UNIVERSIDADE FEDERAL DE JUIZ DE FORA

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA APLICADA AO MANEJO E CONSERVAÇÃO DE RECURSOS NATURAIS

FEDERICO SUCUNZA PEREZ

Aerial surveys for abundance and distribution assessment of the threatened franciscana (Pontoporia blainvillei)

JUIZ DE FORA

2019

FEDERICO SUCUNZA PEREZ

Aerial surveys for abundance and distribution assessment of the threatened franciscana (*Pontoporia blainvillei*)

Tese apresentada ao Programa de Pós-Graduação em Ecologia Aplicada ao Manejo e Conservação de Recursos Naturais da Universidade Federal de Juiz de Fora, como parte dos requisitos necessários à obtenção do grau de Doutor em Ecologia.

Orientador: Alexandre Novaes Zerbini

Co-orientador: Daniel Danilewicz Schiavon

JUIZ DE FORA

2019

Ficha catalográfica elaborada através do programa de geração
automática da Biblioteca Universitária da UFJF,
com os dados fornecidos pelo(a) autor(a)

Sucunza Perez, Federico.
Aerial surveys for abundance and distribution assessment of the threatened franciscana (Pontoporia blainvillei) / Federico Sucunza Perez. -- 2019.
124 f. : il.

Orientador: Alexandre Novaes Zerbini
Coorientador: Daniel Danilewicz Schiavon
Tese (doutorado) - Universidade Federal de Juiz de Fora, Instituto de Ciências Biológicas. Programa de Pós-Graduação em Ecologia, 2019.

1. Abundância. 2. Conservação. 3. Distribuição. 4. Levantamento aéreo. 5. Toninhas. I. Novaes Zerbini, Alexandre , orient. II. Danilewicz Schiavon, Daniel , coorient. III. Título.

"*AERIAL SURVEYS FOR ABUNDANCE AND DISTRIBUTION ASSESSMENT OF THE THREATENED FRANCISCANA (PONTOPORIA BLAINVILLEI)*"

Federico Sucunza Perez

Orientador: Prof. Dr. Alexandre Novais Zerbini

Tese apresentada ao Instituto de Ciências Biológicas, da Universidade Federal de Juiz de Fora, como parte dos requisitos para obtenção do Título de Doutor em Ecologia Aplicada ao Manejo e Conservação de Recursos Naturais.

Aprovado em 18 de novembro de 2019.

Prof. Dr. Alexandre Novais Zerbini
Instituto Aqualie

Prof. Dr. Daniel Danilewicz
Universidade Estadual de Santa Cruz - UESC

Prof. Dr. Paul Gerard Kinas
Universidade Federal do Rio Grande - FURG

Prof. Dr. Leonardo Liberali Wedekin
Socieambiental Consultores Associados

Profa. Dra. Franciele Rezende de Castro
Universidade Federal de Juiz de Fora - UFJF

Prof. Dr. André Guaraldo
Universidade Federal de Juiz de Fora - UFJF

Dedico este trabalho aos meus pais e ao meu irmão.

AGRADECIMENTOS

A todas as pessoas que iluminaram o meu caminho ao longo desta importante jornada de altos e baixos, tristeza e alegria, aprendizado e muito aprendizado!

RESUMO

A perda do habitat e a sobre-explotação dos recursos naturais estão entre os principais fatores associados às elevadas taxas de alteração da biodiversidade global. Compreender os efeitos das atividades humanas – e suas sinergia – sobre as diferentes espécies é um desafio, que depende da disponibilidade de informações robustas. A conservação da toninha, *Pontoporia blainvillei*, é vulnerável à captura incidental em redes de pesca, sendo a espécie considerada um dos cetáceos mais ameaçados de extinção no oceano Atlântico Sul. Obter informações robustas sobre abundância é fundamental para avaliar a viabilidade populacional da toninha ao longo de toda sua distribuição. A presente tese de doutorado visou computar e aplicar fatores de correção específicos para estimativas de abundância de toninha a partir de dados provenientes de levantamentos aéreos. Levantamentos aéreos foram realizados nas regiões Sudeste e Sul do Brasil, amostrando toda a área de ocorrência da espécie na nova área proposta para a FMA II e o hiato sul da distribuição (Florianópolis, SC - Cabo Frio, RJ), além de toda a área de ocorrência na área proposta para a FMA Ia e o hiato norte (Barra de Itabapoana e Itaúnas, ES). Os resultados corroboram estudos pretéritos e indicam que plataformas aéreas apresentam alta eficácia para realizar estimativas populacionais da espécie, contudo, caso não corrigidas, tais estimativas podem ser subestimadas em até ~5 vezes. O viés de disponibilidade (não detecção de indivíduos submersos) foi o principal viés estimado. A partir do uso dos métodos de MRDS e de experimentos simultâneos realizados utilizando um avião e duas embarcações, estimou-se que observadores perdem ~20% dos grupos de toninha disponíveis para detecção (viés de percepção). Contudo, experimentos conduzidos em helicópteros indicaram que ~60% dos grupos de toninha não são detectados em função do viés de disponibilidade, corroborando estudos realizados com outras espécies. A subestimativa do número total de indivíduos em um grupo representou ~30% do viés total em estimativas aéreas. A alta velocidade do avião associada a disponibilidade diferenciada entre indivíduos em um mesmo grupo representam os principais fatores de viés. Estimativas de abundância geradas para a FMA II ($\widehat{N}$ = 6.827, CV = 0,28), e para as novas propostas de subdivisões da população (FMA IIa - $\widehat{N}$ = 1.915, CV = 0,32, e FMA IIb - $\widehat{N}$ = 4.353, CV = 0,24), indicam que a captura incidental em redes de emalhe é insustentável. A FMA II é uma das regiões com maior ocupação da faixa de costa ao longo de toda a distribuição da toninha o que agrava o estado de conservação dessa FMA. A população do extremo norte da distribuição da espécie, FMA Ia ($\widehat{N}$ = 893, CV = 0,30), apresenta potencial isolamento demográfico das demais populações, sendo proposta a classificação "em perigo" segundo a *IUCN Red List Categories and Criteria*. Refinamentos nos fatores de correção aqui apresentados e a utilização de outras técnicas de amostragem (*e.g.* acústica), devem ser estimulados para maximizar o monitoramento da toninha. Adicionalmente, a implementação de ações de conservação concomitante ao monitoramento sistemático da abundância e distribuição da toninha é encorajada.

Palavras-chave: abundância, conservação, distribuição, levantamento aéreo, toninhas.

ABSTRACT

Habitat loss and overexploitation are among the primary causes of contemporary high levels of biodiversity loss. Understanding and predicting the multiple effects of human activities on species extinction are challenging tasks that highly depend on robust data on population numbers. Mortality due to bycatch represents the primary driver of franciscana (*Pontoporia blainvillei*) population reduction. The species is listed as "Critically Endangered" in Brazil, and "Vulnerable" in the IUCN Red List of Threatened Species. Estimating the abundance of the franciscana has been recommended as priority by local and international organizations. The present thesis aimed to develop and implement correction factors for estimating abundance of franciscanas from aerial surveys. Surveys were conducted along the southern and southeastern Brazilian coast, covering the latitudinal range, from the coast up to the 30 m isobath, of the new limits proposed for FMA II and the southern gap in distribution of the franciscana (Florianópolis, SC - Cabo Frio, RJ) as well as the latitudinal range, from the coast up to the 20 m isobath, of the FMA Ia population and the northern distribibitional gap (Barra de Itabapoana - Itaúnas, ES). These results corroborate previous studies and indicate that aerial surveys are highly effective to record data on groups' occurrence and total number of individuals; however, if not accounted for visibility and group size bias, abundance estimates can be underestimated by up to ~5 times. Visibility bias (imperfect counts of submerged individuals) is the main factor affecting abundance estimates of franciscanas from aerial survey data. MRDS methods and experiments with concomitant surveys from aerial- and surface-based platforms indicated that observers typically misperceive ~20% of the available franciscana groups (perception bias). Experiments conducted from a helicopter showed that ~60% of the groups will not be available to be counted during a passing mode aerial survey. Bias in group size estimates represents ~30% of the total bias in abundance estimates from aerial surveys. The high speed of the aircraft associated with the differential availability between individuals within the same group are the main factors to affect group size estimates. The abundance estimated for the whole FMA II ($\widehat{N}$ = 6,827, CV = 0.28) as well as to the new proposed subdivisions FMA IIa ($\widehat{N}$ = 1,915, CV = 0.32) and FMA IIb ($\widehat{N}$ = 4,353, CV = 0.24) indicates that mortality due to bycatch is unsustainable. The coastline of FMA II corresponds to one of the most developed and populated region along the species range and therefore a threat to franciscana conservation. The northernmost franciscana population FMA Ia ($\widehat{N}$ = 893, CV = 0.30) is potentially demographically isolated from all franciscana populations. It is proposed that franciscanas in FMA Ia qualify for listing as “Endangered” under the IUCN Red List Categories and Criteria.

Improvements in correction factors for aerial surveys and the use of other sample methods (*e.g.* acoustic methods) should be conducted and integrated analysis performed. In addition, it is encouraged that conservation plans for the franciscana be implemented, along with an abundance and distribution assessment.

Keywords: abundance, conservation, distribution, aerial survey, franciscanas.

LISTA DE ILUSTRAÇÕES

LISTA DE TABELAS

SUMÁRIO

1 CAPÍTULO I – INTRODUÇÃO

A bidiversidade global vem sendo alterada a uma taxa sem precedentes na história do planeta (Pimm et al. 1995). A perda de habitat e a sobre-explotação dos recursos naturais estão entre os principais fatores relacionados a extinção atual de espécies (Pimm et al. 1995, Sala et al. 2000, Reeves et al. 2003, Meyer et al. 2007, Brook et al. 2008). Contudo, quantificar a magnitude do impacto das atividades humanas, compreender o efeito sinérgico entre diferentes ameaças e estimar o tempo até a extinção das espécies representam grandes desafios para os conservacionistas (Wade 1998, Broock et al. 2008). Espécies ameaçadas são geralmente raras de serem encontradas na natureza e, portanto, estimativas de abundância apresentam baixa precisão, o que torna ainda mais difícil interpretar variações temporais no tamanho populacional (Gerrodette 1987, Wade & Gerrodette 1992, Taylor & Gerrodette 1993 Taylor et al. 2000).

Baleias, botos e golfinhos formam o grupo dos cetáceos (Ordem Cetartiodactyla) que compreende 89 espécies viventes, sendo uma, o Baiji (*Lipotes vexilifer*) possivelmente extinta (Turvey et al. 2007, Committee on Taxonomy 2018). Os cetáceos são mamíferos exclusivamente aquáticos, apresentam alta diversidade de formas e ocorrem em todos as bacias oceânicas, em regiões costeiras e marinhas tropicais, temperadas e polares e em rios e regiões estuarinas (Perrin 1991, Forcada 2009). Essa ampla distribuição torna as populações de cetáceos vulneráveis globalmente a uma gama de atividades humanas, incluindo impactos diretos como a caça e as colisões com embarcações, e indiretos como a degradação do habitat pela ocupação humana, pela poluição química e acústica (Harwood 2001, Gales et al. 2003, Reeves et al. 2003, Slooten et al. 2013). Atualmente, a captura incidental durante atividades de pesca é reconhecida como o principal fator responsável pela redução da maioria das populações de cetáceos em todos os ambientes que o grupo ocorre (Perrin et al. 1994, Read et al. 2006, Read 2008, Reeves et al. 2013). Estima-se que pelo menos 300 mil cetáceos são mortos anualmente em virtude da captura incidental, sendo esta a principal razão apontada para a potencial extinção de uma espécie além de outras que estão seguindo o mesmo caminho (Perrin et al. 1994, Kinas 2002, Read et al. 2006, Slooten et al. 2006, Turvey et al. 2007, Read 2008, Reeves et al. 2013, Taylor et al. 2016). Obter estimativas robustas de abundância é fundamental para avaliar o estado de conservação das populações e/ou espécies de cetáceos e contribuir com a implementação de planos de manejo adequados (Taylor & Gerrodette 1993, Williams 2001).

Plataformas aéreas representam uma ferramenta eficaz para realizar levantamentos populacionais, uma vez que permite amostrar áreas de grande extensão em um curto espaço de tempo (e.g. Andriolo et al., 2010, Crespo et al. 2010, McLellan et al. 2018). A amostragem de distâncias ("Distance Sampling") (Buckland et al. 2001) é um dos métodos mais utilizados para se estimar o tamanho populacional de mamíferos aquáticos (e.g. Barlow et al. 1989, Southwell et al. 2008, Andriolo et al., 2010, Crespo et al. 2010, Stapleton et al. 2014). Na amostragem de distâncias por transecções lineares, tipicamente, um observador percorre uma região retangular de largura $2w$ e comprimento L contendo n animais (ou grupo de animais) e registra a distância perpendicular x para cada animal detectado (Buckland et al. 2001) (Figura 1). A partir da frequência das distâncias registradas, estima-se a probabilidade de detectar um grupo (Pa) dado que o mesmo esteja dentro da área de amostragem ($a = 2w*L$). Assim, o número de grupos em uma determinada área total (assumindo A = a) pode ser estimado a partir da razão entre o número de grupos detectados e a probabilidade de detecção (Pa). O número total de indivíduos é igual ao produto entre o número estimado de grupos e o tamanho médio de grupo (Buckland et al. 2001, Thomas et al. 2010).

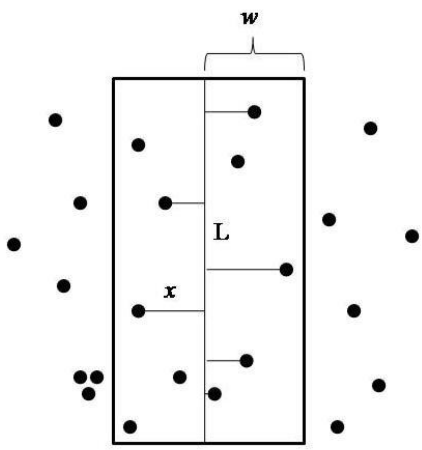

Figura 1. Retângulo amostral de largura $2w$ e comprimento L percorrido por observador ao longo de uma transecção linear para registrar a distância perpendicular x de cada objeto (●) detectado. Fonte: Elaborado pelo autor (2019).

Para tornar essa medida absoluta, a metodologia de transectos lineares tem como uma de suas premissas que todos os indivíduos que estejam no ou próximo do transecto serão detectados ($g(0) = 1$) (Buckland et al. 2001). Contudo, uma vez que os cetáceos passam períodos longos submersos e, assim, indisponíveis para serem detectados, frequentemente as amostragens visuais de cetáceos apresentam $g(0) < 1$ (Hiby & Hammond, 1989, Laake et al. 1997, Barlow 2015, Sucunza et al. 2018). Esta falha na detectabilidade é potencialmente agravada durante levantamentos aéreos devido à alta velocidade das aeronaves (Hiby & Hammond 1989, Buckland et al. 2001). Em tais situações, pressupor que $g(0) = 1$ causa a subestimativa da abundância de indivíduos. O grau em que os métodos de amostragem de distâncias subestimam a abundância de indivíduos, quando a detecção na linha de transecção não é certa ($g(0) < 1$), é diretamente proporcional ao valor real de $g(0)$ (Laake & Borchers 2004). Por exemplo, Laake et al. (1997) estimaram $g(0) = 0{,}29$ para observadores experientes e $g(0) = 0{,}08$ para observadores inexperientes em levantamento aéreo com o boto comum (*Phocoena phocoena*) na região do Puget Sound, Estado de Washington, EUA. Ou seja, para corrigir uma estimativa de abundância cujo $g(0) = 0{,}29$ seria preciso multiplicar a abundância não corrigida por 3,45 (=1/0,29).

Marsh & Sinclair (1989) propuseram o termo viés de visibilidade para descrever as duas formas de perda de indivíduos que estejam na linha ou próximos do transecto ($g(0) < 1$): i) viés de disponibilidade, se refere aos indivíduos que, durante a passagem do observador, estão submersos ou encobertos e, assim, não estão disponíveis para detecção; e ii) viés de percepção, se refere aos indivíduos que estão disponíveis para detecção, mas não são detectados por falha do observador. Diversos métodos são propostos para lidar com o viés de percepção a partir de dados registrados por diferentes observadores em uma mesma plataforma de observação (Alpizar-jara & Pollock 1996, Hiby 1999, Laake & Borchers 2004, Borchers et al. 2006, Pollock et al. 2006). Contudo, para estimar o viés de disponibilidade geralmente é necessário o registro de informações adicionais (*e.g.*, Barlow et al. 1988, Laake et al. 1997, Pollock et al. 2006, Sucunza et al. 2018).

Contabilizar o número total de indivíduos em um grupo de cetáceos é particularmente difícil, uma vez que alguns indivíduos permanecem indisponíveis para serem contados enquanto outros estão disponíveis (Gerrodette et al. 2018, Boyd et al. 2019). A distância entre o observador e o grupo registrado assim como o tempo que o grupo permanece disponível no campo de busca do observador irão influenciar as estimativas do tamanho do grupo, as quais são geralmente imprecisas e subestimadas (Gerrodette et al. 2018, Boyd et al. 2019). Estimativas imprecisas e subestimadas do tamanho de grupo, causam a subestimativa da abundância de indivíduos e reduz a precisão associada a essa estimativa (Gerrodette et al. 2018).

A mesma razão que tornam os levantamento aéreo atrativos ao possibilitar amostrar extensas áreas em curto espaço de tempo, ou seja a alta velocidade das plataformas aéreas, torna o registro de dados a partir dessas plataformas propenso ao viés de visibilidade e ao viés de tamanho de grupo. Assim, identificar os fatores e quantificar os seus efeitos em estimativas de abundância a partir de dados de levantamentos aéreos é fundamental para obter estimativas robustas do tamanho populacional dos cetáceos, assim como, melhor compreender o estado de conservação das diversas espécies que compõem o grupo.

A toninha (*Pontoporia blainvillei*) (Gervais & d'Orbigny, 1844) (Figura 2) é a única espécie atual da Família Pontoporiidae (Mammalia: Cetartiodactyla) (Committee on Taxonomy 2018). A espécie é endêmica do oceano Atlântico Sul ocidental, ocorrendo entre Itaúnas (18º 25'S), no Espírito Santo "ES" (Brasil) e o Golfo Nuevo (42º 35'S), na Província de Chubut (Argentina) (Siciliano 1994, Crespo et al. 1998) (Figura 3). A toninha apresenta uma distribuição descontínua ao longo da costa brasileira, existindo duas áreas onde a espécie não tem sido observada. Um desses hiatos situa-se entre Ilha Grande (22º 56'S, região sul do Rio de Janeiro – RJ) e Macaé (22º 25'S, região centro do RJ), e o outro entre a Barra de Itabapoana e Santa Cruz (21º 18'S e 19º 58'S, região sul do ES) (Siciliano et al. 2002, Danilewicz et al. 2012).

Figura 2: Toninha (*Pontoporia blainvillei*), grupo com quatro indivíduos, incluindo um filhote. Fonte: Elaborado pelo autor (2016).

A toninha ocorre preferencialmente em regiões estuarinas e costeiras até os 30 m de profundidade (Pinedo et al. 1989, Cremer & Simões-Lopes 2005, Danilewicz et al. 2009), embora existam regiões onde a presença da espécie em águas além dos 50 m de profundidade foi observada (Ferreira et al. 2010, obs. pessoal do autor). Grupos de toninha podem variar entre 1 e 13 indivíduos (Bordino et al. 1999, Cremer & Simões-Lopes 2008). Contudo, devido à grande dificuldade em observar a espécie no ambiente natural, informações a respeito da sua ecologia são escassas (Bordino et al. 1999, Crespo 2009).

A existência de subpopulações ao longo da distribuição da toninha é indicada em diversos estudos envolvendo análises da morfologia, história de vida, ecologia trófica, distribuição e genética (Pinedo 1995, Secchi et al. 1998, Ramos et al. 2002, Danilewicz 2003, Lázaro et al. 2004, Mendez et al. 2010, Barbato et al. 2012, Costa-Urrutia et al. 2012, Danilewicz et al. 2012, Cunha et al. 2014). Contudo, ainda não existe um consenso sobre quais seriam os limites entre algumas dessas distintas populações e mesmo qual seria o número total de populações (IWC 2005, Anonymous 2015). Atualmente, é aceita a existência de duas Unidades Evolutivas Significativas, uma que agrupa todos os animais ao sul do RJ e outra que agrupa os indivíduos do norte do RJ e norte do ES (Cunha et al. 2014, Anonymous 2015).

Com o objetivo de ordenar o manejo das atividades humanas com potencial impacto sobre a toninha, quatro áreas de manejo ("Franciscana Management Areas" – FMAs) foram propostas ao longo da distribuição da espécie: FMA I – inclui o ES e o norte do RJ, FMA II – inclui o sul do RJ, São Paulo (SP), Paraná (PR) e o norte de Santa Catarina (SC), FMA III – o sul de SC, o Rio Grande do Sul (RS, Brasil) e o Uruguai, FMA IV – Argentina (Secchi et al. 2003a). Análises genéticas mais recentes indicaram a existência de subestrutura populacional em escalas geográficas menores e propuseram uma subdivisão das FMAs como melhor estratégia de conservação para a espécie (Figura 3) (Mendez et al. 2010, Costa-Urrutia et al. 2012, Cunha et al. 2014).

