0.05–0.88)	0
FMA IIb	0.03 (0.01, 0.02–0.04)	0.02 (0.007, 0.01–0.02)	0.006 (0.003, 0.003–0.009)
FMA II	0.03 (0.01, 0.03–0.04)	0.03 (0.008, 0.02–0.03)	0.005 (0.002, 0.003–9.007)[a]

[a]Indicates statistical significance between the 21–30 m depth category and the 0–10 m (p = .02) and 11–20 m (p = .001).

TABLE 4 Summary of models proposed to fit perpendicular distance data for franciscana in southeastern and southern Brazil. DF: detection function model component, MR: mark recapture model component, Hn: half-normal key function, Hr: hazard-rate key function, AIC: Akaike's information criterion differences between the model in question and the most parsimonious model, *wi*: Akaike weight, Npar: number of parameters, $\bar{P}$: overall probability of detection, $\bar{P}(0)$: probability of detection at 80 m of distance from the track line for both observers combined, *CV*: coefficient of variation.

#	Model specification	ΔAIC	w_i	Npar	$\bar{P}$	$CV(\bar{P})$	$\bar{P}(0)$	$CV(\bar{P}[0])$
1	DF(Hn) + MR(distance + group size + f[sea state] + f[window])	0.00	0.15	7	0.65	0.25	0.86	0.20
2	DF(Hn) + MR(distance + group size + f[sea state])	0.34	0.13	6	0.64	0.26	0.85	0.20
3	DF(Hr) + MR(distance + group size + f[sea state] + f[window])	0.50	0.12	8	0.73	0.23	0.86	0.19
4	DF(Hn) + MR(distance + group size + f[window])	0.70	0.10	6	0.58	0.32	0.77	0.27
5	DF(Hr) + MR(distance + group size + f[sea state])	0.84	0.10	7	0.72	0.24	0.85	0.20
6	DF(Hn) + MR(distance + group size + f[window])	1.04	0.09	6	0.57	0.33	0.75	0.29
7	DF(Hr) + MR(distance + group size + f[window])	1.20	0.08	7	0.65	0.30	0.77	0.27
8	DF(Hr) + MR(distance + group size)	1.54	0.07	6	0.64	0.31	0.75	0.29
9	DF(Hn) + MR(distance + f[sea state] + f[window])	3.60	0.02	6	0.66	0.23	0.87	0.15
10	DF(Hn) + MR(distance + f[window])	3.62	0.02	5	0.63	0.25	0.84	0.18
11	DF(Hn) + MR(distance + f[sea state])	3.95	0.02	5	0.65	0.23	0.87	0.16
12	DF(Hn) + MR(distance)	3.96	0.02	4	0.62	0.25	0.83	0.19
13	DF(Hn) + MR(distance + f[sea state] + f[window])	4.10	0.02	6	0.74	0.20	0.87	0.15
14	DF(Hr) + MR(distance + f[window])	4.12	0.02	6	0.71	0.22	0.84	0.18
15	DF(Hr) + MR(distance + f[sea state])	4.44	0.02	6	0.74	0.21	0.87	0.16
16	DF(Hr) + MR(distance)	4.45	0.02	5	0.71	0.23	0.83	0.19

3.2 | Abundance

Detection probability was computed (after left truncation and rescaling of distances) only using on effort sightings recorded in the whole study area (n = 41 sightings). The most supported model from the data had distance, group size, sea state and window configuration as covariates in the mark-recapture (MR) component and the half-normal detection function to fit perpendicular distance data (Table 4). Plots of estimated detection probability for front, rear, and both observers for best AIC selected model (#1 in Table 4) are illustrated in Figure 3.

