Abundance and distribution of the franciscana (*Pontoporia blainvillei*) in the Franciscana Management Area II (southeastern and southern Brazil)

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ABSTRACT

The franciscana (*Pontoporia blainvillei*) is endemic of the eastern coast of Brazil, Uruguay and Argentina and inhabits coastal waters from Brazil (18º25'S) to Argentina (41º10'S). The species is currently regarded as the most threatened small cetacean in South America due to high bycatch levels throughout its range. Recently, four management stocks (known as Franciscana Management Areas or FMAs) were defined: three in Brazil (FMA I-III), one in Uruguay (FMA III) and one in Argentina (FMA IV). FMA II corresponds to the coasts of the Brazilian states of São Paulo, Paraná and Santa Catarina) and represents one of the least known stocks. This population faces a number of conservation threats including bycatch in fisheries and severe habitat degradation, but the magnitude of these threats have not yet been well understood because of lack of information on population size. In December 2008 and January 2009 aerial surveys were conducted to assess the distribution and to estimate abundance of franciscanas in FMA II. A design based approach was used to sample a costal (coastline to 30m isobath) and an offshore (30-50m isobaths) strata along the range of the species and mark-recapture distance sampling methods (MRDS) were used to estimate abundance. Survey sampling also included an area believed to correspond to a hiatus in the distribution between FMA I and FMA II. A total of 60 franciscana groups (157 individuals) were seen in the coastal stratum. No sightings were recorded in the offshore stratum and in the hiatus, but sampling in the former was limited due to consistent poor weather conditions. Average group size was 2.7 (SE = 0.17). Abundance corrected for perception and availability bias was estimated to range between 8,000 and 9,000 individuals (CVs = 0.32-0.35). Possible sources of bias in these estimates include underestimation of group size from the aircraft, poor survey coverage in the offshore stratum and the use of franciscana diving parameters collected outside of FMA II in the estimation of availability bias. Current estimates of incidental mortality in FMA II correspond to 3.3-6.2% of the estimated population size presented here, suggesting high, likely unsustainable bycatch. Other sources of unaccounted mortality are not well known and require monitoring to better assess the long-term survival of franciscanas inhabiting southeastern and southern Brazil.

INTRODUCTION

The franciscana (*Pontoporia blainvillei*) is endemic of the eastern coast of Brazil, Uruguay and Argentina (e.g. Praderi et al. 1989) and inhabits coastal waters (usually shallower than 30m) from Itaúnas, Brazil (18º25'S) to Golfo San Matías, Argentina (41º10'S) (Siciliano 1994; Crespo et al. 1998). High levels of incidental mortality in coastal fisheries have been recorded throughout its range since the 1940s and the species is currently regarded as the most threatened cetacean species in South America (Van Erp 1969; Ott et al. 2002; Secchi et al. 2003a).

The franciscana range was recently divided into four management stocks (known as Franciscana Management Areas or FMAs): Two in southeastern Brazil (FMA I and II), one in southern Brazil and Uruguay (FMA III) and one in Argentina (FMA IV) (Secchi et al. 2003b). FMA II corresponds to the coasts of the States of São Paulo (SP), Paraná (PR) and Santa Catarina (SC) in Southeastern Brazil (Fig. 1) and represents one of the least known stocks. Historical information indicates that the franciscana has been regularly taken in gillnets by fishermen operating from small villages throughout the range of FMA II since the 1960s (Carvalho 1961; Schmiegelow 1990, Ott et al. 2002). However, the characteristics of the fishery and bycatch mortality of the franciscana in FMA II have been poorly described. In 1998, monitoring was initiated at one of those villages, Praia Grande (SP), through systematic visits to the landing locations and opportunistic on-board observer programs. Results showed that fishing operations were of small scale, fishing grounds were restricted to small geographic areas (within 10-20km from the landing locations) and franciscana mortality was nearly 10 individuals/year (Bertozzi and Zerbini 2002). Bertozzi and Zerbini (2002) noted that the characteristics of the village at Praia Grande were similar to the other villages within the range of the stock and concluded that overall mortality could be significant. An assessment of the number of fishing villages, the size of the fleet, fishing effort and franciscana bycatch was initiated in 2002. It is estimated that the number of fishing villages only in the northern portion of FMA II is nearly 100 and the bycatch mortality is 350-500 individuals/year (IWC, 2005, p. 311; Bertozzi et al., unpublished data).

Fishery mortality is possible not the only conservation threat for franciscanas in FMA II because the coastline in this area corresponds to one of the most developed and populated regions in the western South Atlantic Ocean. The coastal human population was estimated at 15 million in 2001 and three of the five largest Brazilian ports (Santos, Paranaguá and São Sebastião, Fig. 4) are located in this area. For this reason, other conservation issues of significant importance for the franciscana in FMA II are: rapidly increasing (1) habitat degradation, (2) underwater noise and chemical pollution from coastal development and industrial and human waste discharge, (3) oil and gas exploration activities, and (4) vessel traffic.

Despite all these issues, conservation and management actions have never been proposed for the population in FMA II due to, among of others, a lack of knowledge on distribution, critical habitats and abundance. While incidental catches and a few sightings have been observed along the whole range of the stock, catch rates seems to be higher near estuarine and turbid waters (Bertozzi et al. unpublished data) suggesting that such regions are more suitable for the species. Unlike other areas, the habitat of the franciscana in southeastern Brazil is heterogeneous and characterized by pockets of turbid waters under the influence of rivers and estuaries, inserted within areas of higher underwater visibility due to the influence of oceanic waters. In addition, and possibly most important, there are no estimates of abundance of this population and therefore it is impossible to determine the magnitude of the bycatch removal and to assess the status of the population. Without the identification of critical habitats and estimates of abundance, it is unlikely that management advice can be provided and adequate conservation actions be implemented for this stock.