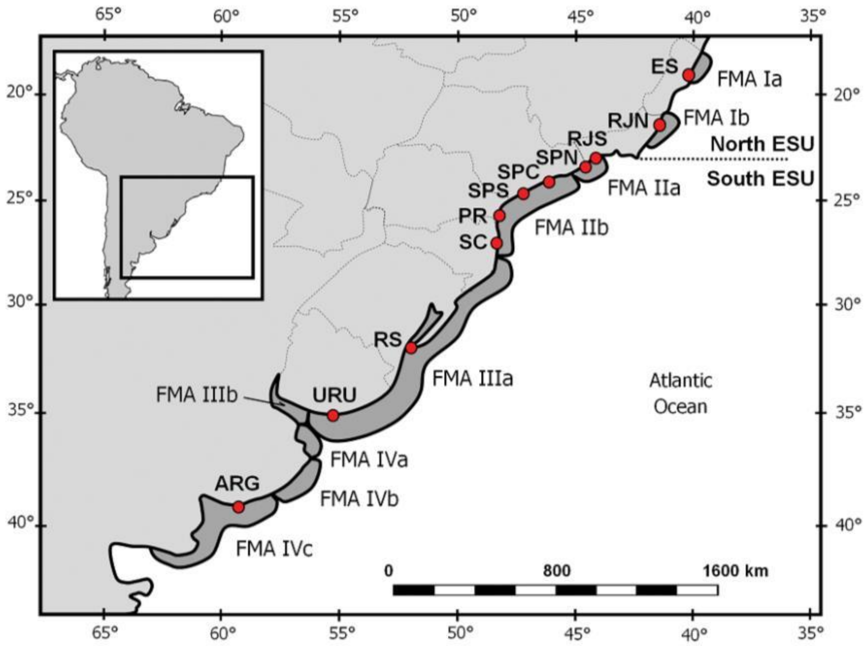

Figura 3. Nova proposta de subdivisão das áreas de manejo da toninha (*Pontoporia blainvillei*): FMA Ia (Espírito Santo) e FMA Ib (norte do Rio de Janeiro), FMA IIa (sul do Rio de Janeiro – norte de São Paulo) e FMA IIb (centro de São Paulo – centro de Santa Catarina), FMA IIIa (centro de Santa Catarina – Uruguai) e FMA IIIb (Rio da Prata), e FMA IVa, IVb e IVc (Argentina). Fonte: Cunha et al. (2014).

O hábitat estritamente costeiro da toninha (Danilewicz et al. 2009) se sobrepõem a diversas áreas de pesca, especialmente a pesca de emalhe, o que torna a espécie altamente vulnerável à capturas acidentais, a principal ameaça à sua conservação (Ott et al. 2002, Secchi et al. 2003b, Secchi 2010). Os primeiros registros de mortalidade de toninhas em redes de pesca foram realizados no Uruguai em meados de 1940 (Van Erp, 1969), sendo observado atualmente em praticamente todas as área onde a distribuição da espécie sobrepõe à distribuição das pescarias de emalhe artesanal e industrial (Corcuera 1994, Crespo et al. 1994, Siciliano 1994, Secchi et al. 1997, Di Beneditto et al. 1998, Bertozzi & Zerbini 2002, Ott et al. 2002, Rosas et al. 2002, Secchi et al. 2003b, Cremer et al. 2013). Valores históricos de captura acidental em redes de pesca indicam a mortalidade média de ~2.000 indivíduos (mínimo: ~200, máximo: ~3.000 toninhas) ao longo de toda a distribuição da espécie, valores estes considerados insustentáveis e que poderiam levar a espécie à extinção (Kinas 2002, Kinas et al. 2002, Ott et al. 2002, Secchi et al. 2006).

A degradação do habitat resultante da ocupação do ambiente costeiro, da contaminação química das águas e da entrada de resíduos sólidos no ambiente marinho, entre outros, são ameaças emergentes para a conservação da toninha (Secchi et al. 2003, Seixas et al. 2007, Yogui et al. 2010, Denuncio et al. 2011, Lailson-Brito et al. 2011, Lavandier et al. 2016). Atualmente, a toninha é considerada o pequeno cetáceo mais ameaçado de extinção no oceano Atlântico Sul ocidental, sendo listada como “criticamente em perigo” no Brasil e “vulnerável” na *IUCN Red List of Threatened Species* (MMA 2014, Zerbini et al. 2017).

O levantamento aéreo é considerado o método mais efetivo para registrar grupos de toninha e, assim, produzir estimativas de abundância e avaliar a distribuição da espécie nas distintas áreas de manejo (Secchi et al. 2001, Crespo et al. 2002, Crespo et al. 2010, Danilewicz et al. 2010, Danilewicz et al. 2012). Desenvolver estimativas robustas de abundância da toninha para as diferentes FMAs, gerar informações a respeito da sua distribuição e avaliar a ocorrência de indivíduos nos hiatos de distribuição da espécie são recomendações prioritárias feitas por organizações nacionais e internacionais para alcançar a conservação efetiva da toninha. Nesse sentido, na presente tese de doutorado, objetivou-se estimar a abundancia de toninhas em duas áreas de manejo (FMA Ia e II) e computar e aplicar fatores de correção para corrigir essas estimativas em consequência do viés de visibilidade e de tamanho de grupo associados aos levantamentos aéreos. Assim, pretende-se contribuir com a produção de estimativas robustas que sirvam de base para o planejamento de medidas de manejo que garantam a viabilidade das distintas populações de toninha ao longo de toda sua distribuição.

1.1 OBJETIVO E ESTRUTURA DA TESE

1.1.1 OBJETIVO GERAL

Produzir estimativas robustas de abundância populacional da toninha a partir de dados provenientes de levantamentos aéreos.

1.1.2 OBJETIVOS ESPECÍFICOS

a - identificar os principais fatores que afetam a detecção e contagem de toninhas durante levantamentos aéreos;

b - quantificar a magnitude do viés causado pelos principais fatores que afetam a detecção e contagem de toninhas durante levantamentos aéreos em estimativas de abundância;

c - produzir um fator de correção para estimativas de abundância de toninha a partir de levantamentos aéreos;

d - avaliar a distribuição e estimar a abundância de toninhas nas novas áreas de manejo propostas para a FAM II;

e - estimar a abundância de toninhas e avaliar o estado de conservação da população da FMA Ia.

1.1.3 ESTRUTURA DA TESE

Seguido da introdução geral, dos objetivos e estrutura da tese, é descrita de forma sucinta a área de estudo e o método de registro das informações.

Logo, são apresentados os três capítulos (em formato de manuscrito a ser submetido à publicação) que compõem a tese:

- O capítulo II abrange os objetivos específicos "a, b e d";

- O capítulo III abrange os objetivos específicos "a, b e c";

- O capítulo IV abrange o objetivo específico "e".

1.2 ÁREA DE ESTUDO E LEVANTAMENTO AÉREO

1.2.1 ÁREA DE ESTUDO

O presente estudo foi realizado nas regiões Sul e Sudeste do Brasil, entre Florianópolis, SC, e Itaúnas, ES. No capítulo II amostrou-se a faixa de costa até os 30 m de profundidade entre Florianópolis, SC, e Cabo Frio, RJ; no capítulo III foram realizados experimentos na Baía da Babitonga, SC, e na região de Ubatuba, SP; no capítulo IV amostrou-se a faixa de costa até a isóbata de 20 m entre a Barra de Itabapoana e Itaúnas, ES (Figura 4).

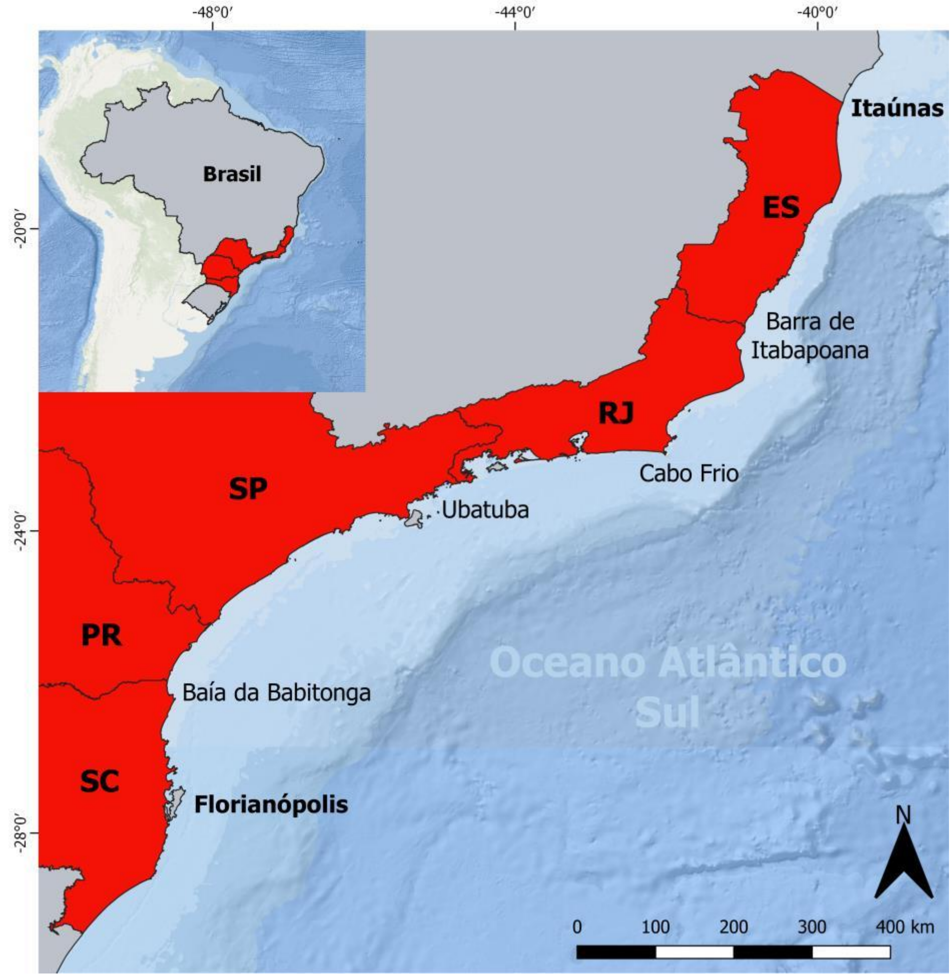

Figura 4. Mapa geral da área de estudo, com limites ao norte em Itaúnas, Espírito Santo - ES, e ao sul em Florianópolis, Santa Catarina - SC. PR = Paraná, SP = São Paulo, RJ = Rio de Janeiro. Fonte: Elaborado pelo autor (2019).

A área de estudo abrange toda a extensão latitudinal dos dois hiatos existentes ao longo da distribuição da toninha e também as áreas propostas para as subpopulações da FMA II (FMA IIa e IIb) e para a subpopulação da FMA Ia (Figura 3).

1.2.2 LEVANTAMENTO AÉREO

Os levantamentos aéreos foram realizados utilizando basicamente dois modelos de aeronave, um avião *Aerocommander 500B* e um helicóptero *Robinson R44* (Figura 5 e 6). O *Aerocommander 500B*, possui asas elevadas, duas janelas-bolha e duas janelas-plana (Figura 5). Um piloto e um copiloto em comunicação acústica e visual com os tripulantes são responsáveis pela condução da aeronave. Quatro observadores compõem a tripulação: i) observadores dianteiros, posicionados em dois assentos individuais e nas janelas-bolha com ângulo máximo de detecção ~90°, e ii) observadores traseiros, posicionados em um assento único e nas janelas-plana com ângulo máximo de detecção ~65°. Durante as linhas de transecção, essa aeronave voou a uma altitude aproximadamente constante de 150 m a uma velocidade de 170-190 km/h. Os quatro observadores trabalharam de forma independente, não havendo comunicação visual ou acústica entre os observadores da frente e de trás. O ruído do avião e o uso de auriculares impossibilitou que um observador ouvisse o registro de uma detecção feita por outro observador. Cada observador foi responsável por fazer o registro das condições ambientais, sendo estas informações tomadas no início de cada linha e a cada vez que uma mudança significativa ocorria. Registrou-se (i) o estado do mar em escala Beaufort, (ii) o reflexo no campo de visão - presença e intensidade, (iii) cor da água - marrom, verde e azul, (iv) transparência da água – turva ou clara, e (v) visibilidade – ótima, razoável ou ruim (classificação subjetiva levando em consideração os quatro pontos anteriores). Para cada detecção, foi determinada a espécie, o tamanho de grupo e a presença de filhotes. O ângulo de declinação entre o horizonte e o grupo detectado foi coletado com o auxílio de um inclinômetro (Suunto, modelo PM-5) assim que o grupo esteve perpendicular ao avião. A partir desse ângulo e da altitude da aeronave, foi calculada a distância perpendicular do grupo detectado em relação à linha de transecção (Lerczak & Hobbs, 1998). Todos os dados foram gravados em gravador digital e referenciados com base na hora de relógios individuais sincronizados a um GPS.

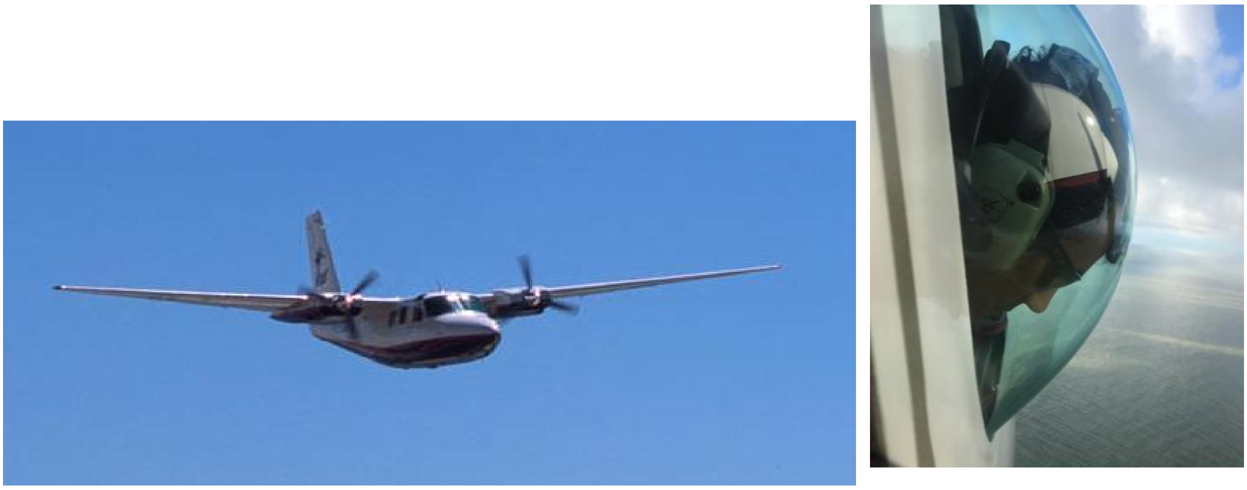

Figura 5. Avião, *Aerocommander 500B*, utilizado durante os levantamentos aéreos para estimativa de abundância (Fonte: Paulo A. Flores (2011)). *direita* Observador posicionado na janela-bolha realizando a busca por grupos de toninhas. Fonte: Cristiano Camejo (2018).

Os sobrevoos realizados com o helicóptero *Robinson R44* (Figura 6) tiveram como objetivo registrar a disponibilidade visual de grupos de toninhas. Os sobrevoos foram realizados a 150 m, altitude consistente com aquela utilizada para estimar a abundância da espécie a partir de aviões. Por motivos meteorológicos, os sobrevoos ocorreram sempre pelo período da manhã e tiveram uma duração aproximada de 4 horas. As portas do lado esquerdo do helicóptero (frente e trás) foram retiradas durante as amostragens para maximizar a visibilidade dos observadores. Dois pesquisadores com experiência em sobrevoos para toninhas foram responsáveis pelo registro dos dados. Após a detecção de grupos de toninha, o piloto foi orientado a pairar sobre os grupos para amostragem do tempo de superfície. Um grupo foi definido como uma agregação de golfinhos bem próximos entre si, movendo-se na mesma direção e em aparente associação. Cada observador realizou os registros de forma independente, ou seja, o registro feito por um dos pesquisadores não influenciou o registro feito pelo outro pesquisador, mesmo que simultâneos. Objetivou-se não coletar dados de um mesmo grupo de forma simultânea entre os observadores, evitando assim produzir réplicas durante um mesmo ciclo de mergulho dos mesmos indivíduos. Contudo, devido à dificuldade de comunicação entre os observadores, não é possível afirmar que isso foi alcançado na totalidade dos casos. Todas as informações foram registradas em gravadores digitais sincronizados a um GPS, possibilitando o georreferenciamento dos dados.

Figura 6. Helicóptero *Robinson* R44 utilizado durante o registro de grupos de toninha (Fonte: Martin Sucunza Perez (2016)). *direita* Observador registrando o tempo de superfície e mergulho de grupos de toninha. Fonte: Daniel Danilewicz (2016).

Cada observador foi responsável por registrar as variáveis ambientais, as quais foram obtidas no início de cada amostragem e a cada vez que uma mudança significativa foi constatada. Foi registrado: (i) estado do mar em escala Beaufort, (ii) reflexo no campo de visão – porcentagem e intensidade, (iii) cor da água, (iv) transparência da água (duas categorias: turva ou clara), e (v) visibilidade (três categorias: ótima, razoável ou ruim, classificação subjetiva levando em consideração os quatro pontos anteriores). Adicionalmente, foi utilizada uma embarcação para coletar variáveis ambientais complementares às registradas pelos observadores no helicóptero (profundidade e transparência da água medida com disco de Secchi). Esses registros foram realizados simultaneamente aos sobrevoos com helicóptero.

2 CAPÍTULO II - DISTRIBUTION, HABITAT USE, AND ABUNDANCE OF THE ENDANGERED FRANCISCANA IN SOUTHEASTERN AND SOUTHERN BRAZIL

Manuscrito aceito para publicação na revista: *Marine Mammal Science*

Autores: Federico Sucunza, Daniel Danilewicz, Artur Andriolo, Alexandre F. Azevedo, Eduardo R. Secchi, Alexandre N. Zerbini

DISTRIBUTION, HABITAT USE, AND ABUNDANCE OF THE ENDANGERED FRANCISCANA IN SOUTHEASTERN AND SOUTHERN BRAZIL

FEDERICO SUCUNZA[1,2,3], DANIEL DANILEWICZ[2,3,4], ARTUR ANDRIOLO[1,2,5], ALEXANDRE F. AZEVEDO[6], EDUARDO R. SECCHI[7], ALEXANDRE N. ZERBINI[1,2,8,9,10]

1 Laboratório de Ecologia Comportamental e Bioacústica, Programa de Pós-graduação em Ecologia, Universidade Federal de Juiz de Fora, Juiz de Fora, MG, Brazil.

2 Instituto Aqualie, Juiz de Fora, MG, Brazil.

3 Grupo de Estudos de Mamíferos Aquáticos do Rio Grande do Sul, Torres, RS, Brazil.

4 Universidade Estadual de Santa Cruz, Ilhéus, Bahia, Brazil.

5 Departamento de Zoologia, Universidade Federal de Juiz de Fora, Juiz de Fora, MG, Brazil.

6 Laboratório de Mamíferos Aquáticos e Bioindicadores, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, RJ, Brazil.

7 Laboratório de Ecologia e Conservação da Megafauna Marinha-EcoMega, Instituto de Oceanografia, Universidade Federal do Rio Grande-FURG, Rio Grande, RS, Brazil.

8 Marine Mammal Laboratory, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, United States of America.

9 Cascadia Research Collective, Olympia, Washington, United States of America.

10 Marine Ecology and Telemetry Research, Seabeck, Washington, United States of America.

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 comprise 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=00.32) 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.

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 and Gerrodette 1993, Williams *et al.* 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 (Hiby and Hammond 1989, Andriolo *et al.* 2010, Crespo *et al.* 2010, 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.*, Sucunza *et al.* 2015, Smultea *et al.* 2017, Mayo *et al.* 2018). For many marine species (*e.g.*, cetaceans and marine turtles) line transect aerial surveys constitute one of the most common methods to estimate abundance (Secchi *et al*. 2001, Slooten *et al.* 2004, Andriolo *et al.* 2010, Thomas *et al.* 2010, Fuentes *et al*. 2015). 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 *et al.* 1997, Laake and Borchers 2004, Sucunza *et al.* 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 (18º 25'S) to Golfo San Matías, Argentina (42º 10'S) (Crespo *et al.* 1998, Siciliano *et al.* 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 *et al.* 2003*a*, Secchi 2010). Incidental catches in fishing gear, especially gillnets and trammel nets, have been reported along most of the species' range since at least the 1940s (Van Erp 1969, Ott *et al.* 2002, Secchi *et al.* 2003*a*). The franciscana is currently listed as 'Vulnerable' in the IUCN Red List of Threatened Species (Zerbini *et al.* 2017) and 'Critically Endangered' by the Brazilian Government (MMA 2014).

In order to guide conservation and management actions on a regional basis, the franciscana range was divided into four zones known as 'Franciscana Management Areas' (FMAs) in the early 2000s (Secchi *et al.* 2003*b*). 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 (Secchi *et al.* 2003*b*, Anonymous 2015). 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 re-evaluation 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 and 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 (Reeves *et al.* 2003, IWC 2005, ICMBio 2011, Anonymous 2015, IWC 2016). 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 (Cunha *et al.* 2014, Anonymous 2015, 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.

METHODS

Study Area and Survey Design

Aerial surveys were conducted on 11-22 December 2008 and 11-18 January 2009 between Arraial do Cabo, RJ (22º56'S, 42º09'W) and southern border of the state of SC (27°37'S, 48º25'W) (Zerbini *et al.* 2010) (Fig. 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 to 47.96 km in length and equally spaced by ~11 km were 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 now also include the northern portion of the latter management area (Anonymous 2015) (Fig. 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 - 23°48'S), and (3) central and southern SP, PR and northern SC or "FMA IIb stratum" (23°48'S - 27°36'S) (Fig. 1). Survey lines were designed to cover an inshore (waters within 30 m of depth) and an offshore stratum - depth ranging from 30-50 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.