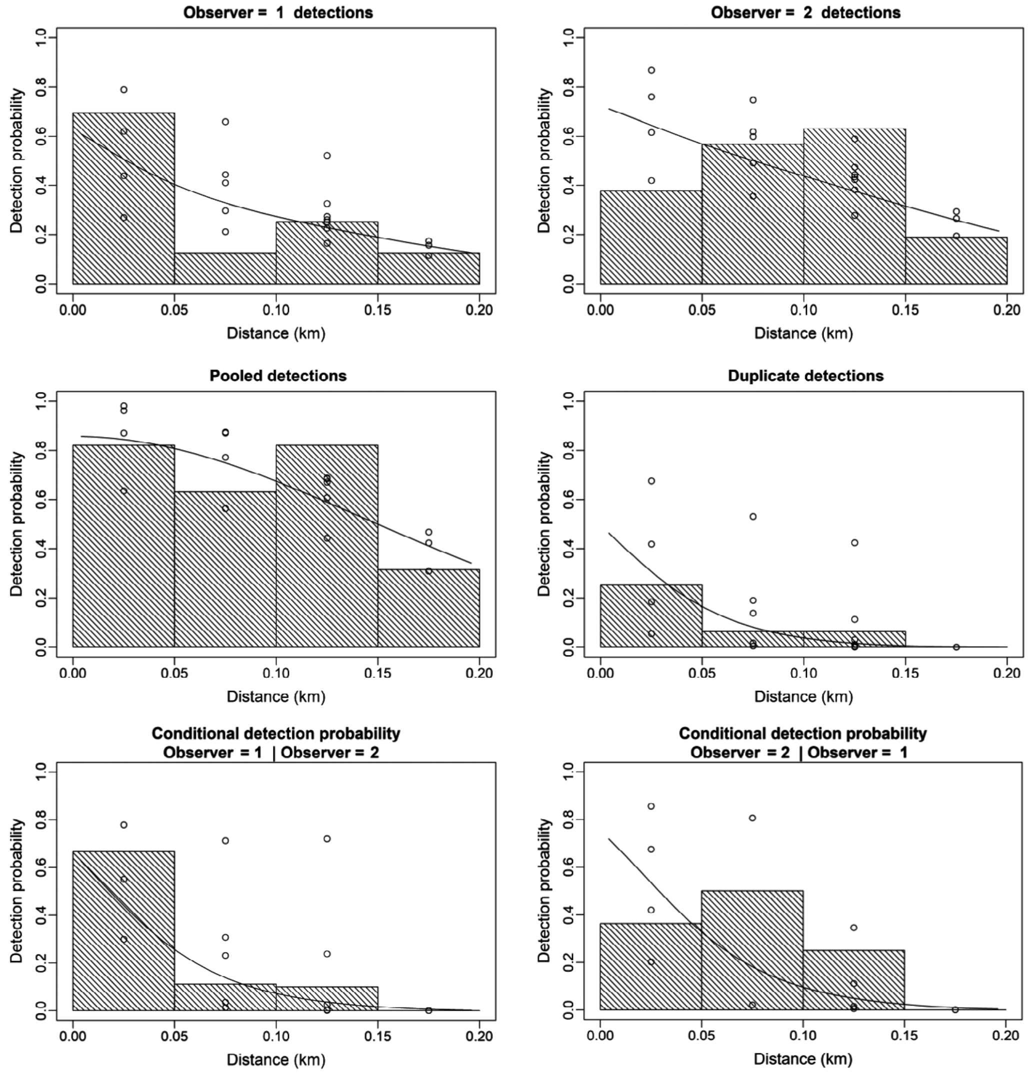

FIGURE 3 Detection probability plots for Model #1 in Table 4. Perpendicular distance data were left truncated during analysis, and distance labeled 0.00 corresponds to a real distance of 0.08 km from the trackline.

TABLE 5 Density and abundance estimates of franciscanas in southeastern and southern Brazil in 2008–2009. Franciscana Management Area II (FMA II). FMA IIa and FMA IIb correspond to areas of occurrence of potential distinct franciscana populations within FMA II (Cunha et al., 2014), and treated in this study as FMA IIa and FMA IIb strata. Coefficient of variation (*CV*). $\bar{P}$ = overall probability of detection (averaged over all candidate models), *n* = number of sightings used for abundance estimation, ER = number of groups/km, $\hat{S}_i$ = estimated average group size (averaged over all candidate models), $\hat{D}_u$ = estimated density of individuals/km2 corrected for perception bias, $\hat{D}_c$ = estimated density of individuals/km2 corrected for perception and availability bias, $\hat{N}_c$ = estimated abundance corrected for perception and availability bias, CI = confidence intervals.

Strata	$\bar{P}$	*n*	ER	$\hat{S}_i$	$\hat{D}_u$	$\hat{D}_c$	$\hat{N}_c$	95% CI
FMA IIa	0.65 (0.27)	14	0.03 (0.42)	2.67 (0.16)	0.23 (0.32)	0.59 (0.32)	1,915 (0.32)	1,034–3,546
FMA IIb	0.65 (0.27)	22	0.02 (0.29)	2.53 (0.18)	0.10 (0.24)	0.25 (0.24)	4,353 (0.24)	2,728–6,946
FMA II	0.65 (0.27)	36	0.02 (0.26)	2.58 (0.18)	0.13 (0.26)	0.33 (0.26)	6,827 (0.26)	4,127–11,294

Only 36 sightings were recorded off FMA II in the proposed survey tracklines (*n* = 14 in FMA IIa stratum and *n* = 22 in FMA IIb stratum). Weighted density of franciscanas across FMA II was 0.33 franciscana/km^2, and abundance through the study period (i.e., 2008–2009) between the shore and the 30 m isobath was estimated at 6,827 individuals (*CV* = 0.26, 95% CI = 4,127–11,294) (Table 5).