In 2007, a proposal to assess the status of the franciscana in FMA II was co-funded by the Brazilian Environmental Agency/Ministry of the Environment (ICMBio/MMA/Brazil), the Marine Marine Mammal Commission (MMC) of the United States, and the Yaqu Pacha foundation (YP/Germany). The main goal of the proposal was to conduct aerial surveys with specific objectives of:

1) Estimating population size of the stock of franciscanas inhabiting FMA II;
2) Documenting distribution and critical habitats;
3) Investigating relationship of the current distribution with environmental parameters (e.g. water turbidity, sea surface temperature and bathymetric parameters).

This document provides results from surveys conducted in December 2008 and January 2009 and first estimates of abundance for franciscanas in FMA II. In addition, the paper discusses some methodological needs to improve abundance estimation of franciscanas. These surveys were a first attempt to address a number of recommendations made by the IWC Scientific Committee (SC) after a review of the status of the franciscana conducted during the SC annual meeting in Sorrento in 2004 (IWC, 2005). For example, the surveys were conducted under an unbiased survey design and incorporated estimation of perception bias and also covered an area believed to correspond to a hiatus in the species distribution in order to assess the occurrence of dolphins between FMA I and FMA II. These were improvements that the IWC SC had previously encouraged (IWC, 2005).

METHODS

Aerial surveys were carried from the northern border of the State of São Paulo (23°23.18'S, 44°43.98'W) to the southern border of the Sates of Santa Catarina (29°20.52'S, 49°44.46'W) (Fig. 1), which corresponds to the latitudinal range of FMA II (Fig. 1). In addition, the region north and east of São Paulo, along the coast of Rio de Janeiro State, was also covered. This has been identified as a hiatus in the distribution of franciscanas in southeastern Brazil due to the lack of records of stranded or incidentally killed dolphins (Siciliano et al. 2002). However, because no systematic visual surveys had yet been conducted in this region, survey lines were designed to cover this area to verify whether franciscanas could be located in the area.

The surveys occurred in two periods: 11-22 December 2008 and 11-18 January 2009. Four survey strata were proposed (Table 1), an inshore (from the coast line to the 30m isobaths, the likely limit of the species – Pinedo et al. 1989; Secchi and Ott 2000) and an offshore (from the 30 to the 50m isobaths), in both FMA2 and the Hiatus strata (Fig. 1). The purpose of the offshore stratum was to investigate the possible occurrence of franciscanas in waters deeper than 30m because recent studies have shown this to be the case in other FMAs (Di Beneditto and Ramos 2001; Danilewicz 2007; Crespo et al. 2010). The proposed study area of each is specified in Table 1.

Table 1 – Survey strata area and proposed survey effort for franciscana aerial surveys in southeastern Brazil.

Stratum	Area (km^2)	#Transects	Effort (km)
FMA 2 – Inshore	23,550	84	2,164
FMA 2 – Offshore	25,393	28	767
Hiatus – Inshore	623	15	56
Hiatus – Offshore	1,042	5	68
Total	50,609	132	3,055

Survey Design and Sampling Methods

Aerial surveys followed design-based line transect methods (Buckland et al. 2001), which assume that the density of animals in the survey area (on the transects) is on average equal to the density in the study area if transect placement provides uniform coverage probability. A set of 132 equally spaced parallel transect lines were placed perpendicular to the coast line (Fig 1). This design makes no assumption about the spatial distribution of the animals, ensures an equal sampling probability and, if needed, allows for post-stratification of the study area. Such design features are desirable because the distribution and abundance of the franciscana in the study area were not previously known. Stratum specific effort is listed in Table 1. Total proposed effort corresponded to 3055km. Effort allocation was three times higher in the inshore than the offshore strata because of the greater likelihood of recording franciscanas in the former (Table 1, Fig. 1).

Visual surveys were made from a high-wing, twin-engine Aero Commander (Fig. 2) aircraft at an approximately constant altitude of 150m (500ft) and a speed of 170-200km/h (~90-110 knots). The aircraft had four observation positions (two on each side of the plane), with bubble and flat windows (Fig. 3) 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 80m 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 collected environmental data (e.g. sea conditions, water transparency) at the beginning and end of each transect, or when conditions changed. The begin and the end of the transects were informed to the observers 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 geo-referenced at the end of each flight. When a sighting 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 sea state, presence of calves in the groups, and water visibility 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 known or suspected areas of high density of franciscanas to increase sample size for the estimation of detection probability. All sightings recorded under such conditions were used for the estimation of the detection function but only sightings detected while flying the originally proposed survey design (Fig. 1) were used to compute the estimates of density and abundance.

An attempt was made to record franciscanas from the airplane utilizing a high-definition video camera. The camera was fixed at the right bubble window and was pointed to the trackline in order to obtain independent estimates of proportion of groups missed and group size (Hobbs et al. 2000). This was conducted only in the first leg of the aerial survey (December 2008) and was not repeated because it failed to record dolphins (probably due to the species small body size and color pattern) detected by the observers within the field of view of the camera.

Analytical Methods

Availability Bias ($\widehat{B_a}$)

In line transect surveys of marine mammals, animals are often missed by the observers due to visibility bias. This is an important source of negative bias in abundance estimates, in particular when surveys were done using airplanes. Marsh and Sinclair (1989) coined the terms 'perception' and 'availability' bias to describe two types of visibility bias. The former correspond to objects (dolphins) that are available at or near the surface but are missed by the observers while the latter corresponds to animals that are not available to be detected. Previous abundance estimates of franciscanas from aerial surveys have only corrected for availability bias (Secchi et al. 2001; Crespo et al. 2010; Danilewicz et al. in press). In this study we attempted to correct for perception bias, in addition to availability bias, using mark-recapture distance sampling methods (MRDS, Laake and Borchers 2004, see section below).