Sampling Methods

Searching for franciscana groups was conducted from a high-wing, twin-engine *Aerocommander 500B* 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. 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 beginning 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.

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.

Analytical Methods

Distribution

Only sightings recorded in either FMA IIa and 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 and 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 between 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.

Line transect analysis methods

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 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 *et al.* (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 and 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 and Anderson 2002). Analyses were performed using a set of customized functions (mrds v.2.2.0, Laake *et al.* 2018) in R (R Development Core Team 2018).

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 *et al.* 1998, Borchers and Burnham 2004). 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 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 *et al.* 2006).

RESULTS

A total of 3,268 km on effort survey were 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.

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

Distribution

A total of 54 franciscana groups were seen within FMA II (both FMA IIa and IIb strata) during the survey, with 49 sightings observed on effort (Fig. 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). Franciscana sightings were recorded in two main regions: between Joinville/Paranaguá, and from Peruíbe to Ubatuba (Fig. 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, Fig. 2). Relative density (encounter rate, ER, or 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) ($p = 0.02$, $p = 0.001$, 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)

Table 3. Relative density (groups/km) of franciscana groups between three intervals of depth: 1) 0-10 m, 2) 11-20 m, and 3) 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 m - 10 m (SE, 95% CI)	11 m - 20 m (SE, 95% CI)	21 m - 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 - 0.007)*

*Indicates statistical significance between the 21-30 m depth category and the 0-10 m (p=0.02) and 11-20 m (p=0.001).

Abundance

Detection probability was computed (after left truncation and re-scaling 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 Fig. 3.

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, ΔAIC - 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 80m of distance from the track line for both observers combined, CV - Coefficient of variation.

#	Model specification	ΔAIC	w_i	Npar	$\bar{P}$	$CV(\overline{P})$	$\bar{P}(0)$	$CV(\bar{P}[0])$
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

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).

Table 5. Density and abundance estimates of franciscanas in southeastern and southern Brazil through the study period (*i.e.*, 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 individuals/km, $\widehat{Si}$ = estimated average group size (averaged over all candidate models), $\widehat{Du}$ = estimated density of individuals/km2 corrected for perception bias, $\widehat{Dc}$ = estimated density of individuals/km2 corrected for perception and availability bias, $\widehat{Nc}$= estimated abundance corrected for perception and availability bias, CI = confidence intervals.

Strata	$\bar{P}$	n	ER	$\widehat{Si}$	$\widehat{Du}$	$\widehat{Dc}$	$\widehat{Nc}$	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

DISCUSSION

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 *et al.* 1999, Crespo 2009) and because of the lack of systematic sighting surveys, most knowledge on the franciscana distribution comes from data on stranded or incidentally captured individuals (*e.g.*, Secchi *et al.* 1997, Siciliano *et al.* 2002, Danilewicz *et al.* 2009). 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 (Fig. 1). Considering that franciscanas inhabiting Babitonga Bay apparently comprise a resident population (Cremer and Simões-Lopes 2008), no 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, multi-year stranding and bycatch monitoring indicate a continuous distribution of franciscanas between central SC and southern RJ (*e.g.*, Simões-Lopes and Ximenez 1993; Bertozzi and Zerbini 2002; Rosas and Monteiro-Filho 2002; Rosas *et al.* 2002; Santos *et al.* 2002; Cremer *et al.* 2013, *webGIS* SIMMAM - http://simmam.acad.univali.br/site/). Lack of sightings in certain areas may have occurred due to 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, Rodriguez *et al.* 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 Fig. 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 (Secchi *et al*. 1997, Danilewicz *et al.* 2009), 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.

Abundance

This is the first study to assess the abundance of franciscanas in the whole new proposed area for FMA II. The overall abundance of FMA II indicates that approximately 6,827 dolphins (CV = 0.26) inhabited the whole FMA II area 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 downward bias as indicated for most small cetaceans' aerial surveys (*e.g.*, Dahlheim *et al.* 2000, Slooten *et al.* 2004, Zerbini *et al.* 2011). The high speed of the aircraft as well as the small body of the franciscana make 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 non-independence in detections by front and rear observers due to unmodeled heterogeneity in estimates of detection probability (Laake and Borchers 2004). Although the effect of variables (*e.g.*, group size) causing heterogeneity was modeled, others 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 negatively biased (Laake and Borchers 2004).

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 and Simões-Lopes 2008, Zerbini *et al.* 2011).

Conservation Implications

Bycatch is currently the main conservation problem for the franciscana throughout its range (*e.g.*, Secchi *et al.* 2003*a*, *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 and Zerbini 2002, Ott *et al.* 2002, 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 (Ott *et al.* 2002, IWC 2005, Bertozzi 2009). These estimates suggest that bycatch mortality of franciscanas in FMA II at the end of the 2000s corresponded to 4.4% to 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.*, Secchi *et al.* 2001, Secchi 2006, Danilewicz *et al.* 2010).

Correctly identifying and effectively managing anthropogenic threats is paramount to 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 regulating gillnet fisheries and reducing bycatch of the franciscana as well as other endangered marine species. The regulation included, *inter alia*, a 3 nmi fishing ban for industrial boats in FMA IIa strata. Franciscana sightings recorded off this protected zone represent 67% of the total sightings recorded off FMA IIa strata, which could be assumed a potential protection for 1,283 franciscanas. Extending this protected zone 1 nmi further (*i.e.*, a 4 nmi fishing ban) would encompass 83% of the total sightings recorded off FMA IIa strata. Estimates of bycatch of franciscanas in FMA II were based mostly in monitoring fishing activities off FMA IIb strata (*e.g.*, Bertozzi and Zerbini 2002). In this area, the INI 12/2012 delimit a 4 nmi fishing zone between central SC and PR, and 3 nmi 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 strata. 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 likely not the unique 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 (Yogui *et al.* 2010, Lailson-Brito *et al.* 2011, Alonso *et al*. 2012, De la Torre *et al.* 2012, Lavandier *et al.* 2016). In these sense, 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.

Acknowledgements

This study was funded by the Brazilian Ministry of the Environment (MMA) – Instituto Chico Mendes para a Conservação da Biodiversidade (ICMBio), the US Marine Mammal Commission (MMC) and the Yaqu Pacha Foundation (YP). Assistance from the following individuals working for these organizations at various stages of this study is greatly appreciated: Henrique Ilha (ICMBio), Mina Innes and Mike Simpkins (MMC) and Lorenzo von Fersen (YP). Data collection was professionally carried out by Tatiana Bisi, Silvina Botta, Emanuel Ferreira, and Jonatas H. F. do Prado. JAD Taxi Aéreo crew’s was key in safely completing this study. The authors are greatly indebted to Jeff Laake for advice on survey design and data analysis prior to data collection and during preparation of this manuscript. The Coordination for the Improvement of Higher Education Personnel (CAPES) provided a scholarship to FS (Process 1548067). The Brazilian Council for Research and Technological Development (CNPq) provided a Research Fellowship to ERS (PQ 307843/2014-0).

LITERATURE CITED

Alonso, M. B., M. L. Feo, C. Corcellas, *et al.* 2012. Pyrethroids: A new threat to marine mammals? Environmental International 47: 99-106.

Amante, C. and B. W. Eakins. 2009. ETOPO-1 1 arc-minute global relief model: Procedures, data source and analysis. U.S. Department of Commerce, NOAA Technical Memorandum NESDIS NGDC-24. 19p.

Andriolo, A., P. G. Kinas, M. H. Engel, C. C. A. Martins and A. M. Rufino. 2010. Humpback whales within the Brazilian breeding ground: Distribution and population size estimate. Endangered Species Research 11:233-243.

Anonymous. 2015. Report of the VIII Workshop for the Research and Conservation of the Franciscana dolphin (*Pontoporia blainvillei*) in the soutwestern Atlantic. UNEP/CMS, São Francisco do Sul, Brazil. 25p.

Bertozzi C. P. 2009. Interação com a pesca: Implicações na conservação da toninha, *Pontoporia blainvillei* (Cetacea, Pontoporiidae) no litoral do estado de São Paulo, SP. Unpublished Thesis, Universidade de São Paulo.

Bertozzi, C. P. and A. N. Zerbini. 2002. Incidental mortality of Franciscana (*Pontoporia blainvillei*) in the artisanal fishery of Praia Grande, São Paulo State Brazil. Latin American Journal of Aquatic Mammals 1:153-160.

Borchers, D. L., S. T. Buckland, P. W. Goedhart, E. D. Clarke and S. L. Hedley. 1998. Horvitz-Thompson estimators for double-platform line transect surveys. Biometrics 54: 1221-1237.

Borchers, D. L. and K. P. Burnham. 2004. General formulation for distance sampling. Pages 10-11 *in* Advanced distance sampling: Estimating abundance of biological populations, eds. S. T. Buckland, D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. Oxford University Press.

Borchers, D. L., J. L. Laake, C. Southwell and C. G. M. Paxton. 2006. Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. Biometrics 62:372-378.

Bordino, P., G. Thompson and M. Iñíguez. 1999. Ecology and behaviour of the franciscana (*Pontoporia blainvillei*) in Bahía Anegada, Argentina. Journal of Cetacean Research and Management 1:213-222.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of wildlife populations. Oxford University Press.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. 2nd ed. New York: Springer.

Burt, M. L., D. L. Borchers, K. J. Jenkins and A. Marques. 2014. Using mark-recapture distance sampling methods on line transect surveys. Methods in Ecology and Evolution 5:1180-1191.

Cremer, M. J. and P. C. Simões-Lopes. 2008. Distribution, abundance and density estimates of franciscanas, *Pontoporia blainvillei* (Cetacea: Pontoporiidae), in Babitonga bay, southern Brazil. Revista Brasileira de Zoologia 25:397-402.

Cremer, M. J., C. M. Sartori, A. C. Holz, B. Schulze, N. Z. dos Santos, A. K. de M. Alves and R. L. Paitach. 2013. Franciscana strandings on the north coast of Santa Catarina State and insights into birth period. Biotemas 26:133-139.

Crespo, E. A., G. Harris and R. González. 1998. Group size and distributional range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845-849.

Crespo, E. A. 2009. Franciscana dolphin Pontoporia blainvillei. Pages 466-469 *in* Encyclopedia of marine mammals, 2nd ed, eds. Perrin, W. F., B. Würsig and J. G. M. Thewissen. Academic Press.

Crespo, E. A., S. N. Pedraza, M. F. Grandi, S. L. Dans and G. V. Garaffo. 2010. Abundance and distribution of endangered Franciscana dolphins in Argentine waters and conservation implication. Marine Mammal Science 26:17-35.

Cunha, H. A., B. V. Medeiros, L. A. Barbosa, M. J. Cremer, J. Marigo, J. Lailson-Brito, A. F. Azevedo and A. M. Solé-Cava. 2014. Population structure of the endangered franciscana dolphin (*Pontoporia blainvillei*): Reassessing management units. PLOS ONE 9:e85633.

Dahlheim, M., A. York, R. Towell, J. Waite and J. Breiwick. 2000 Harbor porpoise (*Phocoena phocoena*) abundance in Alaska: Bristol Bay to southeast Alaska, 1991-1993. Marine Mammal Science 16: 28-45.

Danilewicz, D., E. R. Secchi, P. H. Ott, I. B. Moreno, M. Bassoi and M. Borges-Martins. 2009. Habitat use patterns of franciscana dolphins (Pontoporia blainvillei) off southern Brazil in relation to waters depth. Journal of the Marine Biological Association of the United Kingdom 89:943-949.

Danilewicz, D., I. B. Moreno, P. H. Ott, M. Tavares, A. F. Azevedo, E. R. Secchi and A. Andriolo. 2010. Abundance estimate for a threatened population of franciscana dolphins in southern coastal Brazil: Uncertainties and management implications. Journal of the Marine Biological Association of the United Kingdom 90:1659-1666.

De la Torre, A., M. B. Alonso, M. A. Martínez, *et al.* 2012. Dechlorane-related compounds in franciscana dolphin (*Pontoporia blainvillei*) from southeastern and southern coast of Brazil. Environmental Science & Technology 46:12364-12372.

Fisher, R. A. 1936. The coefficient of racial likeness and the future of craniometry. Journal of the Royal Anthropological Institute 66:57-63.

Fuentes, M. M. P. B., I. Bell, R. Hagihara, *et al.* 2015. Improving in-water estimates of marine turtle abundance by adjusting aerial surveys counts for perception and availability biases. Journal of Experimental Biology and Ecology 471:77-83.

Hiby, A. R. and P. S. Hammond. 1989. Survey techniques for estimating abundance of cetaceans. Reports of the International Whaling Commission (Special Issue) 11:47-80.

ICMBio. 2011. Plano de ação nacional para a conservação do pequeno cetáceo – Toninha (*Pontoporia blainvillei*). 76p.

Innes, S., M. P. Heide-Jørgensen, J. L. Laake, K. L. Laidre, H. J. Cleator, P. Richard and R. E. A. Stewart. 2002. Survey of belugas and narwhals in the Canadian High Arctic in 1996. North Atlantic Marine Mammal Commission Scientific Publication 4:169-190.

International Whaling Commission. 2005. Annex L - Report of the Sub-Committee on Small Cetaceans. Journal of Cetacean Research and Management 7:307-326.

International Whaling Commission. 2016. A conservation management plan for franciscana (*Pontoporia blainvillei*). IWC/66/CC11. 22p.

International Whaling Commission. 2018. Annex J - Report of the Sub-Committee on Non-Deliberate Human Induced Mortality of Cetaceans. Report of the Scientific Committee IWC/67/Rep01(2018). 23p.

Kelleher, G. 1999. Guidelines for marine protected areas. IUCN, Gland, Switzerland and Cambridge, UK.

Laake, J. L., J. Calambokidis, S. D. Osmek and D. J. Rugh. 1997. Probability of detecting harbour porpoise from aerial surveys: Estimating g(0). Journal of Wildlife Management. 61:63-75.
Laake, J. L. and D. L. Borchers. 2004. Methods for incomplete detection at distance zero. Pages 108-189 *in* Advanced distance sampling: Estimating abundance of biological populations, eds. Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers and L. Thomas. Oxford University Press.

Laake, J., D. Borchers, L. Thomas, D. Miller and J. Bishop. 2018. mrds: Mark-recapture distance sampling. Available at https://cran.r-project.org/package5mrds.

Lailson-Brito, J., P. R. Dorneles, C. E. Azevedo-Silva, *et al.* 2011. Organochlorine concentrations in franciscana dolphins, *Pontoporia blainvillei*, from Brazilian waters. Chemospehere 84:882-887.

Lavandier, R., J. Arêas, N. Quinete, *et al.* 2016. PCB and PBDE levels in a highly threatened dolphin species from the southeastern Brazilian coast. Environmental Pollution 208:442-449.

Marques, F. F. C. and S. T. Buckland. 2003. Incorporating covariates into standard line transect analyses. Biometrics 59:924-935.

Marsh, H. and D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management. 53:1017-1024.

Mayo, C. A., L. Ganley, C. A. Hudak, S. Brault, M. K. Marx, E. Burke and M. W. Brown. 2018. Distribution, demography, and behavior of north atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, Massachusetts, 1998-2013. Marine Mammals Science 34:979-996.

McLellan W. A., R. J. McAlarney, E. W. Cummings, A. J. Read, C. G. M. Paxton, J. T. Bell and D. A. Pabst. 2018. Distribution and abundance of beaked whales (Family Ziphiidae) off Cape Hatteras, North Carolina, U.S.A. Marine Mammal Science 34:997-1017.

MMA. 2014. Lista nacional oficial de espécies da fauna ameaçada de extinção—Mamíferos, aves, répteis, anfíbios e invertebrados terrestres. In: Portaria MMA no. 444, de 17 de dezembro de 2014, Brasil. Available from http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2014/p_mma_444_2014_lista_esp%C3%A9cies_ame%C3%A7adas_extin%C3%A7%C3%A3o.pdf. Accessed 27 July 2017.

Ott, P. H., E. R. Secchi and I. B. Moreno, *et al.* 2002. Report of the Working Group on Fishery Interactions. Latin American Journal of Aquatic Mammals 1:55-64.

Pinedo, M. C., R. Praderi and R. L. Brownell Jr. 1989. Review of the biology and status of the franciscana *Pontoporia blainvillei* (Gervais & D'Orbigny, 1844). Pages 46-51 *in* Biology and conservation of the river dolphins, eds. Perrin, W. F., R. L. Brownell Jr., K. Zhou and L. Jiankang. IUCN.

Pitman, E. J. G. 1937. Significance tests which may be applied to samples from any populations. Supplement to the Journal of the Royal Statistical Society 4:119–130.

PMAP-BS. 2017. Relatório técnico semestral, agosto a dezembro de 2016 (Processo IBAMA nº 02022.001735/2013-51). Projeto de monitoramento da atividade pesqueira na Bacia de Santos PMAP-BS. Available from https://www.comunicabaciadesantos.com.br/sites/default/files/Relatorio_Tecnico_Semestral_PMAP-BS_jul-dez_2016.pdf. Accessed 09 July 2019.

Pollock, K. H., H. Marsh, I. R. Lawler and M. W. Alldredge. 2006. Estimating animal abundance in heterogeneous environments: An application to aerial surveys for dugongs. Journal of Wildlife Management 70:255–262.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reeves, R. R., B. D. Smith, E. Crespo and N. G. Di Sciara. 2003. Dolphins, whales, and porpoises: 2002-2010 conservation action plan for the world's cetaceans. IUCN Species Survival Commission.

Rodríguez, D., L. Rivero and R. Bastida. 2002. Feeding ecology of Franciscana (*Pontoporia blainvillei*) in estuarine and marine waters of Argentina. Latin American Journal of Aquatic Mammals (Special Issue) 1:177-94.

Rosas, F. C. W. and E. L. A. Monteiro-Filho. 2002. Reproductive parameters of *Pontoporia blainvillei* (Cetacea, Pontoporiidae), on the coast of São Paulo and Paraná States, Brazil. Mammalia 66:231-245.

Rosas, F. C. W., E. L. A. Monteiro-Filho and M. R. de Oliveira. 2002. Incidental catches of Franciscana (*Pontoporia blainvillei*) on the southern coast of São Paulo State and the coast of Paraná State, Brazil. Latin American Journal of Aquatic Mammals 1:161-167.

Santos, M. C. O., A. F. Z. Vicente, É. Zampirolli, F. S. Alvarenga and S. P. Souza. 2002. Records of Franciscana (*Pontoporia blainvillei*) from the coastal waters of São Paulo State, southeastern Brazil. Latin American Journal of Aquatic Mammals 1:169-174.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin & Company Ltd.

Secchi E. R., A. N. Zerbini, M. Bassoi, L. Dalla Rosa, L. M. Moller and C. C. Rocha-Campos. 1997. Mortality of franciscanas, *Pontoporia blainvillei*, in coastal gillnets in southern Brazil: 1994-1995. Report International Whaling Commission. 47:653–658.

Secchi, E. R., P. H. Ott, E. A. Crespo, P. G. Kinas, S. N. Pedraza and P. Bordino. 2001 A first estimate of franciscana (*Pontoporia blainvillei*) abundance off southern Brazil. Journal of Cetacean Research and Management 3:95-100.

Secchi, E. R., P. H. Ott and D. S. Danilewicz. 2003a. Effects of fishing by-catch and conservation status of the Franciscana dolphin, *Pontoporia blainvillei*. Pages 174-191, *in* Marine mammals: Fisheries, tourism and management issues, eds. Gales, N., M. Hindell and R. Kirkwood. CSIRO Publishing.

Secchi, E. R., D. Danilewicz and P. H. Ott. 2003b. Applying the phylogeographic concept to identify franciscana dolphin stocks: Implications to meet management objectives. Journal of Cetacean Research and Management 5:61-68.

Secchi E. R. 2006. Modelling the population dynamics and viability analysis of franciscana (*Pontoporia blainvillei*) and Hector's dolphins (*Cephalorhynchus hectori*) under the effects of bycatch in fisheries, parameter uncertainty and stochasticity. Unpublished thesis, University of Otago.

Secchi E. R. 2010. Review on the threats and conservation status of franciscana, *Pontoporia blainvillei* (Cetacea, Pontoporiidae). Pages 323-339, *in* Biology, evolution and conservation of river dolphins within south America and Asia, eds. Ruiz-Garcia M. and J. M. Shostell. Nova Science Publishers Inc.

Siciliano, S., A. P. Di Beneditto and R. Ramos. 2002. A toninha, *Pontoporia blainvillei* (Gervais & D'Orbigny, 1884) (Mammalia: Cetacea) nos Estados do Rio de Janeiro e Espírito Santo, costa sudeste do Brasil: caracterização dos hábitats e possíveis fatores de isolamento das populações. Boletim do Museu Nacional, Nova Série, Zoologia 146:1-15.

Simões-Lopes, P. C. and A. Ximenez. 1993. Annotated list of the cetaceans of Santa Catarina coastal waters, southern Brazil. Biotemas 6:67-92.

Slooten, E., S. M. Dawson and W. J. Rayment. 2004. Aerial surveys for coastal dolphins: Abundance of Hector's dolphins off the South Island west coast, New Zealand. Marine Mammal Science 20: 477-490.

Slooten, E., J. Y. Wang, S. Z. Dungan, *et al.* 2013. Impacts of fisheries on the critically endangered humpback dolphin *Sousa chinensis* population in the eastern Taiwan Strait. Endangered Species Research 22:99-114.