4 | DISCUSSION

4.1 | Distribution

The present aerial surveys provided a description of the wide-scale distribution of franciscanas in southeastern and southern Brazil between southeast RJ and central SC, including the hiatus on the northern portion of this range and the whole FMA II area. Because the franciscana is difficult to see (Bordino, Thompson, & Iñíguez, 1999; Crespo, 2009) and because of the lack of systematic sighting surveys, most knowledge on the species distribution comes from data on stranded or incidentally captured individuals (e.g., Danilewicz et al., 2009; Secchi et al., 1997; Siciliano et al., 2002). In the present survey, franciscana groups were observed near Laguna (northern range of FMA III, Zerbini et al., 2010) and again, further to the north, in Babitonga Bay and near Paranaguá. Aggregations of franciscana groups were observed in the central-northern range of the stock between Peruíbe and Ubatuba (Figure 1). Considering that franciscanas inhabiting Babitonga Bay apparently comprise a resident population (Cremer & Simões-Lopes, 2008), no other franciscana groups were observed in open ocean, between Florianópolis and Paranaguá (~200 km). Although these results could indicate gaps in the distribution of franciscanas in FMA II, multiyear stranding and bycatch monitoring indicate a continuous distribution of franciscanas between central SC and southern RJ (e.g., Bertozzi & Zerbini, 2002; Cremer et al., 2013; Rosas & Monteiro-Filho, 2002; Rosas, Monteiro-Filho, & Oliveira, 2002; Santos, Vicente, Zampirolli, Alvarenga, & Souza, 2002; Simões-Lopes & Ximenez, 1993; *webGIS* SIMMAM, http://simmam.acad.univali.br/site/). Lack of sightings in certain areas may have occurred because of a number of factors, including the relatively small coverage of the aerial surveys as well as seasonal variation in distribution.

Qualitatively speaking, the distribution patterns observed in this study suggest that the franciscana inhabit areas with somewhat different environmental characteristics throughout the range of FMA II. The species is believed to prefer nutrient-rich, coastal or estuary-influenced waters with high turbidity and under the influence of continental runoffs (Siciliano et al., 2002). These areas are thought to concentrate juvenile fish species, the most important prey of franciscanas (e.g., Pinedo et al., 1989; Rodríguez, Rivero & Bastida, 2002). Such environmental features are typical of a few areas where franciscanas were seen in this study (e.g., Joinville and Paranaguá), even though the number of sightings in these regions was small. In fact, most sightings occurred in regions with greater water transparency, where the input of river run-offs is relatively limited (e.g., Peruíbe and Ubatuba). The brownish to dark dorsal color of the franciscana (Crespo et al., 2009) difficult its detection in waters with high turbidity under the influence of continental runoffs (see Figure 2) and therefore could explain fewer sightings near estuarine habitats. Nevertheless, our findings suggest that greater water transparency alone is not an ecological restraint for franciscanas.

Although franciscanas are typically found between near shore habitats and the 30 m isobath (Danilewicz et al., 2009; Secchi et al., 1997), in this study no groups were observed in waters deeper than 21 m. Relative density was significant lower beyond the 20 m isobath in FMA II. Despite limited effort, results presented here indicate that the area from the shore to the 20 m isobath represent the preferred habitat for franciscanas in FMA II, at least during the summer.

4.2 | Abundance

This is the first study to assess the abundance of franciscanas in the whole new proposed FMA II range. The overall abundance indicates that approximately 6,800 dolphins (*CV* = 0.26, 95% CI = 4,127–11,294) inhabited FMA II in

2008/2009. Although we corrected for known biases (perception and availability bias), our estimates may still be biased by factors that we could not quantify. The present abundance estimates did not account for bias in group size estimates from airplanes, an important source of negative bias as indicated for most aerial surveys of small cetaceans (e.g., Dahlheim, York, Towell, Waite, & Breiwick, 2000; Slooten et al., 2004; Zerbini et al., 2011). The high speed of the aircraft and the small body of the franciscana makes it difficult to accurately estimate the number of individuals in a group. Zerbini et al. (2011) showed a significant 30% negative bias in franciscanas group sizes estimated from aircraft relative to estimates of this quantity from surface platforms. Another potential source of bias in the estimates of abundance may result from nonindependence in detections by front and rear observers due to unmodeled heterogeneity in estimates of detection probability (Laake & Borchers, 2004). Although the effect of variables (e.g., group size) causing heterogeneity was modeled, other variables not included in the analysis of the detection function, such as glare, could affect the independence between observers and thus the abundance estimated would be underestimated.