Availability bias point estimate ($\widehat{B_a}$ = 0.281) and variance ($\widehat{Var}[\widehat{B_a}]$ = 0.0023) were obtained from diving data of free-ranging franciscanas in Argentina as described by Crespo et al. (2010). This estimate is not statistically different from other estimates of availability bias for franciscanas ($\widehat{B_a}$ = 0.358, $\widehat{Var}[\widehat{B_a}]$ = 0.0047 from Secchi et al. [2001] and $\widehat{B_a}$ = 0.304, $\widehat{Var}[\widehat{B_a}]$ = 0.0003 from Danilewicz et al. [in press]). The choice of Crespo's et al. (2010) is made here because of the use of more recent data and greater sample size in estimating diving parameters (time at surface and diving time) of franciscanas relative to the two previous studies.

Estimation of Detection Probability and Perception Bias

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

Sighting data and covariates from front and rear observation platforms were used in the mark-recapture models for the estimation of perception bias. 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. 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 80m (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. Left truncation of perpendicular distance data caused 11 sightings from front (bubble window) observers to be removed from the analysis. In order to fit the detection function, 80m were subtracted from the set of truncated perpendicular distance, resulting in the assumption that $p(0) = p(80\text{m})$. Due to the relatively small sample of sightings available for estimating detection probability (see Results section), perpendicular distance data were not right truncated.

Only the half normal and the hazard rate functions were proposed to fit distance data. The effect of covariates such as group size and sea state was not investigated due to the small number of sightings remaining after truncation. Observer, distance and water transparency covariates were proposed for the mark-recapture model due to possible differences in sighting (capture) probabilities due to distance (as a numerical covariate), due to the window configuration for front and rear observers (as a factor covariate with two levels: bubble and flat windows) and water transparency (as a factor covariate with two levels: clear and turbid). In addition in some cases, models with a quadratic term (for distance, in the mark-recapture component only) were proposed to investigate possible non-linear detection probability functions. Model selection was performed according to the Akaike Information Criterion (AIC). Only models within 2 ΔAIC units are presented here.

Density and Abundance Estimation

$\widehat{D_u}$ (estimated density corrected for perception bias, but not for availability bias) is estimated using the Horvitz-Thompson estimator as follows (Marques and Buckland 2003):

$$\widehat{D_u} = \sum_{i=1}^{n} \frac{s_i}{\hat{p}(z_i)}$$

Where:

n – number of observations (sightings); s_i – cluster size for observation i; $\hat{p}(z_i)$ – detection probability for vector of sighting-specific covariates z.

Corrected density ($\widehat{D_c}$) was computed by multiplying $\widehat{D_u}$ by $1/\widehat{B_a}$ and abundance was calculated by multiplying $\widehat{D_c}$ by the total area of the survey region.

Variance and Confidence Interval Estimation

Variance of $\widehat{D_u}$ was estimated using the analytical estimator proposed by Innes et al. (2002) and variance of $\widehat{D_c}$ by the delta method as described in Crespo et al. (2010, p. 22). Log-normal 95% confidence intervals of $\widehat{D_c}$ were computed as suggested by Buckland et al. (2001).

RESULTS

A total of 3,615 km were surveyed (Table 2). Realized effort was greater than proposed effort because some transects were repeated when weather conditions improved and because additional transit lines were placed in areas of high density to obtain sighting data for improving estimates of detection probability. Transects in the offshore strata were only surveyed in the southern portion of the FMA 2. Offshore effort was abandoned in the remainder of the study because of consistent poor sea state and visibility conditions in these areas.

Distribution

A total of 60 franciscana groups were seen during the survey (Fig. 4), with 57 sightings observed in either transect or transit lines. Total number of individuals seen was 157 and the average group size for all sightings combined was 2.7 (SE = 0.17, range=1-6). Franciscana sightings were recorded in three main regions: between Laguna and Florianópolis, Joinville/Paranaguá, and from Peruíbe to Ubatuba (Fig. 4). No sightings were recorded in the Hiatus strata or in offshore areas (depths > 30m), where effort existed.

Abundance

Detection probability was computed (after left truncation and re-scaling of distances) using 46 sightings. The model that received more support from the data had distance and observer as a covariate in the mark-recapture (MR) component and a half normal function to fit perpendicular distance data. The second best model had water transparency as a third covariate in the MR component, the third model had water transparency as a covariate in the detection function, and the fourth was similar to the best model except that a hazard rate function was used to fit perpendicular distance data (Table 2). Plots of estimated detection probability for front, rear and both observers for the best model (#1 in Table 2) are illustrated in Fig. 5.

Table 2 – Best models (ΔAIC $\leq$ 2) for estimation of franciscana detection probability

#	Model	Number of parameters	AIC	ΔAIC	AIC weight
1	DF(hn) + MR(distance * f(observer))	5	-60.51	0.00	0.31
2	DF(hn) + MR(distance * f(observer) + f(water transparency))	6	-59.25	1.26	0.16
3	DF(hn + f(water transparency) + MR (distance*f(observer))	6	-58.69	1.81	0.12
4	DF(hr) + MR(distance * f(observer))	6	-58.64	1.87	0.12

DF – detection function model component, MR – mark recapture model component, f – factor covariate, hn – half normal model, hr – hazard rate model, AIC – Akaike Information Criterion.

Only 21 sightings were recorded in the proposed survey tracklines (i.e. excluding transit lines). Abundance was estimated from 8,000 to 9,000 franciscanas for FMA II (Table 3).