Smultea, M. A., D. Fertl, C. E. Bacon, M. R. Moore, V. R. James and B. Würsig. 2017. Cetacean mother-calf behavior observed from a small aircraft off southern California. Animal Behavior and Cognition 4:1-23.

Sucunza, F., E. Doria, L. C. P. de S. Alves, J. H. F. do Prado, E. Ferreira, A. Andriolo and D. Danilewicz. 2015. Observation of antipredator tactics among pantropical spotted dolphins (*Stenella attenuata*) attacked by smooth hammerhead sharks (*Sphyrna zygaena*). Marine Mammals Science 31:748-755.

Sucunza, F., D. Danilewicz, M. Cremer, A. Andriolo and A. N. Zerbini. 2018. Refining estimates of availability bias to improve assessment of the conservation status of an endangered dolphin. PLOS ONE 13:e0194213.

Taylor, B. L. and T. Gerrodette. 1993.The use of statistical power in conservation biology: The vaquita and northern spotted owl. Conservation Biology 7:489-500.

Thomas, L., S. T. Buckland, E. Rexstad, *et al.* 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.

Van Erp I. 1969. In quest of the La Plata dolphin. Pacific Discovery 22:18-24.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14:1-37.

Williams, B. K., J. D. Nichols and M. J. Conroy. 2001. Analysis and management of animal populations: Modeling, estimation, and decision making. Academic Press.

Yogui, G. T., M. C. O. Santos, C. P. Bertozzi and R. C. Montone. 2010. Levels of persistent organic pollutants and residual pattern of DDTs in small cetaceans from the coast of São Paulo, Brazil. Marine Pollution Bulletin 60:1862-1867.

Zerbini, A. N., J. M. Waite, J. L. Laake and P. R. Wade. 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. Deep-sea Research I 53:1772-1790.

Zerbini, A. N., E. R. Secchi, D. Danilewicz, A. Andriolo, J. L. Laake and A. Azevedo. 2010. Abundance and distribution of the franciscana (*Pontoporia blainvillei*) in the Franciscana Management Area II (southeastern and southern Brazil). International Whaling Commission, Scientific Committee paper SC/62/SM7.

Zerbini, A. N, D. Danilewicz, E. R. Secchi, *et al.* 2011. Assessing bias in abundance estimates from aerial surveys to improve conservation of threatened franciscana dolphins: preliminary results from a survey conducted in southern Brazil. International Whaling Commission, Scientific Committee Paper SC/63/SM9.

Zerbini, A. N., E. Secchi, E. Crespo, D. Danilewicz and R. Reeves. 2017. *Pontoporia blainvillei*. In: IUCN 2017. The IUCN Red List of Threatened Species. 2017. Available: www.iucnredlist.org. Accessed 30 January 2018.

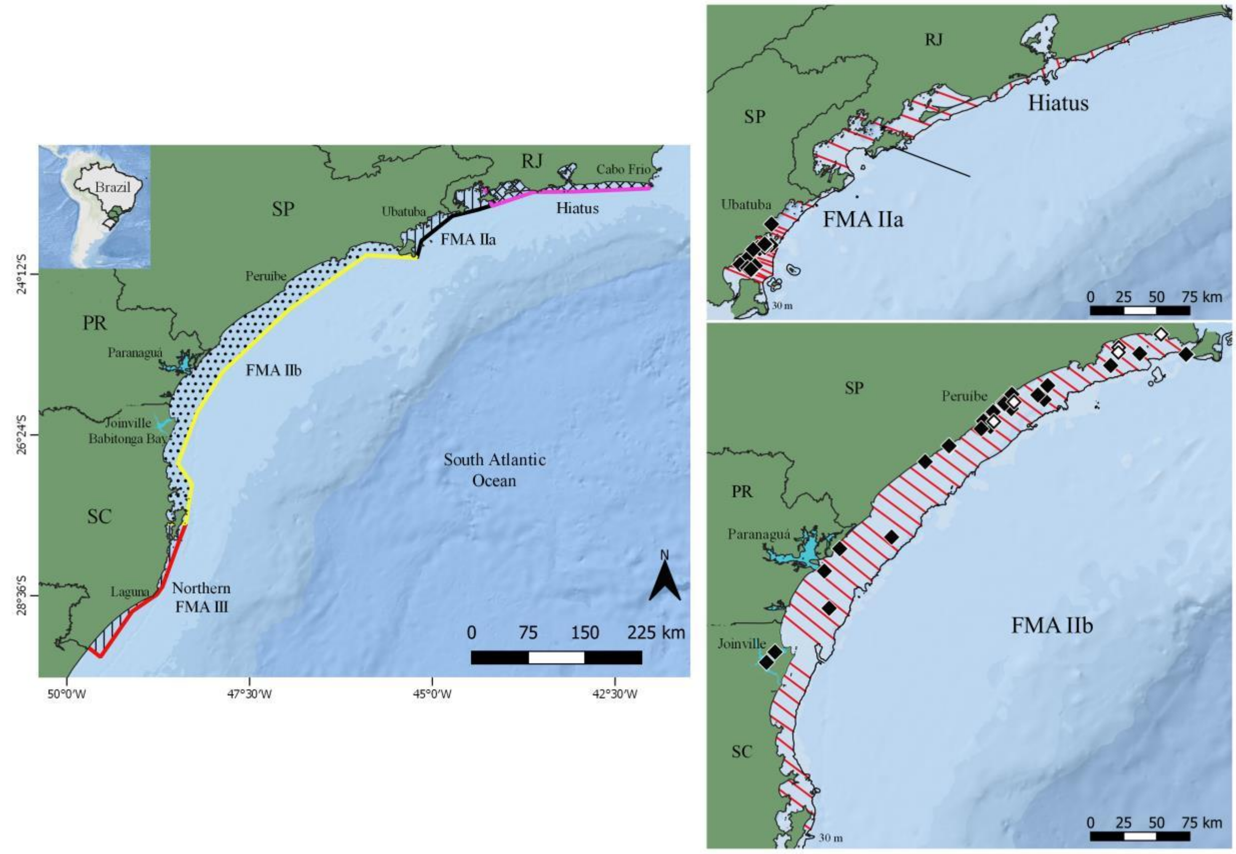

Figure 1. *left*. Covered area during franciscana aerial surveys conducted between 11-22 December 2008 and 11-18 January 2009 off southern and southeastern Brazil. This area encompasses the northern region of the Franciscana Management Area (FMA) III (red line), the whole FMA II (FMA IIb, yellow line, and FMA IIa, black line), and a gap in the franciscana distribution that separates the southern border of FMA I and the northern border of FMA II (Hiatus, pink line). *right*. Survey strata and realized effort (red lines) used for abundance estimation, and franciscana sightings (on effort = black rhombus, off effort = white rhombus). 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. Fonte: Elaborado pelo autor (2019).

Figure 2. Franciscanas recorded in turbid (left) and clear waters (right). Fonte: Elaborado pelo autor (2019).

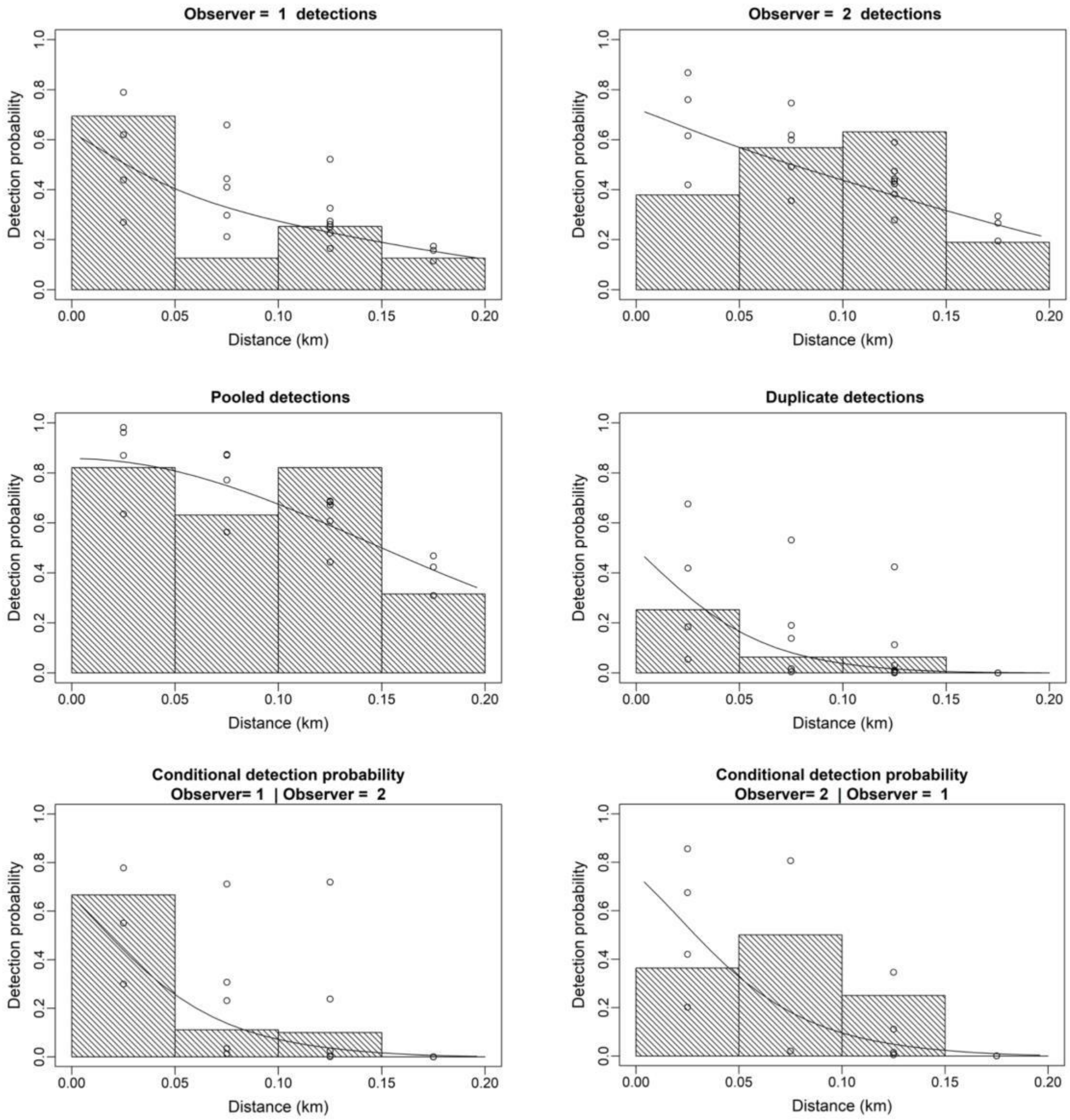

Figure 3. Detection probability plots for Model #1 in Table 4. Perpendicular distance data were left truncated during analysis, and the distance labeled 0.00 corresponds to a real distance of 0.08 km from the trackline. Fonte: Elaborado pelo autor (2019).

3 CAPÍTULO III - ASSESSING BIAS IN AERIAL SURVEYS FOR THREATENED DOLPHINS: RESULTS FROM EXPERIMENTS CONDUCTED WITH THE FRANCISCANA (PONTOPORIA BLAINVILLEI)

Manuscrito em preparação para submissão à revista: *Methods in Ecology and Evolution*

Doutorando: Federico Sucunza Perez

Orientador: Alexandre Novaes Zerbini

Co- Orientador: Daniel Danilewicz Schiavon

ASSESSING BIAS IN AERIAL SURVEYS FOR THREATENED DOLPHINS: RESULTS FROM EXPERIMENTS CONDUCTED WITH THE FRANCISCANA (PONTOPORIA BLAINVILLEI)

SUMMARY

1. Line transect aerial survey methods are widely used for estimating abundance of threatened dolphins. However, estimates obtained with data collected from aircrafts are often underestimated because of visibility bias or bias in estimating group sizes from a fast-moving platform.

2. Independent boat and aerial surveys were concurrently carried out in southern Brazil to assess potential bias in aerial surveys for franciscanas. In addition, experiments with helicopter were conducted in southern and southeastern Brazil to estimate the availability of franciscana groups from observers in an aerial platform.

3. Estimates of density and group sizes from the boats were assumed to be accurate (i.e. not affected by visibility or group size biases) and a correction factor (CF=4.42, CV=0.05) was computed as the ration of the density estimated by boats 2.99 ind/km^2 (CV=0.23) and by the aircraft 0.68 ind/km^2 (CV=0.28). Availability of franciscana groups was estimated at 0.39 (SE = 0.008).

4. Visibility bias was substantial and accounted for ~70% of the total bias. Group sizes estimates from the boats were significantly different (~30% larger) than those from the aircraft and accounts for some of the bias in the aerial survey estimates.

5. The correction factor reported above can be used to refine rangewide abundance estimates of franciscanas given certain assumptions are met. The lack of observed effects of environmental variables (e.g. depth and water transparency) on franciscana groups availability indicates the potential use of the independent estimated availability bias along all the species range.

1 INTRODUCTION

Aircrafts are widely used to conduct biological assessments mainly because they provide the opportunity to search large and/or inaccessible areas in a relatively short period of time (e.g. Hiby and Hammond 1989, Andriolo et al. 2010, Crespo et al. 2010, McLellan et al. 2019). However, aerial surveys are commonly plagued by imperfect counts of individuals or groups that are within the sampling area (Caughley 1972, Barlow et al. 1988, Heide-JØrgensen et al. 2007, Boyd et al. 2019). Bias results from a variety of factors and, if not accounted for, can lead equivocal actions for the conservation of threatened species. In order to compute unbiased estimates, line-transect methods assume that all individuals or group of individuals are seen on the survey trackline ($g(0) = 1$) and that group sizes are accurately estimated (Buckland et al. 2001). Because marine mammal species spend periods of time unavailable to be seen neither of these assumptions often hold during aircraft surveys (e.g. Laake et al. 1997, Pollock et al. 2006, Sucunza et al. 2018, Boyd et al. 2019). Marsh and Sinclair (1989) defined two categories for visibility bias (animals missed on the survey line): availability bias occurs when animals are unavailable to be detected during a passing observer (e.g. on a plane) because they are submerged and perception bias occurs when animals are available but not detected (e.g. due to observer fatigue). In addition, a variable proportion of the individuals within a group will be available at the same time to be counted which makes the estimation of group size of marine mammals species imprecise (Gilpatrick 1993, Gerrodette et al. 2018, Boyd et al. 2019). The high speed of the aircrafts reduce the time an observer has to search through a given area, resulting in a higher proportion of undetected animals as well as in underestimation of the total number of individuals in a group. In this sense, experiments to investigate the magnitude of bias in aerial surveys are essential to produce robust results and, consequently, promote conservation.

The franciscana (*Pontoporia blainvillei*) is a small dolphin endemic to coastal waters off the eastern coast of South America. The species occurs in waters typically shallower than 30 m (Danilewicz et al. 2009) between Itaúnas, Brazil (18°25'S) and Golfo San Matías, Argentina (41°10'S) (Crespo et al. 1998, Siciliano et al. 2002). The species is regarded as one of the most threatened small cetaceans in the western South Atlantic Ocean due to high, possibly unsustainable, bycatch levels as well as increasing habitat degradation throughout its range (Ott et al. 2002, Secchi et al. 2003, Secchi 2010) and is listed as Vulnerable by the IUCN Red List of Threatened Species (Zerbini et al. 2017).

Aerial surveys have been considered the most appropriate survey method to estimate abundance of franciscanas (e.g. Secchi et al. 2001, Crespo et al. 2002). However, developing abundance estimates from aerial surveys for this species can be challenging because franciscanas are difficult to detect from fast-moving platforms. In addition, surface-based observations have suggested that franciscana groups seen from airplanes are often two to four times smaller than those seen from stationary or slow moving platforms (Bordino et al. 1999, Cremer and Simoes-Lopes 2008, Crespo et al. 2010, Danilewicz et al. 2010), indicating that biases in estimates of the size of groups from an fast-moving, aerial platform can be substantial.

In this sense, the goal of the experiments presented here was to investigate potential sources of visibility bias and group size bias in aerial survey of franciscanas and to investigate whether correction factors to improve/correct estimates of abundance of the species could be developed.

2 METHODS

Experiments were conducted to estimate visibility bias and group size bias in abundance numbers from data recorded during aircraft surveys. Two mainly experiments were conducted: 1) concomitant aerial- and boat-based surveys and 2) helicopter surveys.

2.1 *Experiment 1*

2.1.1 *Study Area and Survey Design*

Concomitant aerial and boat-based surveys were conducted in Babitonga Bay (26^{o}16'S, 048^{o}42'W), southern Brazil from 13 to 24 February 2011. Babitonga Bay is a shallow (average depth 6 m) small estuarine area in northern Santa Catarina State (SC), southern Brazil (Cremer and Simões-Lopes 2008) (Fig. 1). This area presents a number of advantages for the type of study intended here: (1) it is a region where franciscanas predictably occur in relatively large densities throughout the year and show limited or no avoidance to small boats (Cremer and Simões-Lopes 2008), (2) group sizes seen in the bay are believed to be representative of those seen through most of the franciscana range and (3) the bay is relatively protected and therefore provides good weather conditions (e.g. relatively calm waters) for sighting surveys.

A planned area of 160km^2 (Area A, Fig. 1) was defined based on locations where franciscanas where known to occur (e.g. Cremer and Simões-Lopes 2008). Aerial and boat surveys followed design-based line transect methods (Buckland et al. 2001). A sampling grid of 16-17 equally spaced (at 600 m from each other) tracklines was proposed. To ensure sampling was random and independent for each platform, the starting point of the grid was randomly selected for each realization of the design for both survey platform types. The total trackline length (74 km) of the design was specified in a way that the planned area could be fully surveyed by two boats in a period of four hours. This period was chosen to maximize sampling during calm weather, typically observed in this region between dawn and noon. In this four-hour period, the airplane could complete 3-4 realizations of the trackline design.

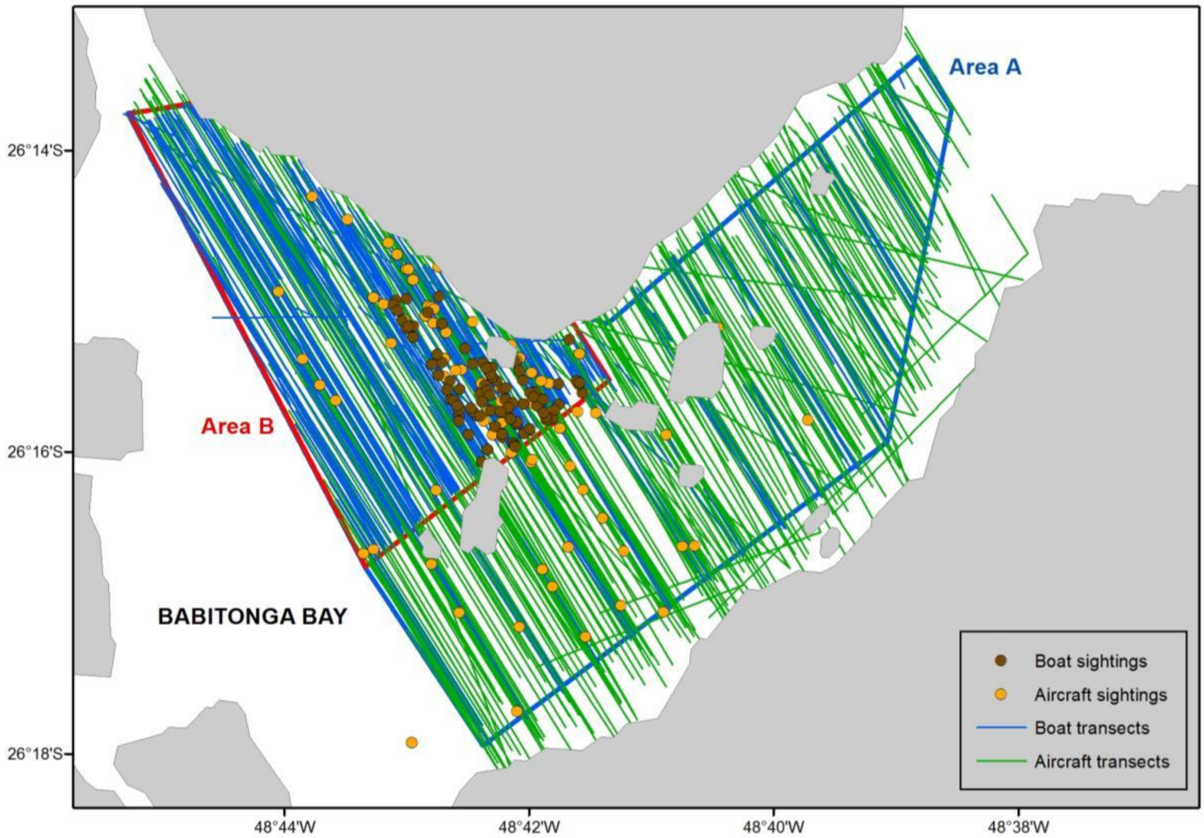

Figure 1. Map of Babitonga Bay, southern Brazil, showing survey areas, realized trackline effort and franciscana sightings for both aircraft and boats. Fonte: Elaborado pelo autor (2019).

After the first two survey days, it became clear that franciscanas were concentrated in a smaller region within the planned region. Based on this information and because of identified restrictions for the navigability of some planned tracklines, the sampling area for the boat surveys was reduced (Area B - 17 km^2, Fig. 1) to maximize records of francicana groups. The trackline design, however, maintained the same line spacing as the original design. The sampling strategy was not modified for the airplane because it could cover the entire survey area (Area A) much faster and because sample sizes collected on the first two days indicated that sufficient sightings (60-80 records, Buckland et al. 2001) would be recorded for estimation of detection probability for this platform. For the purpose of the analysis presented here, only data collected in Area B for both platforms is considered for density estimation.