It is important to note that abundance estimates presented in this study do not include the area of Babitonga Bay, northern SC. The bay is formed by an estuary characterized by calm and shallow waters where franciscanas potentially form an isolated population and the population of franciscanas inhabiting this region has been estimated at nearly 50 individuals (Cremer & Simões-Lopes, 2008; Zerbini et al., 2011).

4.3 | Conservation implications

Bycatch is currently the main conservation problem for the franciscana throughout its range (e.g., Secchi et al., 2003a, b). The annual fishery-related mortality of the species in FMA II is not well understood because of difficulties in monitoring the small, medium, and large-scale fisheries that operate year-round (Bertozzi & Zerbini, 2002; Ott et al., 2002; Projeto de Monitoramento da Atividade Pesqueira na Bacia de Santos [PMAP-BS], 2017). Current estimates of bycatch are not available for any of these fisheries. The limited information available is relatively outdated and pertains mostly to the small artisanal communities. Rough estimates of bycatch within the past decade have suggested an annual mortality of 300–500 franciscanas in FMA II (Bertozzi, 2009; IWC, 2005; Ott et al., 2002). These estimates suggest that bycatch mortality of franciscanas in FMA II at the end of the 2000s corresponded to 4.4%–7.3% of the estimated size of the FMA II population, numbers that are largely considered unsustainable for small cetacean populations (Wade, 1998) and the franciscana in particular (e.g., Danilewicz et al., 2010; Secchi, 2006; Secchi et al., 2001).

Correctly identifying and effectively managing anthropogenic threats is paramount for protecting endangered species (Kelleher, 1999; Slooten et al., 2013). Based on the potential demographic isolation between franciscanas inhabiting FMA IIa and FMA IIb (Cunha et al., 2014), results presented in this study should be used to guide local management actions at finer geographic scale. The present results indicate that franciscanas occur in relatively high densities in FMA IIa stratum. Artisanal (i.e., <20 gross tonnage) and industrial (i.e., >20 gross tonnage) fisheries operate off FMA IIa with high overlap with franciscana habitats (PMAP-BS, 2017), and evidence from stranded individuals indicates that bycatch occurs regularly throughout the area (IWC, 2018). In 2012, fishing regulation actions (INI 12/2012) were established by the Brazilian government authorities with the goal of improving management of the gill net fisheries and reducing bycatch of the franciscana as well as other endangered marine species. The regulation included, inter alia, a three nautical mile fishing ban for industrial boats in FMA IIa stratum. Franciscana sightings recorded off this protected zone represent 67% of the total sightings recorded within the FMA IIa stratum, which could be assumed a potential protection for 1,283 franciscanas. Extending this protected zone one nautical mile further (i.e., a four nautical mile fishing ban) would encompass 83% of the total sightings recorded within the FMA IIa stratum. Estimates of bycatch of franciscanas in FMA II were based mostly in monitoring fishing activities off FMA IIb stratum (e.g., Bertozzi & Zerbini, 2002). In this area, the INI 12/2012 delimit a four nautical mile fishing zone between central SC and PR, and three nautical mile for SP region. These protected zones account for, respectively, 61% (or 2,655 franciscanas) and 54% (or 2,351 individuals) of the total sightings recorded off FMA IIb stratum. Even though there is consensus among franciscana specialists that INI 12/2012 represented an important legal framework to minimize bycatch, it is not clear if regulations have been fully complied with (Anonymous, 2015).

Bycatch is not the only conservation threat for franciscanas in FMA II. The coastline in this area corresponds to one of the most developed and populated regions in the western South Atlantic Ocean, with several studies demonstrating that the quality of the franciscana habitat is deteriorating (Alonso et al., 2012; De la Torre et al., 2012; Lailson-Brito et al., 2011; Lavandier et al., 2016; Yogui, Santos, Bertozzi, & Montone, 2010). For these reasons, 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 franciscanas inhabiting southeastern and southern Brazilian coast.

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