Table 3 – Parameters of the abundance estimation equation, density and abundance of franciscanas in FMA II, southeastern Brazil (Model # corresponds to models in Table 2).

Model #	Average p	CV(p)	s_i	CV(s_i)	D_u[1]	CV(D_u)	D_c[1]	CV(D_c)	N_c	CV(N_c)	95% LCL	95% UCL
1	0.696	0.21	2.43	0.13	0.102	0.34	0.362	0.34	8,525	0.34	4,434	16,390
2	0.671	0.22	2.43	0.13	0.107	0.35	0.380	0.35	8,949	0.35	4,571	17,517
3	0.695	0.22	2.43	0.13	0.100	0.34	0.355	0.34	8,289	0.34	4,334	15,850
4	0.723	0.17	2.43	0.13	0.098	0.32	0.348	0.32	8,195	0.32	4,419	15,194

p - detection probability, CV – Coefficient of variation, s_i – average cluster size, D_u – density uncorrected for availability bias, D_c – corrected density, N_c – corrected abundance estimation, LCL – lower confidence limit, UCL – upper confidence limit. [1]Density is expressed in individuals/km^2.

DISCUSSION

Distribution

Previous research on the occurrence of franciscanas in FMA II was based primarily on stranded or incidentally captured individuals, with relatively limited and often non-systematic geographic coverage of the range of the stock (e.g. Simões-Lopes and Ximinez 1993; Bertozzi and Zerbini 2002; Rosas and Monteiro-Filho 2002; Santos et al. 2002). Yet, these studies showed that franciscanas were found in almost every location where observation effort existed and therefore indicated a somehow continuous distribution. The present aerial surveys are the first to provide a large scale description of the distribution of the franciscana in FMA II (Brazilian states of Santa Catarina [SC], Paraná [PR] and São Paulo [SP]) and to cover the area known as the 'Hiatus' along northern SP and southern Rio de Janeiro (RJ) states. The distribution depicted here shows a somewhat different pattern from what was described by previous studies. A few sightings were observed in the southern range of the stock near

Laguna and again, further to the north, near Joinville and Paranaguá. More sightings were recorded in the central-northern range of the stock between Peruíbe and Ubatuba. However, two relatively large gaps in distribution were observed, one between Florianópolis and Joinville (160km) and another between Paranaguá and Peruíbe (100km) (Fig. 4). Whether such gaps represent areas where franciscanas are absent or rare requires a greater research effort. Lack of sightings in certain areas may have occurred due to a number of factors, including seasonal variation in distribution.

One of the objectives of this study was to investigate the relationship of the franciscana distribution with environmental parameters. The sample size of on-effort sightings obtained during the present surveys precludes a more quantitative analysis of the franciscana distribution pattern at this point. 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 estuarine waters with high turbidity under the influence continental runoffs. These areas are thought to concentrate juvenile fish species, the most important prey of franciscanas (e.g. Pinedo et al. 1989; Rodriguez et al. 2002). Such environmental features are typical of a few areas where franciscana were seen in this study (e.g. Joinville and Paranaguá), but not in large numbers. In fact, most sightings occurred in regions with greater water transparency, where the input of river run-offs is relatively small (e.g. Peruíbe and Ubatuba). Fewer sightings may be explained by reduced visibility in areas where water turbidity is high (low transparency). The effect of such factor in the detectability of franciscana groups was investigated in this study. Detection probability models with water turbidity as covariate ranked relatively high among the best models (Models 2 and 3 in Table 2), indicating that water transparency plays an important role in detecting franciscanas from aerial surveys.

Abundance

This is the first study to cover the full latitudinal range of the franciscana in FMA II. Numbers provided here suggest that from 8,000 to 9,000 franciscanas inhabit this management area between the coastline and the 30m isobaths. There is currently no evidence that franciscanas occur in deeper waters in FMA II. No individual was seen in the few transect lines surveyed in the 30-50m depth range during the present surveys and information from bycatch of franciscana dolphins throughout FMA II show that all captures reported to date occurred in waters shallower than 30m (e.g. Bertozzi and Zerbini 2002; Rosas and Monteiro-Filho 2002). However, it is not possible to rule out that some individuals may occur in waters deeper than 30m because survey effort is still small in more offshore areas and because the species is present up to about the 50m isobaths in other FMAs (Corcuera et al. 1994; Secchi et al. 1997; Crespo et al. 2010).

There was only one previous estimate of abundance for franciscanas in FMA II from a boat survey conducted in Babitonga Bay (SC) (N = 50, CV = 030, 95% CI = 28-89, Cremer and Simões-Lopes, 2008). This bay, with an area of 160km^2, is located near Joinville (Fig. 4) and corresponds only to 0.6% of the area covered in the present aerial survey. Assuming dolphins inside and outside of the bay correspond to the same population, the estimate by Cremer and Simões-Lopes (2008) corresponds to a small fraction of the total population in FMA II.

Point estimates of density presented in this study are comparable to those obtained for Babitonga Bay (FMA II, Cremer and Simões-Lopes, 2008) and for Argentina (FMA IV, Crespo et al. 2010), but are lower than those for Rio Grande do Sul (FMA III, Secchi et al. 2001 and Danilewicz et al. in press) (Table 4). However, widely overlapping confidence intervals indicate that all existing estimates are not statistically different (Table 4).

Table 4 – Density estimates for franciscanas throughout the species range.