2.1.2 *Field Methods*

Sampling occurred under good weather conditions and calm seas (Beaufort Sea State < 3). Water transparency was measured with a Secchi disc at the beginning, middle and end of every boat transect and cloud cover was registered once changes were observed. Surveys were conducted in "passing mode" for both survey platforms (i.e. aircraft and boats).

2.1.2.1 *Aerial surveys*

Visual surveys were made from a high-wing, twin-engine *Aerocommander 500B* 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. Different window configuration resulted in a partial overlap in the front and rear observer's field of view (beyond 80 m from the trackline). Observers worked independently during on effort periods, with neither visual nor acoustic communication. The beginning and the end of each transects were informed to the observers by the pilot. Data were recorded by each observer on audio digital recorders and every record was time-referenced based on digital watches synchronized to a GPS. Environmental data (e.g. Beaufort sea state, water transparency, intensity of glare) was recorded at the beginning and end of each transect or whenever conditions changed. When a group of dolphins 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 observer. Additional information such as presence of calves, Beaufort sea state, and water transparency were also recorded along with each sighting.

2.1.2.2 *Boat surveys*

Visual surveys were conducted with two small (5 and 6 m) open boats equipped with 40 and 60 hp outboard engines and a crew of four people: two observers, a data recorder and a pilot. The observers were located at the bow of the boat and searched for dolphins groups with the naked eyes. Observers on the left and right of the bow searched for a 0-50^{o} to the port and starboard, respectively. Once a group was detected, information on the estimated radial distance to the group, the radial angle (measured with an angle board), the species and the group size were relayed to the recorder and registered in a standard data sheet. The recorder was not involved in searching or distance estimation, but assisted the observers in identifying species, tracking detected groups and estimating group size and group composition. Sightings recorded during transit between transects or from or to the harbor were considered off effort sightings.

There is evidence that group size estimation during passing mode can be biased low because observers do not spend sufficient time to obtain an accurate count of the individuals in a group (e.g. Gerrodette et al. 2018). To assess whether this occurred in this study, the boats returned to areas of high density after the end of certain transect lines and randomly approached franciscana groups. A count of individuals in the group during these 'off-effort'/'closing' approaches was then compared to group size estimation on the transect lines.

2.1.2.3 *Distance calibration experiments*

Because observers on the boats estimated the radial distance for the groups with the naked eyes, experiments were conducted to assess measurement error in distance estimation and to correct for such error for each individual observer. The experiment was repeated three times during the study, the first before the surveys started, the second half way through the survey period and the last one at the end of the study. During these experiments, five observers (two for each boat and a standby observer) stood in a fixed platform and independently estimated their distance from a moored object painted with colors resembling the franciscana color pattern. This object was placed at various known distances (measured with a GPS) from the platform. The experiment was conducted in a location with similar visibility conditions to those found in the survey area and the distances at which the moored object was placed from the observers were within the range franciscanas were seen in boat surveys previously conducted in Babitonga Bay (Cremer and Simões-Lopes 2008). For each of the three experiments, 12 distance estimates were obtained for each observer. True (measured) and estimated distances were used to correct for bias in radial distance estimation in a regression framework (Williams et al. 2007).

2.1.3 *Analytical Methods*

2.1.3.1 *Magnitude of bias in group size estimates from the airplane*

A generalized linear model (GLM) with a Poisson error structure was used to assess differences in group sizes estimated from the boats and the airplane. This potential difference is interpreted here as the bias in groups size estimates from the airplane, assuming that estimates from the boats were unbiased. The GLM takes the following form:

$$Log(\mu) = \beta_0 + \beta_1 x_1 + \beta_k x_k + \varepsilon$$

Where: μ is the response variable (group size-1), β_0 is the intercept, $\beta_1 \ldots \beta_k$ are the coefficients for the $x_1 \ldots x_k$ predictor variables (distance - numerical covariate, and platform - factor covariate with two levels "boat" and "airplane") and ε is an error term.

Four models were proposed and Akaike weights *wi* were calculated for each model as a representation of the probability of the model be the actual "best model" within the full set of models (Burnham and Anderson 2002). Inference about the relative importance (RI) of each predictor variable in determining the group size was based on the sum of Akaike weights of each variable across all candidate models containing the variable, and ranged from 1 (most important) to 0 (least important). Model averaging was conducted across a set of models including all possible permutation of the two predictor variables, and model-averaged parameters were estimated for each predictor variable, with unconditional standard errors incorporating model uncertainty (Burnham and Anderson 2002). Model assumptions were verified by plotting residual versus fitted values and versus each covariates in the model (Zuur and Ieno 2016). Model averaging was performed using the package MuMIn (Barton 2017).

Because the perspective from what constitute a group from the boats and from the airplane may be different, observers from both platforms were trained to use the same group definition. A group was defined as an aggregation of dolphins in close proximity of each other (within ~10 body lengths), moving in the same direction and in apparent association (Shane 1990).

2.1.3.2 *Estimation of Detection Probability*

Detection probability was estimated using Conventional (CDS) and Multiple Covariate Distance Sampling (MCDS) methods (Buckland et al. 2001, Marques and Buckland 2003). MCDS differs from CDS as it allows for the inclusion of multiple covariates in the estimation of detection probability (Marques and Buckland 2003). Only the half-normal and the hazard-rate detection functions were proposed to fit distance data for both platforms. Exploratory analyses indicated that adequate fits were obtained by modeling grouped distance data for both platforms (plane grouping intervals: 0-30m, 30-60, 60-130, 130-200m, 200-270m; boats grouping intervals: 0-25m, 25-55m, 55-90m, 90-130m, 130-180m). Beaufort sea state (factor covariate with two levels: "calm", Beafourt sea state between 0 and 1, and "high" between 2 and 3), glare (factor covariate with two levels "presence" and "absence") and group size (numerical covariate) were considered as covariates to model distance data from the airplane. For the boat data analyses, only Beaufort sea state (factor covariate with two levels: "calm", Beafourt sea state ≤ 0, and "high" between 1 and 2) was considered as a 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 and Anderson 2002). Analyses were performed using a set of customized functions (mrds v.2.2.0, Laake et al. 2018) in R (R Development Core Team 2018). Only data recorded by the front observers in the airplane (bubble windows) are considered in the analysis presented in this study because of the partial overlap between front and rear observers (Sucunza et al. 2019).

2.1.3.3 *Group Size, Density, and Abundance Estimation*

Abundance of groups (N_g) and individuals (N_i) was estimated using the Horvitz-Thompson-like estimator as follows (Marques and Buckland 2003):

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

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

Where:

n – number of groups recorded; s_i – group size of each recorded group i; $\hat{p}(z_i)$ – detection probability for vector of sighting-specific covariates z for each recorded group i.

Expected group size was estimated by dividing N_i/N_g (Innes et al. 2002). Variance was estimating 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).

2.1.3.4 *Computing a Correction Factor for Aerial Surveys*

A factor to correct for visibility and group size biases in aerial survey-based estimates of density was computed from the following ratio:

$$CF = \frac{\widehat{D}_{boat}}{\widehat{D}_{plane}}$$

and variance for this CF was approximated by the delta method (Seber 1982).

This CF assumes that no visibility bias occurred in the density estimated by the boat survey (i.e. $g(0)_{\text{boat}} = 1$) and that group sizes were accurately estimated (i.e. underestimation of group size by the boat observers would result in an underestimation of the CF and vice versa).

2.2 *Experiment 2*

2.2.1 *Availability of franciscana groups*

Data on availability of franciscana groups was obtained from helicopter surveys conducted in Babitonga Bay from 23 to 31 January 2014 (Sucunza et al. 2018), and in Ubatuba (23°28'S, 045°03'W), State of São Paulo (SP), southeastern Brazil from 28 November to 15 December. While studies conducted in Babitonga Bay have proved useful (Sucunza et al. 2018), sampling in more heterogeneous habitats are required for correction factors to be more representative of the habitats used by franciscanas. In these sense, new helicopter surveys were conduceted in Ubatuba, a relative high-density area for franciscanas and a region with contrasting environmental conditions from those of Babitonga Bay (i.e. clearer and deeper waters).

A four-seat helicopter Robinson R44 was used during visual surveys in both areas. Flights were conducted at 150 m (500 ft), an altitude consistent with that flow during aerial surveys to estimate abundance of franciscanas (e.g. Secchi et al. 2001, Danilewicz et al. 2010, Crespo et al. 2010, Sucunza et al. 2019). Surveys were carried out during the morning in calm conditions (Beaufort sea state < 3), and had an average duration of 4 h. To maximize visibility for the observers, the doors of the helicopter were detached. Two observers with substantial experience in aerial surveys and familiar with the identification of franciscanas searched for groups of dolphins on the left side of the helicopter. Once a group was detected, the pilot hovered over it and each observer recorded surfacing and dive times independently. A group was defined as an aggregation of dolphins in close proximity of each other, moving in the same direction and in apparent association (Shane 1990). Each observer was responsible for recording biological (e.g., group size, presence of calves) and environmental (e.g. Beaufort sea state, water color) variables. Depth and water transparency (measured with a Secchi disc) at the location of each sighting were recorded from boats operating in the same area and in radio communication with the helicopter. A detailed description of data collection is presented in Sucunza et al. (2018).

A surfacing interval was defined as the period of time in which at least one individual in a group of franciscanas was visually available, at or near the surface, to the observer in a helicopter while a diving interval was defined as the period of time in which all individuals of the group were not visible. A surface-dive cycle was define as the period from the beginning of one surfacing to the next. The proportion of time at surface was calculated as the ratio between a surfacing period and a surface-dive cycle (Sucunza et al. 2018).

Generalized linear mixed-effects model (GLMM) were used to evaluate the effects of biological and environmental predictors on the proportion at surface (the response variable) using the package nlme (Pinheiro and Bates 2019). Model-averaged parameters were estimated for each predictor variable following the modeling processes described in Sucunza et al. (2018).

To estimate the probability of one franciscana group be visually available within the visual range of a passing observer in a fixed-wing aircraft, or availability of franciscana groups, the model proposed by Laake et al. (1997) was used:

$$\widehat{Pr} = \frac{E(s)}{E(s)E(d)} + \frac{E(d)[1 - \mathrm{e}^{-\frac{w(x)}{E(d)}}]}{E(s) + E(d)}$$

where $E(s)$, $w(x)$, and $E(d)$, correspond, respectively, to the mean time of each individual surfacing interval, the window of time during which a franciscana group is in the observer's view at a distance x ($w(0)$ = 6 seconds, Sucunza et al. 2018) and the mean time of each individual diving interval. Standard errors and confidence intervals of $\widehat{Pr}$ were estimated with 1,000 replicates of a nonparametric bootstrap procedure (Manly 2006).

Additional data on franciscana availability was obtained using an artificial franciscana model. The model was constructed using a fresh carcass from a franciscana by-caught in southern Brazil, which makes it identical to an adult franciscana. The experiment followed the methods proposed by Pollock et al. (2006). The model was positioned at different depths in the water column, and each observer in the helicopter recorded if the model was or not recognizable for detection of a passing observer in a fixed-wing aircraft.

3 RESULTS

3.1 *Experiment 1*

The realized effort in areas A and B by boat and aircraft are summarized in Table 1. In nearly 1,900 km of trackline, a total of 356 franciscana groups were recorded in Babitonga Bay.

Table 1. Survey effort conducted by boats and airplane to estimate density of franciscanas in Babitonga Bay, southern Brazil, in February 2011. Survey effort in Area B represents the effort used for density estimation.

	Boats	Airplane
Total survey effort (km) in Areas A and B	551	1,396
Survey effort (km) in Area B	447	476

3.1.1 *Group Size*

Group size statistics for the franciscana aerial and boat surveys in Babitonga Bay are summarized in Table 2. Group sizes varied between 1 and 7 individuals during the survey for both platforms.

Table 2 – Summary of average (SE in parenthesis) group sizes of franciscanas in Babitonga Bay, southern Brazil in February 2011.

	Boat		Plane					
	All		Front		Rear		All	
	Mean (SE)	N	Mean (SE)	N	Mean (SE)	n	Mean (SE)	n
On effort groups	2.96 (1.20)	114	2.18 (0.96)	91	1.95 (1.20)	60	2.09 (1.06)	151
Off effort groups	2.87 (1.08)	50	2.35 (1.47)	31	2.4 (1.26)	10	2.36 (1.40)	41
Total		164		122		70		192

The most parsimonious approximating GLM to assess the influence of distance and platform to the group sizes estimates included both variables as the predictor variables (Table 3). This model suggested that group sizes estimates from the aircraft were significantly smaller than those from the boat. Predicted group sizes for each platform can be computed from the model-averaged predictor coefficients (boat average = exp(0.537)+1 = 2.71 and plane = exp(0.537-0.507)+1 = 2.03) and that indicate that boat group size estimates are 33% greater than those from the airplane (Table 4).

Table 3 – Models proposed to assess differences in group size estimation between boat and aircraft. *wi* = Akaike weights.

Model	Explanatory variables	AIC_c	ΔAIC_c	*wi*
#1	Distance and platform	559	0.00	0.71
2	Platform	561	1.76	0.29
3	Null	574	14.93	0.00
4	Distance	575	16.25	0.00

Table 4. Model-averaged parameter estimates. SE = standard error. RI = relative importance.

Parameter	Mean	SE	RI	*P*
Intercept	0.537	0.123	-	<0.001
Platform (plane)	-0.507	0.127	1.00	<0.001
Distance	2.060	1.046	0.71	0.05

There was no significant difference in group sizes estimated by observer on the boat while surveying the transect lines (mean = 2.96, SE = 1.20) and when groups were approached off effort (mean = 2.87, SE = 1.08) for a more accurate estimation of the number of individuals in the group (*p*-value = 0.71).

3.1.2 *Distance Calibration*

Radial distance data was log-transformed to address the observed heteroscedasticity problem in the least-square regression. One out of five observers tended to underestimate distance by 9% on average. The other four observers overestimated distance by on average 8-40%. Results of the calibration experiment are summarized in Table 5.

Table 5. Observer bias in estimating radial distance from calibration experiments.

Observer	Bias	p-value
1	+34%	<0.001
2	+8%	0.002
3	-9%	<0.001
4	+19%	0.083
5	+40%	0.421

3.1.3 *Density and Abundance Estimates and Correction Factor Computation*

The hazard rate model with size covariate or with Beaufort sea state covariate provided the best fit for perpendicular distance data for airplane and boats, respectively (Fig. 2, Table 6). Boat (2.99 ind/km^2, 95% CI = 1.92-4.66) and plane (0.68 ind/km^2, 95% CI = 0.39-1.16) densities were significantly different and the ratio of the two resulted in a correction factor of 4.42 (CV=0.05). Quantities related to density and abundance estimation are summarized in Table 6.

Table 6. Quantities used for estimation of density of franciscanas in Babitonga Bay, southern Brazil in February 2011. Coefficients of variation are shown in parenthesis when applicable.

	Boats	Airplane
Survey effort	447	476
On effort sightings in Area B	114	56*
Encounter rate	0.69 (0.21)	0.12 (0.24)
Number of sightings used in fitting the detection function	108	88
Average detection probability (*p*)	0.65 (0.08)	0.67 (0.09)
Expected group size[1]	2.91 (0.04)	2.04 (0.09)
Density	2.99 (0.23)	0.68 (0.28)
Abundance	49 (0.23)	11 (0.28)

*Sightings recorded only from front observers; [1]Expected group size was computed after truncation and fitting a detection probability function.

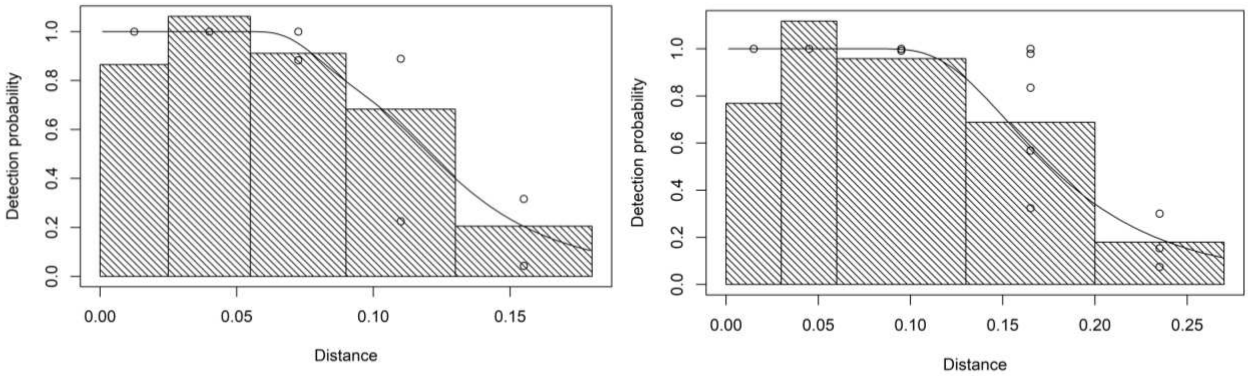

Figure 2. - Detection probability functions fit to perpendicular distance data collected in Babitonga Bay by the boats (left) and the aircraft (right). Fonte: Elaborado pelo autor (2019).

3.2 *Experiment 2*

A total of 45 hours were flown during the helicopter experiments in Babitonga Bay (15hs) and Ubatuba (30hs). A total of 373 complete surface-dive cycles were recorded for 167 franciscana groups. Biological and environmental variables recorded in both areas are summarized in Table 7. The depth at which the franciscana model became recognizable to an aerial platform at 150 m of altitude vary between the areas from 1.40 m in Babitonga Bay and 2.25 m in Ubatuba.

The most parsimonious GLMM only included group size as the predictor variable, suggesting a significant positive effect on the proportion of time at surface (Table 8). Group was the most important predictor variable (RI = 1.0) and was significant in some cases but not other while all the other predictor variables were non-significant in all cases. Model validation indicated no problem when ploted residuals versus fitted values and versus each covariate in the model.

Surfacing and dive intervals were significantly smaller in Babitinga Bay than in Ubatuba (p<0.001), but the proportion of time at surface did not vary significantly between the study areas (Babitonga Bay = 0.36, Ubatuba = 0.34, p = 0.32) (Table 9). The estimated window of time $w(0)$ = 6 seconds, resulted in an estimation of availability of 0.39 (SE=0.008) for both areas combined.

Table 7. Summary of biological and environmental variables recorded in Babitonga Bay and Ubatuba region and tested in the generalized mixed-effects models. SE= standard error.

Variable	Factor/Numeric	Levels	Mean	SE
Group size	Factor	*small* (1-3) and *large* (4-7)	3.03	1.12
Presence of calves	Factor	*yes* and *no*	0.33*	-
Water transparency (m)	Numeric	0.77-7.16	2.49	1.84
Depth (m)	Numeric	4.4-17.3	9.90	3.62

Table 8. Model-averaged predictor coefficients and relative importance (RI). *β* = coefficient values for the averaged model, SE = standard error.

Parameter	*β*	SE	RI	*p*
Group size - *large*	0.20	0.07	1.00	0.007
Transparency	0.01	0.01	0.24	0.31
Depth	0.008	0.009	0.23	0.33
Presence of calves - *yes*	0.003	0.07	0.14	0.97

Table 9. Summary of franciscana groups surface-dive cycles data recorded during helicopter experiments in Babitonga Bay (BB) and Ubatuba region. n-groups = total number of groups, n-cycles = total number of surface-dive cycles. Standard errors shown in parenthesis when applicable.

Area	n-groups	n-cycles	Mean surface (sec.)	Mean dive (sec.)	Proportion at surface
BB	101	248	16.10 (9.75)	39.77 (29.06)	0.36 (0.23)
Ubatuba	66	125	38.78 (13.07)	77.26 (19.98)	0.34 (0.09)
Total	167	373	23.70 (15.33)	52.33 (31.75)	0.35 (0.19)

4 DISCUSSION

This study clearly demonstrates that estimates from aircraft are biased low to a relatively large extent if no correction is applied for visibility bias and group size bias. Visibility bias and group size bias are the main factors affecting estimates of species' occurrence and abundance (e.g. Cockcroft et al. 1992, Gu and Swihart 2004, Fuentes et al. 2015, Williams et al. 2016, Williams et al. 2017), and, although a variety of techniques have been developed to correct for these biases (e.g. Marsh and Sinclair 1989, Laake et al. 1997, Borchers et al. 2006, Pollock et al. 2006, Thomson et al. 2012, Gerrodette et al. 2018), addresses both biases is a challenge frequently not achieved. The present results indicate that abundance estimates computed from aerial surveys data underestimate the true abundance by about 4 times.

Once cetaceans remain short periods of time available to be counted during a passing mode survey, observers tend to underestimate the number of individuals in a group (Gilpatrick et al. 1993, Gerrodette et al. 2018, Boyd et al. 2019). The fast speed of the aircraft reduce the period of time that a dolphins group is within the observers view, reducing the time available to precisely count and thus increasing the magnitude that group sizes are underestimated by an observer in an aircraft. Results of this study shown that there is a significant negative bias (~30%) in the estimated size of groups detected from the aircraft. This result relies on the assumption that observers from the surface (i.e. boats) and from the aerial (i.e. aircraft) platforms used the same group definition and that estimates of group size from the boats were unbiased. Both assumptions were considered to be achieved in this study because there were no doubt between observers about group definition, and because groups seen off effort during boats surveys (i.e. those for which group sizes were estimated after observers spent significant more time with the animals) were not statistically different from those seen during passing mode while sampling survey lines. In addition, the range and mean group size estimated from the boats in this study (range = 1-7, mean = 2.91) were identical to those obtained during an independent experiment conducted from helicopter in the same area (range = 1-7, mean = 2.90, Sucunza et al. 2018), suggesting that group definition was consistent between surface- and aerial-based observers and that estimates of group size from the boats were likely unbiased. However, if group sizes estimated from the boats are biased low, the ~30% group size bias computed here for the airplane is also negatively biased.