Location	Year	Density (ind/km^2)	95% CI (Density)	Observations and source
Rio Grande do Sul, Southern Brazil (FMA III)	1996	0.651	0.516-0.836	Aerial survey, Secchi et al. (2001)
Rio Grande do Sul, Southern Brazil (FMA III)	2004	0.510	0.278-0.944	Aerial survey, Danilewicz et al. (in press)
Babitonga Bay, SC (FMA II)	2001-2003	0.318	0.178-0.570	Boat survey, Cremer and Simões-Lopes (2008)
Argentina coastal waters (FMA IV)	2003-2004	0.377	0.223-0.636	Aerial survey, northern stratum to depths of up to 30m, Crespo et al. (2010)
Present study (FMA II)	2008-2009	0.348	0.188-0.641	Lower and higher values on Table 3 above
		0.362	0.189-0.692	

In addition, and perhaps more important, interpretation of potential differences/similarities in density across areas/studies must be done cautiously because of comparability issues (methodological differences across the surveys) and timing of the studies. Previous franciscana abundance surveys did not account for perception bias in their estimates of density or were conducted under an unbiased survey design that sampled the whole range of the stock of interest. Therefore bias may have been introduced into the estimates due to lack of correction for animals missed by observers or due to uneven coverage probability, making density estimate comparisons difficult. In addition, because of high, possibly unsustainable, levels of bycatch for some populations, comparison of density estimates far apart in time (e.g. the one in the present study with that of FMA III, Secchi et al. 2001) are not appropriate. Finally, average within-FMA densities may vary due to possible differences in density across various habitats within the range of the stocks, a factor that could also influence comparison of density estimates across different FMAs.

Conservation Implications

Bycatch is currently the main conservation problem for the franciscana throughout its range (e.g. Secchi et al. 2003a and b). The annual fishery-related mortality of the species in FMA II is not well understood because of difficulties in monitoring the fisheries. In this region, most of the coastal (within the range of the franciscana) fisheries is carried out from small boats operating for more than 150 fishing villages distributed along the coast (Tiago et al. 1995; Zanelatto 1997; Bertozzi and Zerbini 2002; Rosas et al. 2002). The characteristics of these fishing communities suggest that the fishing grounds are restricted to small geographic areas, probably extending to a few dozen miles away from the landing. In addition, there is a wide range of fishing gear and a substantial variability in the fishing season and effort for each net type across villages (Bertozzi and Zerbini 2002). Therefore, comprehensive monitoring of franciscana bycatch in FMA II requires substantial effort and financial resources. Despite these difficulties, however, rough estimates of bycatch within the past decade have suggested an annual mortality of 300-500 franciscanas in this management area (Ott et al. 2002; IWC 2005, Bertozzi, unpublished data).

Assuming that the abundance estimates provided above are accurate (see discussion below for possible sources of bias and improvements in survey design and estimation procedures), the estimated incidental mortality of franciscanas in FMA II corresponds to 3.3 to 6.2% of the estimated stock size, numbers that are largely considered unsustainable for small cetacean populations (Wade 1998) and the franciscana in particular (e.g. Secchi et al. 2001; Crespo et al. 2010).

In addition to bycatch, habitat degradation in the form of increasing vessel traffic, underwater noise, chemical pollution from coastal development, and industrial and human waste discharge are likely a major source of impact to the population in FMA II. This is particularly relevant here for at least two reasons. First, habitat available for the franciscana in FMA II is much more limited than that of other populations. For example, the area within the coast line and the 30m isobaths (possibly the typical habitat for the franciscana, Pinedo et al. 1989) in FMA II (23,500 km^2) corresponds to only 36% and 45% of the same habitat available for franciscanas in FMA III and IV, respectively (e.g. Secchi et al. 2001; Crespo et al. 2010). Therefore, impact from degradation may affect the FMA II population in a more significant way due to its more restricted habitat. Second, this management area corresponds to the most industrialized area and one with the longest history of degradation along the coast of Brazil. The potential effects of habitat loss to the FMA II franciscana are poorly understood, but may be highly significant for the conservation of this population in the years to come. This is important because the oil and gas exploration industry is expanding its activities towards the Santos Basin, an area with important oil reserves located at the outer continental shelf and slope off the southeastern coast of Brazil. While the areas of oil exploration (oil fields) do not overlap with the range of the franciscana, it is expected that development of activities related to this industry will substantially increase boat traffic (and boat noise) in the franciscana habitat as ships move between the coast and the oil platforms located offshore. In addition, the expansion of the oil industry is triggering coastal development (e.g. construction of new ports, establishment of new industries and increasing human population in coastal areas) with potential major negative effects to the ecosystem to which franciscanas are a part of. Monitoring the impact of these activities to the FMA II franciscana is not trivial, but essential to understand the long-term viability of this population.

Possible Sources of Bias in Density/Abundance Estimation

A number of factors may influence data collection and analysis in aerial survey, often resulting in biased estimates of density/abundance. The main factors affecting the estimates presented in this study and their possible implications to the estimates are discussed below.

Geographical Survey Coverage

The estimates presented here only account for the area within the coastline and the 30m isobaths (the proposed inshore stratum) because this was the only area appropriately sampled during the survey. Only a few transects were flown in the southern portion of the offshore stratum (Fig 2), but no sightings were recorded. If franciscanas occur beyond the 30m isobaths, lack of coverage in the offshore stratum will result in an underestimation of abundance of the FMA II stock because a proportion of the population will remain unsampled. The magnitude of this bias will remain unknown until proper sampling is conducted. In other FMAs, it has been observed that density further offshore is much lower than in waters shallower than 30m (e.g. Crespo et al. 2010).

Estimation of Mean Group Size

Like for most small cetacean aerial surveys (e.g. Dahlheim et al. 2000; Slooten et al. 2004), the estimation of group size from an aircraft has been pointed out as an important source of downwards bias in franciscana abundance due to the difficulties in seeing and accurately counting individuals of this species from an airplane (Secchi et al. 2001; Danilewicz et al. in press). Previous studies have shown that franciscana group sizes estimated from still or slow-moving platforms are typically larger than those estimated from the air. Bordino et al. (1999) estimated an average of 2.8 franciscanas/group in Anegada Bay, Argentina, from shore- or boat-based surveys. A recent aerial survey carried out off Argentina, which included the area of Anegada Bay, resulted in average groups sizes that are nearly half (1.43 individuals/group; Crespo et al. 2010) of those from Bordino et al. (1999), suggesting that abundance estimates from aerial surveys in Argentina may be underestimated by about 50% if land/boat-based estimates of group size are accurate.