Another way of assessing bias in group size estimates from the aircraft would be to compare the expected group sizes computed with the Horvitz-Thompson abundance estimates. In the estimates presented above, groups estimated from the plane (mean group size = 2.04 ind/group) are 43% smaller ($p < 0.001$) than those seen from the boats (mean group size = 2.91 ind/group). This figure is comparable to that computed with the GLM analysis (33%) and likely occurs because the sample sizes used in the two approaches are different and because different factors are considered in their computations. While the GLM uses all on effort sightings detected by the boats and by the airplane (front/bubble windows only), the expected group sizes calculated when computing the abundance estimates only consider groups within the truncation distances of the two platforms. The GLM analysis is preferred here because it uses more data and takes into account perpendicular distance at which groups were estimated from the trackline.

During aircraft surveys, the window of time that an observer have to search on an specific area of the ocean is primarily conditioned by the aircraft speed (Caughley 1974). Increasing speeds, negatively affect the probability of detection of available groups (perception bias) as well as the probability that a group became available during the passage of the aircraft (availability bias). Although perception bias can be computed from data recorded during line-transect surveys (e.g. Pollock et al. 2006, Southwell and Low 2009, Hammond et al. 2013), estimation of availability typically requires additional effort, such as the independent estimates of the availability processes produced in this study.

Environmental variables (e.g., water transparency, depth) have been demonstrated to affect availability of marine species (Slooten et al. 2004, Pollock et al. 2006, Thomson et al. 2011). However, in the present experiments, only the size of the group had a significant effect on the availability of franciscana groups. This apparent lack of effects of environmental variables on the availability process of franciscanas was previously reported by Sucunza et al. (2018), who credited it to the relative narrow range of the values recorded of the environmental covariates in Babitonga Bay. In this study, data from Sucunza et al. (2018) were combined with surface-dive data recorded in Ubatuba waters, which are deeper and clear than those in Babitonga Bay. Although the mean surface and dive intervals varied significantly between both areas (e.g. Table 07), the proportion of time at surface was very similar, which explains, at least partly why environmental covariates may have little effect on the availability of franciscana groups seen from the air.

A potential shortcoming of the present analysis is that no information is available on the surface-dive cycles of franciscana in shallow and clear waters. Although such features are not typical of the franciscana habitat the availability of individuals in areas where the bottom can be seen should equal 1 (Pollock et al., 2006). Based on the observations of the franciscana model, it can be assumed that franciscanas are available to be seen when they are within 1m from the surface irrespective of the transparency of the water.

If one assumes that 33% of the bias in estimates of franciscana abundance from aerial surveys comes from underestimation of group sizes the fraction of the correction factor computed above that correspond to visibility bias is 2.96 (=4.42*(1-0.33)), which is equivalent to an estimate of $g(0) = 0.338$. Once the availability of franciscana groups estimated in this study is equal to 0.39, the proportion of groups available that were missed by the observers can be estimated at 13% (=1-(0.338/0.39)). Similar values of perception bias were reported using mark-recapture distance sampling methods (MRDS, Borchers et al. 1998, 2006) during aerial surveys for franciscana in south and southeast Brazil (perception bias = 13% - 23%, Sucunza et al. 2019). It is interesting to note that the observers changed between the surveys in Sucunza et al. (2019), which indicate a similar rate of miss-detection of franciscana groups between observers with similar experience. Laake et al. (1997) reported that experienced observers missed 14% of available harbor porpoise groups while inexperienced observers missed 77% of the available groups during aerial surveys in coastal waters of Washington State. In the present study perception bias was not assessed because inconsistencies in determining groups that were seen by only front, rear or both observers during the experiments in Babitonga Bay.

4.1 *Application of the Correction Factor to Existing and Future Franciscana Abundance Estimates*

The use of the correction factor computed here to correct existing and future estimates of franciscana abundance requires considerations about the field of view and the speed of the aircraft, flight altitude and experience of the observers. If differences between aircrafts result in different field of view (e.g. Secchi et al. 2001, Crespo et al. 2010), the correction factor may not be applicable. For surveys using the same aircraft and observers with similar experience the use of the correction factor is valid and should be performed.

The new estimates of availability of franciscana groups reported in this study can be used independently of the assumptions described to the correction factor. Experiments to address availability of franciscana groups to aerial platforms are recommended in other regions to compute improved and/or area-specific correction factors. However, the availability of franciscana groups reported here appears to be a robust estimate considering that surveys were carried out in two different locations with environmental characteristics that differ but are consistent with those found throughout most of the species range. Therefore correction factors for availability can be applied in range-wide aerial surveys to improve abundance estimates even if surveys are conducted with different aircrafts.

Acknowledgements

Funding for this study was provided by the IWC Small Cetacean Conservation Fund and Instituto Chico Mendes para a Biodiversidade (Brazilian Government). Data collection was professionally carried out by, Beatriz Schulze, Camila M. Sartori, Dan Pretto, Eduardo R. Secchi, Emanuel Ferreira, Franciele R. de Castro, Luiz Claudio de S. Alves, Marta Cremer, Pablo Denuncio and Paulo A. C. Flores. Assistance with survey design and data analysis was provided by Artur Andriolo and Jeff Laake. Logistical support during field activities was provided by Yatch Clube de Joinville, Univille, Instituto Aqualie (Gustavo Miranda), and Rodrigo Belesso. JAD Taxi Aéreo crew's was key in safely completing this study.

References

Andriolo, A., P. G. Kinas, M. H. Engel, C. C. A. Martins and A. M. Rufino. 2010. Humpback whales within the Brazilian breeding ground: Distribution and population size estimate. Endangered Species Research 11:233-243.

Barlow, J., Oliver, C. W., Jackson, T. D. and B. L. Taylor. 1988. Harbor porpoise, Phocoena phocoena, abundance estimation for California, Oregon, and Washington: II. Aerial Surveys. Fishery Bulletin 86:433-444.

Barton, K. 2017. MuMIn: Multi-Model Inference. R package version 1.40.0.

Borchers, D. L., S. T. Buckland, P. W. Goedhart, E. D. Clarke and S. L. Hedley. 1998. Horvitz-Thompson estimators for double-platform line transect surveys. Biometrics 54: 1221-1237.

Borchers, D. L., J. L. Laake, C. Southwell and C. G. M. Paxton. 2006. Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. Biometrics 62:372-378.

Boyd, C., Hobbs, R. C., Punt, A. E., Shelden, E. W., Sims, C. L. and P. R. Wade. 2019. Bayesian estimation of group size for a costal cetacean using aerial survey data. Marine Mammal Science XX:1-25.

Bordino, P., G. Thompson and M. Iñíguez. 1999. Ecology and behaviour of the franciscana (*Pontoporia blainvillei*) in Bahía Anegada, Argentina. Journal of Cetacean Research and Management 1:213-222.

Boyd, C., Hobbs, A. C., Punt, A. E., Shelden, K. E. W., Sims, C. L. and P. R. Wade. 2019. Bayesian estimation of group sizes for a coastal cetacean using aerial survey data. Marine Mammal Science XXX:1-25.

Buckland S.T., Anderson D.R., Burnham K.P., Laake J.L., Borchers D.L. and Thomas L. 2001. Introduction to Distance Sampling: Estimating Abundance of Wildlife Populations. Oxford University Press, New York.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and L. Thomas. 2004. Advanced Distance Sampling: estimating abundance of biological population. New York: Oxford University Press.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. 2nd ed. New York: Springer.

Caughley, G. 1974. Bias in aerial survey. The Journal of Wildlife Management 38:921-933.

Cockcroft, V. G., Ross, G. J. B., Peddemors, V. M. and D. L. Borchers. 1992. Estimates of abundance and undercounting of bottlenose dolphins off northern Natal, South Africa. South Africa Journal of Wildlife Research 22:102-109.

Cremer, M. J. and P. C. Simões-Lopes. 2008. Distribution, abundance and density estimates of franciscanas, *Pontoporia blainvillei* (Cetacea: Pontoporiidae), in Babitonga bay, southern Brazil. Revista Brasileira de Zoologia 25:397-402.

Crespo, E. A., G. Harris and R. González. 1998. Group size and distributional range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845-849.

Crespo, E. A., Secchi, E. R., Rosa, L. D., Kinas, P. G., Danilewicz, D., Bordino, P. 2002. Report of the working group on abundance estimates. Latin American Journal of Aquatic Mammals 1:65-66.

Crespo, E. A., S. N. Pedraza, M. F. Grandi, S. L. Dans and G. V. Garaffo. 2010. Abundance and distribution of endangered Franciscana dolphins in Argentine waters and conservation implication. Marine Mammal Science 26:17-35.

Danilewicz, D., E. R. Secchi, P. H. Ott, I. B. Moreno, M. Bassoi and M. Borges-Martins. 2009. Habitat use patterns of franciscana dolphins (Pontoporia blainvillei) off southern Brazil in relation to waters depth. Journal of the Marine Biological Association of the United Kingdom 89:943-949.

Danilewicz, D., I. B. Moreno, P. H. Ott, M. Tavares, A. F. Azevedo, E. R. Secchi and A. Andriolo. 2010. Abundance estimate for a threatened population of franciscana dolphins in southern coastal Brazil: Uncertainties and management implications. Journal of the Marine Biological Association of the United Kingdom 90:1659-1666.

Fuentes, M. M. P. B., Bel, I., Hagihara, R., Hamann, M., Hazel, J., Huth, A., Seminoff, J. A., Sobtzick, S. and H. Marsh. 2015. Improving in-water estimates of marine turtle abundance by adjusting aerial survey counts for perception and availability biases. Journal of Experimental Marine Biology and Ecology 471:77-83.

Gerrodette, T., Perryman, W. L. and C. S. Oedekoven. 2018. Accuracy and precision of dolphin group size estimates. Marine Mammal Science XXX:XX-XX.

Gilpatrick Jr., J. W. 1993. Method and precision in estimation of dolphin school size with vertical aerial photography. Fishery Bulletin, 91:641-648.

Gu, W. and K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife-habitat models. Biological Conservation 116:195-203.

Hammond, P. S., Macleod, K., Berggren, P. et al. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164:107-122.

Heide-JØrgensen, M. P., Laidre, K., Borchers, D., Samarra, F. and H. Stern. 2007. Increasing abundance of bowhead whales in west Greenland. Biology Letters 3:577-580.

Hiby A.R. and Hammond P.S. 1989. Survey techniques for estimating abundance of cetaceans. Report of the International Whaling Commission (Special Issue) 11: 47–80.

Innes, S., M. P. Heide-Jørgensen, J. L. Laake, K. L. Laidre, H. J. Cleator, P. Richard and R. E. A. Stewart. 2002. Survey of belugas and narwhals in the Canadian High Arctic in 1996. North Atlantic Marine Mammal Commission Scientific Publication 4:169-190.

Laake J.L., Calambokidis J., Osmek S.D., Rugh D.J. 1997. Probability of detecting harbour porpoise from aerial surveys: estimating g(0). Journal of Wildlife Management, 61: 63-75.

Laake, J., D. Borchers, L. Thomas, D. Miller and J. Bishop. 2018. mrds: Mark-recapture distance sampling. Available at https://cran.r-project.org/package5mrds.

Manly, B. F. J. 2006. Randomization, Bootstrap and Monte Carlo Methods in Biology: 3rd ed. Boca Raton: Chapman & Hall/CRC.

Marques, F. F. C. and S. T. Buckland. 2003. Incorporating covariates into standard line transect analyses. Biometrics 59:924-935.

Marsh, H. and D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management 53:1017-1024.

Ott, P. H., E. R. Secchi and I. B. Moreno, *et al.* 2002. Report of the Working Group on Fishery Interactions. Latin American Journal of Aquatic Mammals 1:55-64.

Pinheiro, J. and D. Bates. 2019. nlme: Linear and nonlinear mixed effects models. R. package version 3.1-140.

Pollock, K. H., H. Marsh, I. R. Lawler and M. W. Alldredge. 2006. Estimating animal abundance in heterogeneous environments: An application to aerial surveys for dugongs. Journal of Wildlife Management 70:255–262.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin & Company Ltd.

Secchi, E. R., P. H. Ott, E. A. Crespo, P. G. Kinas, S. N. Pedraza and P. Bordino. 2001 A first estimate of franciscana (*Pontoporia blainvillei*) abundance off southern Brazil. Journal of Cetacean Research and Management 3:95-100.

Secchi, E. R., P. H. Ott and D. S. Danilewicz. 2003. Effects of fishing by-catch and conservation status of the Franciscana dolphin, *Pontoporia blainvillei*. Pages 174-191, *in* Marine mammals: Fisheries, tourism and management issues, eds. Gales, N., M. Hindell and R. Kirkwood. CSIRO Publishing.

Secchi E. R. 2010. Review on the threats and conservation status of franciscana, *Pontoporia blainvillei* (Cetacea, Pontoporiidae). Pages 323-339, *in* Biology, evolution and conservation of river dolphins within south America and Asia, eds. Ruiz-Garcia M. and J. M. Shostell. Nova Science Publishers Inc.

Shane, S.H. 1990. Behavior and ecology of the bottlenose dolphin at Sanibel Island, Florida. In: Leatherwood, S. and R. R. Reeves, , editors. The bottlenose dolphin. San Diego: Academic Press. pp. 245–265.

Siciliano, S., A. P. Di Beneditto and R. Ramos. 2002. A toninha, *Pontoporia blainvillei* (Gervais & D'Orbigny, 1884) (Mammalia: Cetacea) nos Estados do Rio de Janeiro e Espírito Santo, costa sudeste do Brasil: caracterização dos hábitats e possíveis fatores de isolamento das populações. Boletim do Museu Nacional, Nova Série, Zoologia 146:1-15.

Slooten, E., S. M. Dawson and W. J. Rayment. 2004. Aerial surveys for coastal dolphins: Abundance of Hector's dolphins off the South Island west coast, New Zealand. Marine Mammal Science 20: 477-490.

Southwell, C. and M. Low. 2009. Black and white or shades of grey? Detectability of Adélia penguins during shipboard surveys in the Antarctic pack-ice. Journal of Applied Ecology 46:136-143.

Sucunza, F., D. Danilewicz, M. Cremer, A. Andriolo and A. N. Zerbini. 2018. Refining estimates of availability bias to improve assessment of the conservation status of an endangered dolphin. PLOS ONE 13:e0194213.

Thomson, J. A., Cooper, A. B., Burkolder, D. A., Heithaus, M. R. and L. M. DILL. 2012. Heterogeneous pattern of availability for detection during visual surveys: Spatiotemporal variation in sea turtle dive-surfacing behaviour on a feeding ground. Methods in Ecology and Evolution 3:378-387.

Williams, P. J., Hooten, M. B., Womble, J. N. and M. R. Bower. 2017. Estimating occupancy and abundance using aerial images with imperfect detection. Methods in Ecology and Evolution 8:1679-1689.

Williams, R., Leaper, R., Zerbini, A. N. and P. S. Hammond. 2007. Methods for investigating measurement error in cetacean line-transect surveys. Journal of the Marine Biological Association of the U. k. 87:313-320.

Williams, R. J. E. Moore, C. Gomez-Salaz, F. Trujilo and L. Burt. 2016. Searching for trends in river dolphin abundance: Designing surveys for looming threats, and evidence for opposing trends of two species in the Colombian Amazon. Biological Conservation 195:136-145.

Zerbini, A. N., J. M. Waite, J. L. Laake and P. R. Wade. 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. Deep-sea Research I 53:1772-1790.

Zerbini, A. N., E. Secchi, E. Crespo, D. Danilewicz and R. Reeves. 2017. *Pontoporia blainvillei*. In: IUCN 2017. The IUCN Red List of Threatened Species. 2017. Available: www.iucnredlist.org. Accessed 30 January 2018.

4 CAPÍTULO IV - POPULATION SIZE AND IUCN RED LISTING OF THE ISOLATED NORTHERN POPULATION OF THE FRANCISCANA (*PONTOPORIA BLAINVILLEI*)

Manuscrito em preparação para submissão à revista: *Endangered Species Research*

Doutorando: Federico Sucunza Perez

Orientador: Alexandre Novaes Zerbini

Co- Orientador: Daniel Danilewicz Schiavon

Population size and IUCN Red Listing of the isolated northern population of the franciscana (*Pontoporia blainvillei*)

ABSTRACT

The franciscana (*Pontoporia blainvillei*) is endemic of coastal waters from Brazil (18°25'S) to Argentina (42°10'S). The species is regarded as the most threatened small cetacean in the western South Atlantic Ocean due to high bycatch levels and habitat degradation. The franciscana is listed as Vulnerable in the IUCN Red List of Threatened Species. Recent analysis of mtDNA suggested that individuals found in the species' northern range (Brazilian State of Espírito Santo, ES) represent an isolated population. Aerial surveys (March/2018 and January-February/2019) following design-based line transect methods were conducted to assess distribution and estimate abundance of franciscanas off ES. A total of 2,883 km on siginting effort was carried out from the shore up to the 20 m isobath between Itaúnas (18°25'S) and Presidente Kennedy (21°17'S), north and south ES boundaries respectively. A total of 47 franciscana groups were seen (average group size = 2.5, CV=0.07) in coastal habitats (average distance from the shore = 3.3 km, SE = 2.3 km, range = 0.4 - 8 km). Abundance corrected for visibility and group size biases was estimated at 893 individuals (CV = 0.30, 95% CI = 499 - 1,600) combining data from 2018 and 2019. Results suggest that, at least during the summer, franciscanas in ES are distributed in very coastal habitats between Conceição da Barra (18°35'S) and Santa Cruz (19°56'S), within an area of only 2,400km^2. This is probably the smallest and the one presenting the most restricted range among all franciscana populations. The estimated abundance indicate that the ES population qualifies for listing as "Endangered" under the IUCN Red List criterion C2a(ii) because of the small size (less than 2,500 mature individuals) and because of an inferred decline in abundance as a consequence of bycatch

and habitat degradation. In order to reduce threats to this population management actions are urgently needed.

INTRODUCTION

The franciscana (*Pontoporia blainvillei*), also known as toninha and formerly referred to as the La Plata dolphin, is the only extant member of the family Pontoporiidae (Committee on Taxonomy 2018). The species is endemic of the southwestern Atlantic Ocean waters of Brazil, Uruguay and Argentina (Brownell Jr. 1989, Crespo 2009). Franciscanas occur in coastal and estuarine habitats typically shallower than 30 m, between Itaúnas, Brazil (18º25'), and Golfo San Matías, Argentina (42º10') (Crespo et al. 1998, Siciliano et al. 2002, Danilewicz et al. 2009). There are two gaps in the northern distribution of the franciscana (Siciliano et al. 2002), one, at about 23ºS, subdivides the species into two Evolutionary Significant Units (south and north ESU; Secchi et al. 1998, Cunha et al. 2014). Franciscanas within the northern ESU likely form two demographically isolated populations separated by a latitudinal gap in distribution of approximately 200 km (Fig. 1, Siciliano et al. 2002, Danilewicz et al. 2012, Cunha et al. 2014, Amaral et al. 2018).

The species is considered one of the most threatened cetacean species in South America mainly due to bycatch in gillnet fisheries (Ott et al. 2002, Secchi et al. 2003a, Danilewicz et al. 2010a, Secchi 2010). Bycatch (i.e. mortality and injury due to incidental fishing) in gillnet fishing is a worldwide recognized threat to marine mammal populations since 1970s (*see* Perrin et al. 1994, Read et al. 2006, Read 2008, Reeves et al. 2013). Mortality during fishing activities, especially gillnets and trammel nets, is believed to be unsustainable and have been reported along most of the franciscana's range for the last 70 years (Van Erp 1969, Ott et al. 2002, Secchi et al. 2003a). Habitat degradation in its multiple forms have become better documented and nowadays is considered as another important threat to the survival of franciscana populations (Yogui et al. 2010, Lailson-Brito et al. 2011, Alonso et al. 2012, De la Torre et al. 2012, Lavandier et al. 2016). The species is currently listed as "Vulnerable" in the IUCN Red List of Threatened Species (Zerbini et al. 2017) and "Critically Endangered" by the Brazilian Government (MMA 2014).

In order to guide conservation and management actions the franciscana range was divided into four zones known as ‘Franciscana Management Areas’ (FMAs) (Secchi et al. 2003b): two in Brazil

(FMA I and FMA II), one shared between Brazil and Uruguay (FMA III), and one in Argentina (FMA IV) (Secchi et al. 2003b, Anonymous 2015). Studies on genetics, morphology, distribution, and population parameters provide evidence for population substructure within each FMA (Secchi et al. 1998, Barbato et al. 2013, Crespo et al. 2010, Mendez et al. 2010, Cunha et al. 2014) and call for a reassessment of the FMA boundaries in order to enhance franciscana conservation and management actions.

FMA I encompasses the latitudinal range of the northern ESU, including the Espírito Santo (ES) State and the northern Rio de Janeiro (RJ) State in southeastern Brazil. A recent re-evaluation of the franciscana population structure based on the analysis of mtDNA control region sequences proposed that individuals from FMA I comprise two distinct populations, one in the northern coast of ES (referred to as FMA Ia) and the other along the northern coast of RJ (referred to as FMA Ib) (Cunha et al. 2014). Demographic isolation within FMA I may represent an additional challenge for the conservation of the franciscana, especially if anthropogenic threats are greater for smaller units within more restricted habitats.

FMA I is the least known franciscana stocks. Aerial surveys conducted off FMA I indicate that franciscanas occur in relatively low numbers in the area (Moreno et al. 2003, Danilewicz et al. 2012). During an abundance aerial survey conducted in 2011, more than 1,000 km were surveyed but just three franciscana groups were recorded. Neither of these groups were recorded during on effort transect lines (Danilewicz et al. 2012). Although no quantitative bycatch data are available for FMA Ia, reports from the 1990s indicate that the gillnet fisheries along the ES coast overlaps with the franciscana preferred habitat and bycatch of mature and immature franciscanas has been documented in this fisheries (Siciliano 1994). In 2016 the International Whaling Commission (IWC) adopted the first Conservation Management Plan (CMP) for a small cetacean species (IWC 2016). The CMP for Franciscana has the main objective of protecting franciscana habitat and minimising anthropogenic threats, particularly bycatch. In addition, monitoring of abundance and bycatch, and development of protected areas are included among the CMPs priority actions (IWC 2016). Understanding gaps in distribution along the franciscana range has 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 IWC (Reeves et al. 2003, IWC 2005, ICMBio 2011, Anonymous 2015, IWC 2016).

In this study, aerial surveys were conducted along the range of FMA Ia to assess abundance and distribution within FMA Ia and to assess whether franciscanas occurred in the distributional gap between FMA Ia and FMA Ib. It is expected that results from these surveys will address many of the recommendations referred to above and will assist range states to better manage and conserve franciscanas in these areas.

MATERIAL AND METHODS

Line-transect aerial surveys (Buckland et al. 2001) were conducted on 17-31 March 2018 and 15-31 January/01 February 2019 between the northern (18º25'S) and southern (21º17'S) boundaries of the ES (Fig. 1). This area includes the whole latitudinal range of FMA Ia as well as the gap in the distribution of the franciscana between FMA Ia and FMA Ib (Fig. 1). A set of 177 (105 in 2018 and 72 in 2019) parallel transect lines ranging from 2 to 20 km in length and spaced by ~2.5 km were placed perpendicular to the coast line. This design makes no assumption about the spatial distribution of the animals, maximizes equal sampling probability, and, if needed, allows for poststratification of the study area. To increase sample size data from 2018 and 2019 surveys were combined for the analyses presented in this study.

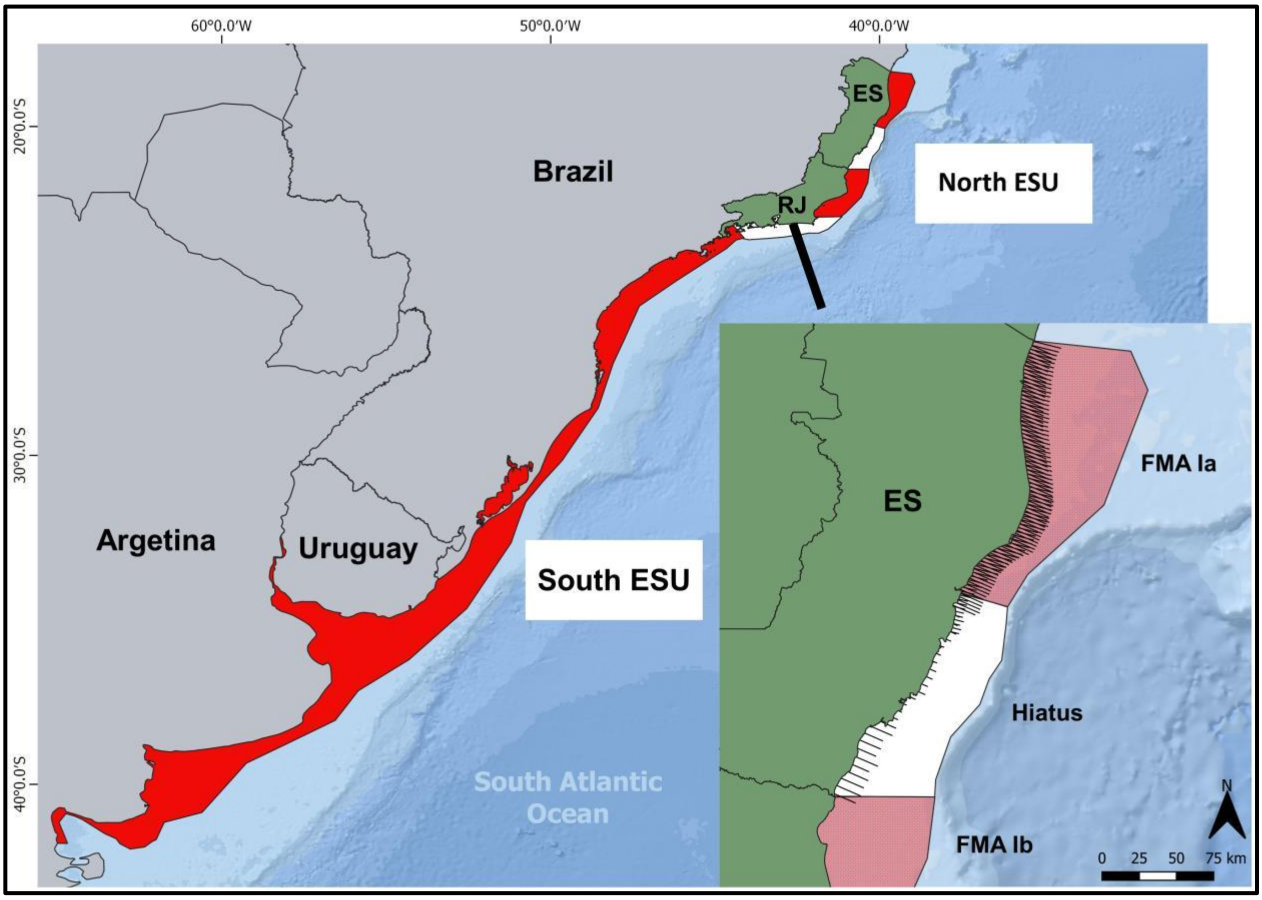

Fig. 1. *large* Map indicative of the franciscana distribution (red areas), the two gaps in the species distribution (white areas) and the two Evolutionary Significant Units (ESU) of the franciscana (boundary pointed by the rectangle). *small* Map of the study area and total realized effort during aerial surveys conducted off the Espírito Santo State ES on March/2018 and January-February/2019. This area encompasses the latitudinal range of the franciscana Management Area (FMA) Ia, and the hiatus in the distribution of the franciscana between FMA Ia and FMA Ib. RJ = Rio de Janeiro State. Fonte: Elaborado pelo autor (2019).

Post-stratification of the study area was carried out by geographic region to accommodate differences in encounter rate (Buckland et al. 2001). Three survey strata were proposed: (1) FMA Ia north stratum (18°36'S - 19°29'S), (2) FMA Ia south stratum (19°29'S - 19°57'S), and (3) the distributional gap in southern ES "Hiatus stratum" (19°57'S - 21°18'S). Total planned effort within the three survey strata corresponded to 2,626 km (2018 = 1,512 km, 2019 = 1,114). Total effort by unit of area was equal to 0.8 within FMA Ia north stratum and equal to 1 within FMA Ia south stratum.

Searching for franciscana groups was conducted from a high-wing, twin-engine *Aerocommander 500B* 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 <= 3). The searching team consisted of four observers, who recorded environmental data (*e.g.*, Beaufort sea state, glare) at the beginning of each transect and whenever conditions changed. The beginning and the end of the transects 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. When a group of franciscanas was detected, the size of the group and additional information such as presence of calves in the groups and Beaufort sea state were recorded. The declination angle between the horizontal and the sighting was obtained using an inclinometer when the group passed abeam of the plane. 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.

Additional transit lines were proposed in areas of high density of franciscanas to increase sample size for the estimation of detection probability. All sightings recorded in these lines were used, along with "on effort" sightings, for the estimation of detection probability. Only sightings detected while flying actual transect lines were used to estimate density and abundance.

Analytical Methods

All sightings recorded in either FMA Ia north and south strata were used to assess distribution patterns of franciscanas in FMA Ia. Bathymetry data were extracted for each franciscana group from the ETOPO1 1 Arc-Minute Global Relief Model (Amante and Eakins 2009*).* Distance from the shore was calculated for each group using *GPS TrackMaker Pro* software*.* A buffer zone was created from the northern limit of the FMA Ia north stratum to the southern limit of the FMA Ia south stratum with a with equal to the maximum distance from the shore that a franciscana group was recorded and its area was assumed to represent the area of occurrence of franciscanas in FMA I. The maximum range of the franciscana in FMA I was calculated as the sum of the covered areas of FMA Ia and Ib strata (Table 1).

Detection probability (*P*) was estimated using conventional distance sampling methods (Buckland et al. 2001). Exploratory analyses indicated that binning the data into four intervals (grouping intervals: 0-40 m, 41-80 m, 81-160 m, 161-200 m) resulted in better model fits. Due to the small sample size only the half-normal detection function without covariates or series expansions was proposed to fit perpendicular distance data (Buckland et al. 2001).

A nonparametric bootstrap was used to estimate detection probability, encounter rate, group size and density variance and intervals (Manly 2004, Williams and Thomas 2009). Analyses were performed using a set of customized functions in R (Laake et al. 2018, R Development Core Team 2018). Bootstrap resample datasets (n = 10,000) were generated by sampling with replacement from the replicate lines within each stratum, ensuring that the number of lines in the resample equals the number in the original data set. For each resample dataset, mean group size and mean detection probability were estimated globally, while encounter rate and density were estimated by stratum. Density (D_B) was then estimated for each resample dataset using the Horvitz-Thopson-like estimator (Thomas et al. 2010) for each stratum, and then taking a weighted average for FMA Ia (Williams and Thomas 2009).

Estimates of detection probability, encounter rate, group size and density (D_B) were taken as the mean of the bootstrap resample estimates (Buckland et al. 1997), and coefficients of variation (CVs) were calculated as standard deviation of the bootstrap estimates divided by the mean. Confidence intervals were obtained using the percentile method (Buckland et al. 2001).

A correction factor for visibility bias (Marsh and Sinclair 1989) and groups size bias computed to correct abundance estimates of franciscana from aerial survey data (CF = 4.86, CV = 0.05; Chapter III of this thesis) was applied to correct the density estimated over bootstrap resamples (D_B). The corrected density estimate (D_c) was computed by multiplying the uncorrected estimate (D_B) by the correction factor mentioned above. Abundance was then estimated as the product of correct density and the total area. The variance of the corrected abundance was approximated by the Delta method (Seber 1982).

RESULTS

A total of 1,547 km and 1,336 km of sighting effort was conducted in 2018 and 2019 aerial surveys respectively, and a total of 47 franciscana groups were sighted in both FMA Ia north and FMA Ia south strata (Fig. 2). No sightings were recorded in the Hiatus stratum (Fig. 2). Franciscana groups were sighted within a maximum of 8 km of distance from shore (average = 3.3 km, SE = 2.3 km, range = 0.4 - 8 km). Area of occurrence was estimated at 1,400 km^2. Group size range from 1 to 6 with a median of 3 individuals per group, and a mean averaged over bootstrap resamples of 2.51 (CV = 0.07, 95% CI = 2.19 - 2.85).

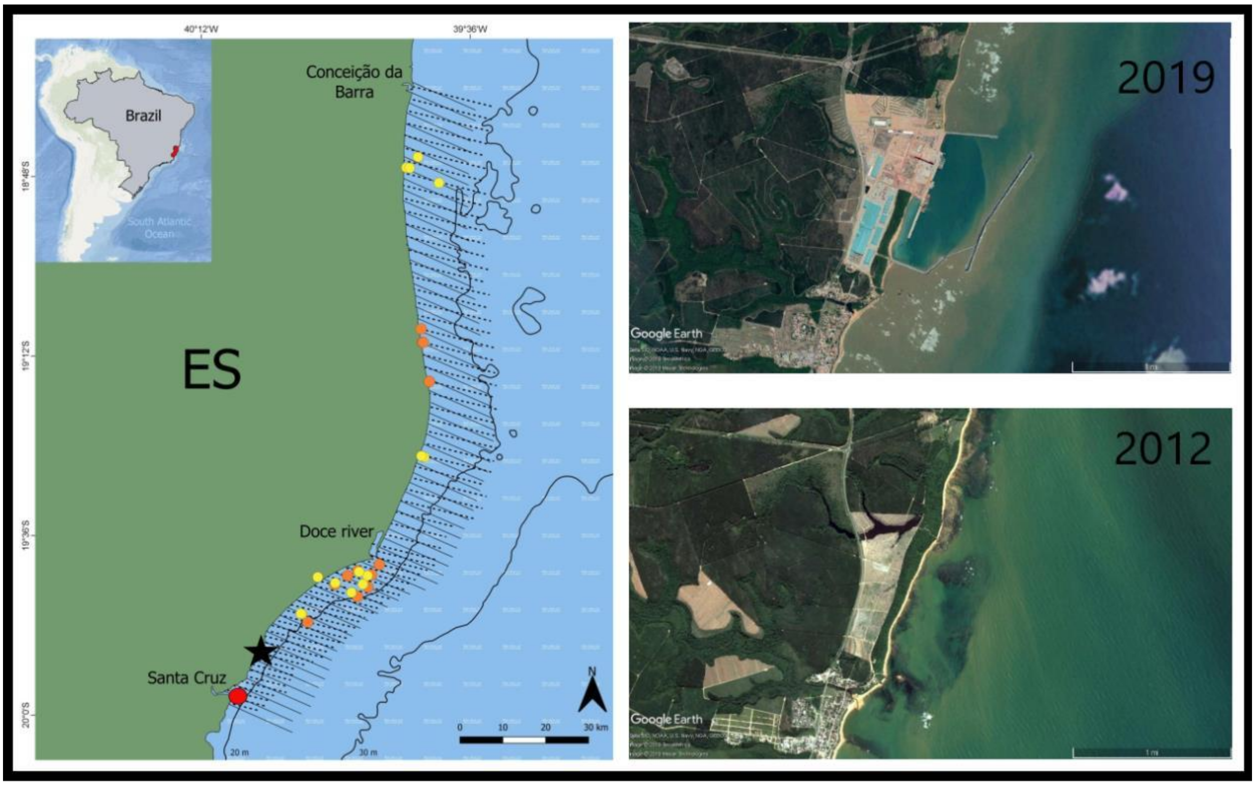

Fig. 2. *left*. Franciscana groups sighted during aerial surveys conducted in 2018 (yellow dots) and 2019 (orange dots) off the Espírito Santo State (ES), and survey effort used for abundance estimation (unbroken lines = 2018 effort, dashed lines = 2019 effort). The red circle indicate a franciscana group recorded during aerial surveys conducted in 2012 off the ES coast (Danilewicz et al. 2012) and the star indicate the location where a shipyard was build after the 2012 surveys. *right*. Google Earth images of the area before (bellow) and after (top) the construction of the shipyard indicated by the star in the left panel. Fonte: Elaborado pelo autor (2019).

The realized effort used for abundance estimation is reported in Table 1. The mean detection probability was 0.81 (CV = 0.13, 95% IC = 0.62 - 0.99). Mean uncorrected density overall combining data from 2018 and 2019 surveys, averaged over bootstrap resamples, was 0.08 individuals/km^2 (CV = 0.30, 95% CI = 0.06 - 0.10). Density corrected for visibility bias and group size bias ($\widehat{Dc} = \widehat{D_B} * FC$) was estimated at 0.38 individuals/km^2 (CV = 0.30, 95% CI = 0.21 - 0.68). This estimate corresponds to a total abundance of 893 individuals (CV = 0.30, 95% CI = 499 - 1,600) in FMA Ia.

Table 1. Survey strata, covered area, number of transects and aerial survey effort used for abundance estimation of franciscanas off Espírito Santo State, Brazil.

Stratum	Area (km^2)	#Transects	Effort (km)
(1) FMA Ia north	1,440	62	933
(2) FMA Ia south	926	65	1,128
(3) Hiatus	-	41	333
Total	2,366	168	2,394

Table 2. Density estimates of franciscanas in Espiríto Santo State, southeastern Brazil, through the study period (*i.e.*, 2018-2019). Franciscana Management Area Ia (FMA Ia). FMA Ia south and FMA Ia north correspond to geographic regions (i.e. strata) used for density estimation. Coefficient of variation (CV). n = number of sightings used for abundance estimation, ER = number of individuals/km, $\widehat{Si}$ = estimated average group size (averaged over all bootstrap resamples), $\widehat{D_B}$ = estimated uncorrected density of individuals/km^2 (averaged over all bootstrap resamples), $\widehat{Dc}$ = estimated density of individuals/km2 corrected for visibility bias and group size bias, CI = confidence intervals.

Strata	n	ER	$\widehat{Si}$	$\widehat{D_B}$	$\widehat{Dc}$	95% CI
FMA Ia sul	12	0.01 (0.30)	2.51 (0.07)	0.10 (0.33)	0.49 (0.33)	0.26 - 0.93
FMA Ia north	9	0.008 (0.47)	2.51 (0.07)	0.06 (0.49)	0.30 (0.49)	0.12 - 0.76
FMA Ia	21	0.01 (0.27)	2.51 (0.07)	0.07 (0.30)	0.38 (0.30)	0.21 - 0.68

DISCUSSION

The present study indicate that FMA Ia population is probably the smallest and the one presenting the most restricted range (maximum of 2,366 km^2) among all franciscana populations. Franciscanas in FMAIa are distributed along the northern range of the species and are likely isolated from all other populations (Siciliano et al. 2002, Danilewicz et al. 2012, Cunha et al. 2014, Amaral et al. 2018). During more than 300 km of sighting effort no franciscana groups were sighted in the distributional gap between FMA Ia and FMA Ib, reinforcing the evidence of demographic isolation within FMA I.

Habitat degradation in the form of overfishing, pollution by debris, chemical and biological agents, noise and disturbance caused by ongoing shipping as well as coastal construction among other human activities, is considered a major threat for the conservation of the franciscana along its entire range (Yogui et al. 2010, Lailson-Brito et al. 2011, Alonso et al. 2012, De la Torre et al. 2012, Lavandier et al. 2016). Recently, one of the most catastrophic environmental disaster of Brazil, caused by the collapse of a tailing dam in the Doce river, discharged millions of meters of metal-contaminated slurry into ES coastal waters (Hatje et al. 2017, Magris et al. 2019). The plume of pollutant sediments from the dam collapse spread towards the area where most franciscana sightings were recorded during this study (e.g., compare Fig. 2 above with Fig. 9 in Magris et al. 2019). The effect of the collapse of the dam on franciscanas in FMA Ia is still unknown and may have contributed to reduce the population to its current abundance.

Habitat degradation may also be playing an important role in shaping habitat use of the franciscana in ES, and potentially causing loss of habitat for the species. During aerial surveys conducted in 2011 franciscana groups were recorded as far south as Santa Cruz (19º58') (Danilewicz et al. 2012). In the present surveys, franciscana groups were not detected as far south as Santa Cruz (Fig. 2). The closest sighting was about 20 km north of this location despite an increase of up to 30 times in sighting effort in the area between the 2011 and 2018-2019 surveys and an expected increase in experience in detecting franciscana groups by the observer surveying this area in the two time periods. Between the surveys, a shipyard was build (Fig. 2) near Santa Cruz in response to the needs to provide vessels to the growing offshore oil exploration of the Brazilian pre-salt region. Construction of this shipyard increased ship traffic and potentially altered the array of features that typify the habitat of the franciscana (Pinedo et al. 1989, Bordino et al. 1999, Danilewicz et al. 2009, Amaral et al. 2018). It is difficult with the existing data to suggest that the construction of the shipyard displaced franciscanas from the region, but this serves as a potential example of the effect that habitat modification can have on this population. Erosion of habitat quality associated with shrinking available habitat would increase the exposure of individual dolphins to human impacts and thus impinge the conservation of the franciscana.

While the threats from habitat degradation are pervasive and complex, the mortality due to bycatch in gillnets is recognized as the major pressure on the long-term viability of franciscana populations (e.g. Kinas 2002, Ott et al. 2002, Secchi 2006). Incidental mortality of this species in gillnets and other types of fishing gear have been documented since 1940 in Uruguay (Van Erp 1969), and is currently reported for almost all areas where the franciscana habitat overlaps with gillnetting fishing grounds (Corcuera 1994, Crespo et al. 1994, Siciliano 1994, Secchi et al. 1997, Di Beneditto et al. 1998, Bertozzi and Zerbini 2002, Ott et al. 2002, Rosas et al. 2002, Cremer et al. 2013).

Mortality due to bycatch is considered unsustainable and will likely drive the species to extinction if no management actions are effectively enforced (Kinas 2002, Kinas et al. 2002, Secchi 2006, Danilewicz et al. 2010b).

Data from the 1990's suggested that fishing communities along the ES coast captured franciscanas in various stages of maturity, including adult females and calves, and operated well within the preferred habitat of the species (Siciliano 1994). However, no statistically valid estimates of bycatch numbers had been computed at that time. New fisheries monitoring data have become available since the late 2010s. They show an apparent increase in fishing effort through most fishing communities of ES, and they also suggest mortality in gillnets continues to occur (Marcondes et al. 2018). Yet, quantitative estimates of bycatch mortality are needed to better understand the impact of fisheries on the small FMA Ia franciscana population.