The magnitude of the bias caused due to underestimation of group sizes could be even greater in FMA II if group size estimates from boat and aerial surveys in Babitonga Bay are assumed as representative samples of the whole population. For example, Cremer and Simões-Lopes (2008) estimated that groups of franciscanas seen from boats in this area had 5 individuals on average (SE = 0.59, n = 38, range = 1-13). This is four times greater than the average size of groups seen in the Bay from the aerial surveys reported here (mean = 1.25 dolphins/group, SE = 0.16, n = 4, range = 1-2). It must be pointed out, however, that water turbidity both in Anegada and Babitonga Bay is high, which makes estimation of group sizes more difficult from the air. If water transparency is greater, such as in some of the areas where franciscanas were seen in this study, bias in estimation of group size may be lower.

Accounting for Visibility Bias

Visibility bias (availability and perception bias) typically causes downward bias in estimates of abundance from aerial surveys (Laake et al. 1997; Buckland et al. 2004). While previous franciscana abundance estimates using airplanes as the sampling platform incorporated availability bias (Secchi et al. 2001; Crespo et al. 2010; Danilewicz et al. in press), no attempts have been made to data to estimate the proportion of animals that were available at the surface but were missed by the observers. The importance of determining this quantity and their potential effects on estimates of abundance was illustrated by Laake et al. (1997) in an experiment conducted with harbor porpoises. These authors estimated that nearly 15% and 75% of the groups available to be detected at the surface were missed by experienced and inexperienced observers, respectively.

In this study, perception bias was estimated with mark-recapture methods from sightings collected by two independent teams of observers on the aircraft. It was estimated that nearly 27-33% of franciscanas were missed by the observers (average p = 0.67-0.72, Table 2). This is likely an overestimation because the methods used to estimate perception bias rely on sightings recorded by either or both teams of observers. However, some proportion of franciscana groups may not have been detected by either team and therefore are not accounted for in the analysis.

In this study, no attempts were made to estimate availability bias ($\widehat{B_a}$), primarily because information on diving parameters (time at surface and dive duration) have never been reported for franciscanas in FMA II. Instead, $\widehat{B_a}$ was taken from another franciscana aerial survey (Crespo et al. 2010) and assumed to apply for the present study. Crespo et al. (2010) computed this quantity using the model proposed by Barlow et al. (1988), which accounts for the surface time, dive duration and time a group of dolphins within the field of view of observers in an airplane. Diving parameters were used from studies conducted in Anegada Bay (Bordino et al. 1999 and subsequent unpublished data) and the time available for detection was computed assuming dolphins were within a field of view of 292m for an aircraft flying at 160km/h. The latter were consistent with the field of view and flying speed of the plane used in the present study.

The assumption that the $\widehat{B_a}$ computed by Crespo et al. (2010) applies to the FMA II study can also lead to biases. For example, the diving parameters (time at surface and dive duration) used by Crespo et al. (2010) were obtained from a population in Argentina and are not necessarily applicable to populations elsewhere along the range of the species. In addition, these authors used the average dive duration to compute availability bias. The average may not be the most representative quantity here because the distribution of dive duration for franciscanas is dramatically skewed (see Bordino et al. [1999] for the characteristics of the data and Danilewicz et al. [in press] for a more detailed discussion on the implications of this issue to franciscana abundance estimates). These diving parameters were obtained from visual surveys from shore of from a boat and the availability of dolphins for observer located in such “platforms” is different from those on a plane. Because franciscana dolphins may be available to an observer on an airplane before it surfaces, especially if the visibility conditions through the water are good, it is likely that time at surface and diving time are different (e.g. longer time at surface and shorter diving time) in aerial surveys relative to boat/shore-based surveys (e.g. Danilewicz et al. in press). Because diving parameters for franciscanas in FMA II are not known, it is not possible to assess what would be the direction of the bias in the abundance estimates presented here because of the use of the estimated availability bias with diving data from Argentina.

Clearly, the development of improved estimates of $\widehat{B_a}$ is required in order to increase accuracy in estimates of franciscana abundance. Methods typically used to estimate availability bias (*e.g.* Barlow, 1988) only take into account the diving parameters of the animals and the amount of time a group is available to the observer (within viewing range from the aircraft window). However, availability bias may also be affected by a number of other factors including distance from the airplane, group size, sea conditions (e.g. Beaufort scale), water transparency, water depth, cloud cover and behavior of both the animals and the observers while searching. Therefore, it would be valuable to develop methods to estimate $\widehat{B_a}$ that took these factors into consideration.

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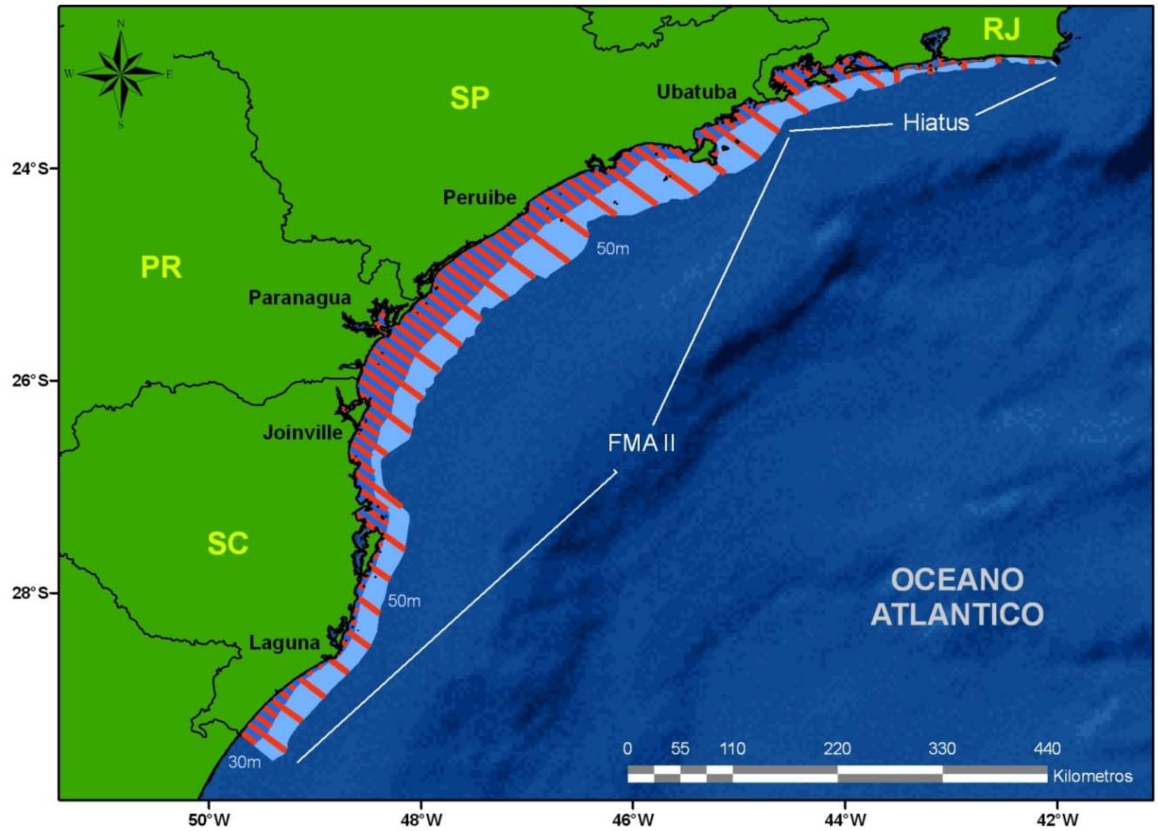


Fig. 1 – Proposed survey effort (red lines) for franciscana aerial survey in FMA II and Hiatus sampling areas (southeastern Brazil). Dark and light blue areas correspond to inshore and offshore strata. SC = Santa Catarina State, PR = Paraná State, SP = São Paulo State and RJ = Rio de Janeiro State.

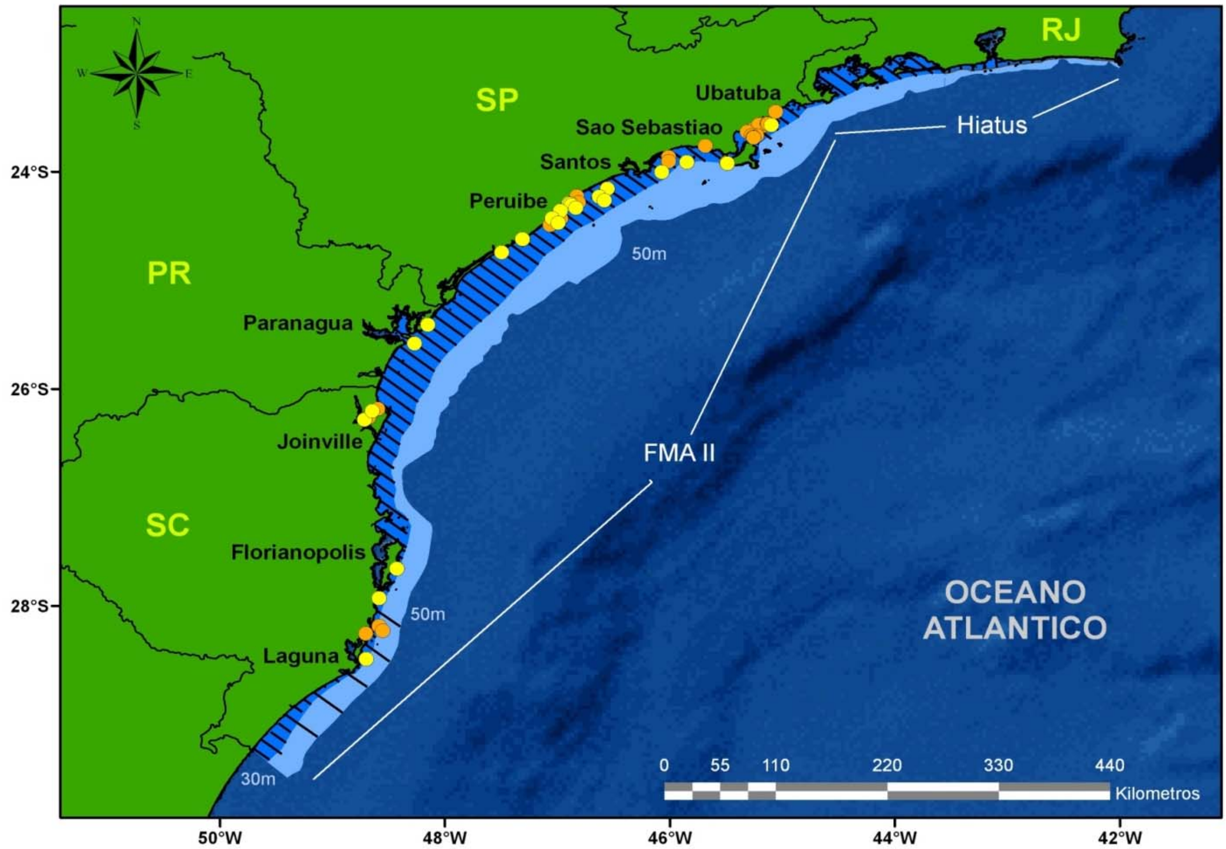
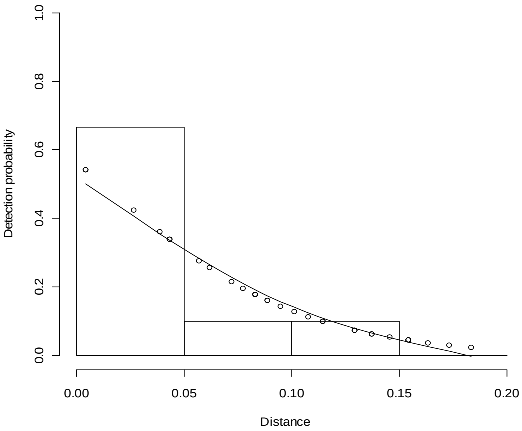
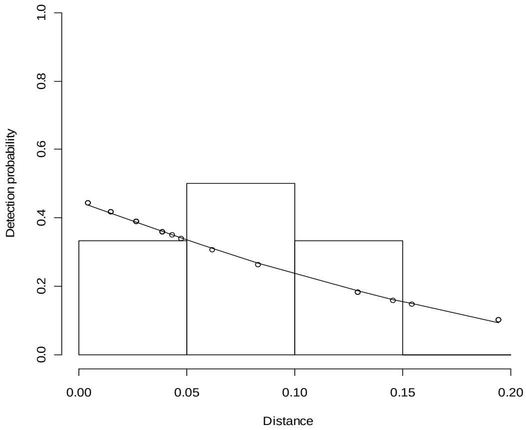


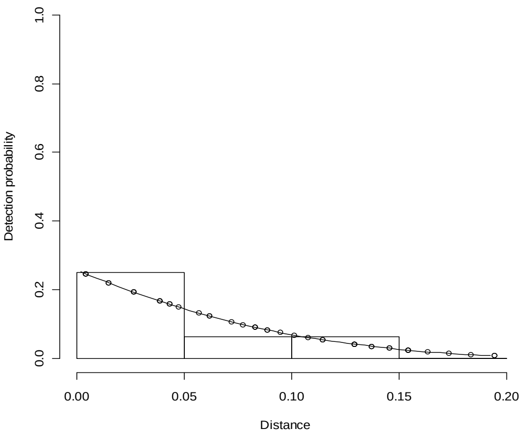
Fig. 2 – Realized effort (black lines) and franciscana sightings (in transect lines = yellow dots, in transit lines = orange dots) in FMA II and Hiatus sampling areas (southeastern Brazil). Dark and light blue areas correspond to inshore and offshore strata. SC = Santa Catarina State, PR = Paraná State, SP = São Paulo State and RJ = Rio de Janeiro State. Sightings that appear on land (near Joinville) have been recorded inside an estuary (Babitonga Bay) where franciscanas are known to commonly occur.



Front observer | Rear observer



Rear observer | Front observer



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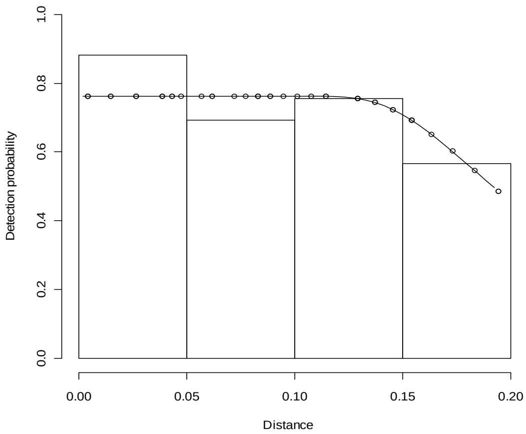
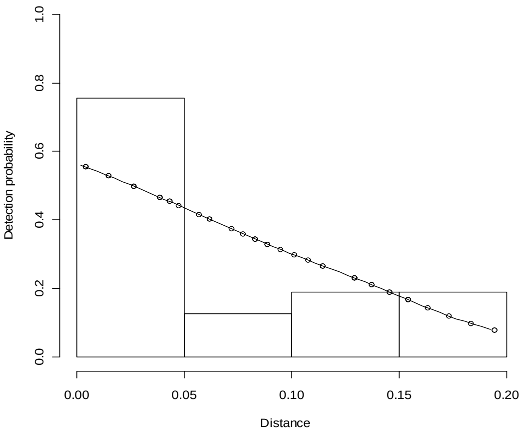


All observers



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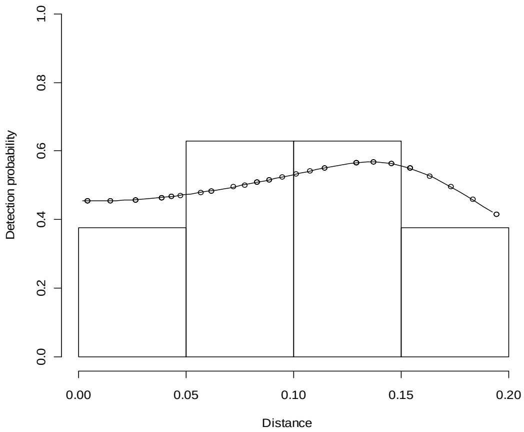

Rear observer

Fig. 3 – Detection probability plots for Model #1 in Table 2 (line = average detection functions, dots = detection probability for each individual sighting).