Although research to assess and monitor population abundance and trends provides key information to plan effective management actions, it is remarkable difficult to detect declines in population numbers before the population has been severely depleted, especially for small populations (Gerrodette 1987, Wade and Gerrodette 1992, Taylor and Gerrodette 1993, Fujiwara 2001, Taylor et al. 2016). In this sense, an attempt is made here to assess what levels of bycatch mortality could be sustainable given the present estimate of population size. An internationally recognized assessment method, the potential biological removal (PBR) (Wade 1998, Taylor et al. 2000) can be calculated as a reference for sustainable bycatch. PBR is calculated as the product between the minimum population size (N_{min} = 788, the 20th percentile of the abundance estimated), 0.5 the maximum net population growth rate (Rmax = 0.04, default value used for cetaceans, Wade 1998) and a recovery factor (F_R) that allow to account for uncertainty in population status. F_R was defined equal 0.1 because of the proposed "Endangered" conservation status of the FMA Ia population (Wade 1998). Following this PBR for the ES franciscana population would be computed as 2, suggesting that the mortality of two franciscanas per year due to bycatch in gillnets could lead to depletion of this isolated population.

The Brazilian fishing regulation INI 12/2012 (MPA/MMA 2012) was established to regulate gillnet fisheries and reduce bycatch of the franciscana by banning fishing off ES coastal waters for motorized boats and industrial boats (i.e., >20 gross tonage) within one and three nautical miles (nm) from the coast, respectively. These protected zones account for, respectively, 35% (or 312 potentially protected franciscanas within 1 nm) and 79% (or 705 potentially protected franciscanas within 3 nm) of the total sightings recorded off FMA Ia. These numbers suggest that if that full compliance of the INI 12/2012 along the ES coast would likely reduce bycatch and result in protection and thus management actions should be directed to guarantee fully compliance with among fishing communities.

Continued population monitoring is crucial to better understand the impacts of bycatch as well as other human-caused mortality on the long-term population viability of franciscanas inhabiting the ES coastal waters. It is important to note that the PBR appropriately include all human-caused mortality, and that although the PBR do not evidence decline in population numbers, it flags populations that may be experiencing unsustainable mortality aiming to start reducing mortality before the population has been depleted (Wade 1998, Taylor et al. 2000). The PBR, however, should not substitute proper population viability analysis (Gilpin and Soule 1986) that allow to incorporate factors known to affect specially small and threatened populations, such as environmental and demographic stochasticity.

Based on the estimated abundance of 893 (CV = 0.30) individuals and assuming an even sex ration and an even proportion of mature and immature animals in the population, it is expected that no more than 447 are mature individuals and no more than 224 are mature females. Under these circumstances, the FMA Ia population qualifies for listing as "Endangered" under the IUCN Red List criterion C2a(ii) because of the small size (less than 2,500 mature individuals) and because of an inferred decline in abundance as a consequence of bycatch and habitat degradation. While bycatch has not been estimated, increasing fishing effort in coastal waters of ES in recent years suggests that mortality has probably also increased. In addition, habitat degradation due to expansion of human occupation along the coast of ES has expanded in the last few years has also increased so threats to this species continues in higher levels than in the past. The relatively low abundance of franciscanas in FMA Ia highlights the higher risk of extinction of this population as it qualifies for a higher threat category than the species as a whole, which is currently listed as "Vulnerable" (Zerbini et al., 2017).

CONCLUSIONS

The information presented above suggests that the demographically isolated franciscana population of FMA Ia should be listened as “Endangered” under the IUCN Red List Categories and Criteria (IUCN 2012). In order to reduce threats to this population management actions are needed. An important one would be to reduce gillnet fishing effort or reduce the spatial overlap between franciscanas and gillnets. Although the current gillnet fishing regulations INI 12/2012 represents an important legal framework to reduce bycatch, it is necessary to enforce the fishing ban areas to effectively evaluate the conservation impact of these regulations. New data on abundance, distribution and bycatch mortality will allow to continue monitoring the ES population status and refine existing management actions or plan for future ones.

Distribution models could be used to assess the effectiveness of temporal and/or spatial area closure with an increase in survey effort and franciscana sighting data. In addition, levels of mortality due to chemical pollution, ship disturbance, noise and other human activities must be quantitatively evaluated. Habitat degradation is potentially shrinking available habitats for franciscanas in ES, increasing the exposure of individuals to threats and the probability that mortality in fisheries is unsustainable. Clearly, additional conservation efforts are needed to minimize the risk of extinction of the smallest and northernmost franciscana population.

References

Alonso, M. B., M. L. Feo, C. Corcellas, *et al.* 2012. Pyrethroids: A new threat to marine mammals? Environmental International 47: 99-106.

Amante, C. and B. W. Eakins. 2009. ETOPO-1 1 arc-minute global relief model: Procedures, data source and analysis. U.S. Department of Commerce, NOAA Technical Memorandum NESDIS NGDC-24. 19p.

Amaral, K. B. do, Danilewicz, D., Zerbini, A. et al. 2018. Reassessment of the franciscana Pontoporia blainvillei (Gervais & d'Orbigny, 1844) distribution and niche characteristics in Brazil. Journal of Experimental Marine Biology and Ecology 508:1-12.

Anonymous. 2015. Report of the VIII Workshop for the Research and Conservation of the Franciscana dolphin (*Pontoporia blainvillei*) in the soutwestern Atlantic. UNEP/CMS, São Francisco do Sul, Brazil. 25p.

Barbato, B. H. A., E. R. Secchi, A. P. M. Di Beneditto, et al. 2013. Geographical variation in franciscana (*Pontoporia blainvillei*) external morphology. Journal of the Marine Biological Association of the United Kingdom 92:1645-1656.

Bertozzi, C. P. and A. N. Zerbini. 2002. Incidental mortality of Franciscana (*Pontoporia blainvillei*) in the artisanal fishery of Praia Grande, São Paulo State Brazil. Latin American Journal of Aquatic Mammals 1:153-160.

Bordino, P., G. Thompson and M. Iñíguez. 1999. Ecology and behaviour of the franciscana (*Pontoporia blainvillei*) in Bahía Anegada, Argentina. Journal of Cetacean Research and Management 1:213-222.

Buckland, S. T., K. P. Burnham and N. H. Augustin. 1997. Model selection: An integral part of inference. Biometrica 53:603-618.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of wildlife populations. Oxford University Press.

Committee on Taxonomy. 2018. List of marine mammal species and subspecies. Society for Marine Mammalogy. Available from www.marinemammalscience.org. Accessed 25 July 2019.

Corcuera, J. 1994. Mortality of Pontoporia blainvillei in Northern Buenos Aires Province: the threat of small fishing camps. Pages 291-294 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan and J. Barlow. International Whaling Commission, Special Issue 15.

Cremer, M. J., C. M. Sartori, A. C. Holz, B. Schulze, N. Z. dos Santos, A. K. de M. Alves and R. L. Paitach. 2013. Franciscana strandings on the north coast of Santa Catarina State and insights into birth period. Biotemas 26:133-139.

Crespo, E. A., J. F. Corcuera and A. L. Cazorla. 1994. Interactions between marine mammals and fisheries in some coastal fishing areas of Argentina. Pages 269-282 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan and J. Barlow. International Whaling Commission, Special Issue 15.

Crespo, E. A., G. Harris and R. González. 1998. Group size and distributional range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845-849.
Crespo, E. A. 2009. Franciscana dolphin Pontoporia blainvillei. Pages 466-469 *in* Encyclopedia of marine mammals, 2nd ed, eds. Perrin, W. F., B. Würsig and J. G. M. Thewissen. Academic Press.

Crespo, E. A., S. N. Pedraza, M. F. Grandi, S. L. Dans and G. V. Garaffo. 2010. Abundance and distribution of endangered Franciscana dolphins in Argentine waters and conservation implication. Marine Mammal Science 26:17-35.
Cunha, H. A., B. V. Medeiros, L. A. Barbosa, M. J. Cremer, J. Marigo, J. Lailson-Brito, A. F. Azevedo and A. M. Solé-Cava. 2014. Population structure of the endangered franciscana dolphin (*Pontoporia blainvillei*): Reassessing management units. PLOS ONE 9:e85633.

Danilewicz, D., E. R. Secchi, P. H. Ott, I. B. Moreno, M. Bassoi and M. Borges-Martins. 2009. Habitat use patterns of franciscana dolphins (Pontoporia blainvillei) off southern Brazil in relation to waters depth. Journal of the Marine Biological Association of the United Kingdom 89:943-949.

Danilewicz, D., I. B. Moreno, M. Borges-Martin, M. Muelbert, L. Oliveira, P. H. Ott, E. R. Secchi and M. Tavares. 2010a. Toninha, *Pontoporia blainvillei*. Pages 466-469 *in* Espécies da Fauna Ameaçada de Extinção: Recomendações para o manejo e políticas públicas, ed. Rambaldi, D. MMA.

Danilewicz, D., I. B. Moreno, P. H. Ott, M. Tavares, A. F. Azevedo, E. R. Secchi and A. Andriolo. 2010b. Abundance estimate for a threatened population of franciscana dolphins in southern coastal Brazil: Uncertainties and management implications. Journal of the Marine Biological Association of the United Kingdom 90:1659-1666.

Danilewicz, D., A. N. Zerbini, A. Andriolo, *et al.* 2012. Abundance and distribution of an isolated population of franciscana dolphins (*Pontoporia blainvillei*) in southeastern Brazil: Red alert for FMA I?. International Whaling Commission, Scientific Committee Paper SC/64/SM17.

De la Torre, A., M. B. Alonso, M. A. Martínez, *et al.* 2012. Dechlorane-related compounds in franciscana dolphin (*Pontoporia blainvillei*) from southeastern and southern coast of Brazil. Environmental Science & Technology 46:12364-12372.

Di Beneditto, A. P. M., R. M. A. Ramos and N. R. W. Lima. 1998. Fishing activity in northern Rio de Janeiro State (Brazil) and its relation with small cetaceans. Brazilian Archives of Biology and Technology 41: 296-302.

Fujiwara, M. and H. Caswell. 2001. Demography of the endangered North Atlantic right whale. Nature 414:537-541.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364-1372.

Gilpin, M. E. and M. **E.** Soulé. 1986. Minimum viable populations: The process of species extinctions. Pages 13-34 *in* Conservation biology: The science of scarcity and diversity, ed., M. E. Soulé. Sinauer Associated.

Hatje, V., R. M. A. Pedreira, C. E. De Rezende, et al. 2017. The environmental impacts of one of the largest tailing dam failures worldwide. Scientific Report 7:1–13.

ICMBio. 2011. Plano de ação nacional para a conservação do pequeno cetáceo – Toninha (*Pontoporia blainvillei*). 76p.

International Whaling Commission. 2005. Annex L - Report of the Sub-Committee on Small Cetaceans. Journal of Cetacean Research and Management 7:307-326.

International Whaling Commission. 2016. A conservation management plan for franciscana (*Pontoporia blainvillei*). IWC/66/CC11. 22p.

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1., second edition. IUCN.

Kinas, P. G. 2002. The impact of incidental kills by gill nets on the franciscana dolphin (*Pontoporia blainvillei*) in southern Brazil. Bulletin of Marine Science 70:409-421.

Kinas, P. G., E. R. Secchi, R. Ramos, D. Danilewicz and E. A. Crespo. 2002. Report of the Working Group on Vital Parameters and Demography. Latin American Journal of Aquatic Mammals 1:43-46.

Laake, J., D. Borchers, L. Thomas, D. Miller and J. Bishop. 2018. mrds: Mark-recapture distance sampling. Available at https://cran.r-project.org/package5mrds.

Lailson-Brito, J., P. R. Dorneles, C. E. Azevedo-Silva, *et al.* 2011. Organochlorine concentrations in franciscana dolphins, *Pontoporia blainvillei*, from Brazilian waters. Chemospehere 84:882-887.

Lavandier, R., J. Arêas, N. Quinete, *et al.* 2016. PCB and PBDE levels in a highly threatened dolphin species from the southeastern Brazilian coast. Environmental Pollution 208:442-449.

Magris, R. A., M. Marta-Almeida, J. A. F. Monteiro and N. C. Ban. A modelling approach to assess the impact of land mining on marine biodiversity: Assessment in coastal catchments experiencing catastrophic events (SW Brazil). Science of Total Environment 659:828-840.

Manly, B.F.J. 2006. Randomization, Bootstrap and Monte Carlo Methods in Biology: Third edition. United States of America: Chapman & Hall/CRC.

Marcondes, M. C. C., M. Angeli, F. Fontes, J. T. Pallazo Jr., R. Campos, C. Daper and M. Cremer. 2018. Report on franciscana fisheries interaction. International Whaling Commission, Scientific Committee Paper SC/67b/SM/03.

Marsh, H. and D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management. 53:1017-1024.

Mendez, M., H. C. Rosenbaum, A. Subramaniam, C. Yackulic and P. Bordino. 2010. Isolation by environmental distance in mobile marine species: Molecular ecology of franciscana dolphins at their southern range. Molecular Ecology 19:2212-2228.

MMA. 2014. Lista nacional oficial de espécies da fauna ameaçada de extinção—Mamíferos, aves, répteis, anfíbios e invertebrados terrestres. In: Portaria MMA no. 444, de 17 de dezembro de 2014, Brasil. Available from http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2014/p_mma_444_

2014_lista_esp%C3%A9cies_ame%C3%A7adas_extin%C3%A7%C3%A3o.pdf. Accessed 27 July 2017.

Moreno, I. B., C. C. A. Martins, A. Andriolo, M. H. Engel. 2003. Sightings of franciscana dolphins (*Pontoporia blainvillei*) off Espírito Santo, Brazil. Latin American Journal of Aquatic Mammals 2:131-132.

MPA/MMA. 2012. Instrução Normativa Interministerial MPA/MMA Nº 12, de 22 de agosto de 2012. Available from http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Instrucao_normativa/2012/in_inter_mpa_mma_12_2012_redesemalhe_se_s.pdf. Accessed 27 July 2017.

Ott, P. H., E. R. Secchi and I. B. Moreno, *et al.* 2002. Report of the Working Group on Fishery Interactions. Latin American Journal of Aquatic Mammals 1:55-64.

Perrin, W. F., G. P. Donovan and J. Barlow eds. 1994. Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps. Report of the International Whaling Commission, Special Issue 15.

Pinedo, M. C., R. Praderi and R. L. Brownell Jr. 1989. Review of the biology and status of the franciscana *Pontoporia blainvillei* (Gervais & D'Orbigny, 1844). Pages 46-51 *in* Biology and conservation of the river dolphins, eds. Perrin, W. F., R. L. Brownell Jr., K. Zhou and L. Jiankang. IUCN.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Read, A. J., P. Drinker and S. Northridge. 2006. Bycatch of marine mammals in US and global fisheries. Conservation Biology 20: 163-69.

Read, A. J. 2008. The looming crisis: Interactions between marine mammals and fisheries. Journal of Mammalogy 89:541-548.

Reeves, R. R., B. D. Smith, E. Crespo and N. G. Di Sciara. 2003. Dolphins, whales, and porpoises: 2002-2010 conservation action plan for the world's cetaceans. IUCN Species Survival Commission.

Reeves, R. R., K. McClellan and T. B. Werner. 2013. Marine mammal bycatch in gillent and other entangling net fisheries, 1990 to 2011. Endangered Species Research 20:71-97.

Rosas, F. C. W., E. L. A. Monteiro-Filho and M. R. de Oliveira. 2002. Incidental catches of Franciscana (*Pontoporia blainvillei*) on the southern coast of São Paulo State and the coast of Paraná State, Brazil. Latin American Journal of Aquatic Mammals 1:161-167.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin & Company Ltd.

Secchi E. R., A. N. Zerbini, M. Bassoi, L. Dalla Rosa, L. M. Moller and C. C. Rocha-Campos. 1997. Mortality of franciscanas, *Pontoporia blainvillei*, in coastal gillnets in southern Brazil: 1994-1995. Report International Whaling Commission. 47:653–658.

Secchi, E. R., J. Y. Wang, B. W. Murray, C. C. Rocha-Campos and B. N. White. 1998. Population differentiation in the franciscana (Pontoporia blainvillei) from two geographic locations of Brazil as determined from mitochondrial DNA control region sequences. Canadian Journal of Zoology 76: 1622-1627.

Secchi, E. R., P. H. Ott and D. S. Danilewicz. 2003a. Effects of fishing by-catch and conservation status of the Franciscana dolphin, *Pontoporia blainvillei*. Pages 174-191, *in* Marine mammals: Fisheries, tourism and management issues, eds. Gales, N., M. Hindell and R. Kirkwood. CSIRO Publishing.

Secchi, E. R., D. Danilewicz and P. H. Ott. 2003b. Applying the phylogeographic concept to identify franciscana dolphin stocks: Implications to meet management objectives. Journal of Cetacean Research and Management 5:61-68.

Secchi E. R. 2006. Modelling the population dynamics and viability analysis of franciscana (*Pontoporia blainvillei*) and Hector's dolphins (*Cephalorhynchus hectori*) under the effects of bycatch in fisheries, parameter uncertainty and stochasticity. Unpublished thesis, University of Otago.

Secchi E. R. 2010. Review on the threats and conservation status of franciscana, *Pontoporia blainvillei* (Cetacea, Pontoporiidae). Pages 323-339, *in* Biology, evolution and conservation of river dolphins within south America and Asia, eds. Ruiz-Garcia M. and J. M. Shostell. Nova Science Publishers Inc.

Siciliano S. 1994. Review of small cetacean and fishery interaction in coastal waters of Brazil. Pages 241-450 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan and J. Barlow. International Whaling Commission, Special Issue 15.

Siciliano, S., A. P. Di Beneditto and R. Ramos. 2002. A toninha, *Pontoporia blainvillei* (Gervais & D'Orbigny, 1884) (Mammalia: Cetacea) nos Estados do Rio de Janeiro e Espírito Santo, costa sudeste do Brasil: caracterização dos hábitats e possíveis fatores de isolamento das populações. Boletim do Museu Nacional, Nova Série, Zoologia 146:1-15.

Slooten, E., J. Y. Wang, S. Z. Dungan, *et al.* 2013. Impacts of fisheries on the critically endangered humpback dolphin *Sousa chinensis* population in the eastern Taiwan Strait. Endangered Species Research 22:99-114.

Taylor, B. L. and T. Gerrodette. 1993.The use of statistical power in conservation biology: The vaquita and northern spotted owl. Conservation Biology 7:489-500.

Taylor, B. L., P. R. Wade, D. P. De Master and J. Barlow. Incorporating uncertainty into management models for marine mammals. Conservation Biology 14:1243-1252.

Taylor, B. L., L. Rojas-Bracho, J. Moore, et al. 2016. Extinction is imminent for Mexico's endemic porpoise unless fishery bycatch is eliminated. Conservation Letters XX:1-8.

Thomas, L., S. T. Buckland, E. Rexstad, *et al.* 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.

Van Erp I. 1969. In quest of the La Plata dolphin. Pacific Discovery 22:18-24.

Wade, P. R. and T. Gerrodette. 1992. Estimates of dolphin abundance in the eastern tropical Pacific: Preliminary analysis of five years of data. Report of the International Whaling Commission 42:533-539.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14:1-37.

Williams, B. K., J. D. Nichols and M. J. Conroy. 2001. Analysis and management of animal populations: Modeling, estimation, and decision making. Academic Press.

Williams, R. and L. Thomas. 2009. Cost-effective abundance estimation of rare animals: Testing performance of small-boat surveys for killer whales in British Columbia. Biological Conservation 142:1542-1547.

Yogui, G. T., M. C. O. Santos, C. P. Bertozzi and R. C. Montone. 2010. Levels of persistent organic pollutants and residual pattern of DDTs in small cetaceans from the coast of São Paulo, Brazil. Marine Pollution Bulletin 60:1862-1867.

Zerbini, A. N., E. Secchi, E. Crespo, D. Danilewicz and R. Reeves. 2017. *Pontoporia blainvillei*. In: IUCN 2017. The IUCN Red List of Threatened Species. 2017. Available: www.iucnredlist.org. Accessed 30 January 2018.

5 CONSIDERAÇÕES FINAIS

As plataformas aéreas tripuladas, atualmente, representam a forma mais efetiva de estimar a abundância e avaliar a distribuição da toninha. O elevado grau de ameaça que a espécie enfrenta, associado à constante degradação da biodiversidade marinha, demanda a produção de respostas robustas e rápidas, no tempo necessário para a implementação de medidas de manejo. Embora as plataformas aéreas possibilitem gerar estimativas populacionais em curtos períodos de tempo, os resultados do presente estudo indicam que se não corrigidas tais estimativas são significativamente subestimadas.

O viés de visibilidade representa o maior erro associado as estimativas aéreas de abundância de toninha. Embora detectar grupos de toninhas a 150 m de altura e 170 - 190 km/h represente um grande desafio para observadores, a porcentagem de perda de grupos disponíveis para serem detectados na ou perto da linha de transecção "viés de percepção" foi de ~20%. Uma potencial forma de eliminar o viés de percepção nas estimativas de abundância de toninha seria realizar o registro fotográfico da linha de transecção durante o esforço de observação. A possibilidade de rever as fotografias potencialmente eliminaria esse viés. Contudo, a maior taxa de perda de grupos de toninha ocorre como resultado do viés de disponibilidade. O presente estudo indicou que ~60% dos grupos de toninha estariam indisponíveis "mergulhando" para serem detectados durante a passagem da aeronave. Esse viés não pode ser eliminado das estimativas, mesmo utilizando helicópteros, e, assim, deve ser computado sempre que possível. Os resultados indicaram que a disponibilidade de grupos de toninha não varia significativamente em função de variáveis ambientais como profundidade e transparência da água, o que possibilita, na falta de uma estimativa pontual, utilizar a correção para o viés de disponibilidade deste estudo ao longo da distribuição da espécie.

Como observado para outras espécies de cetáceos (Gerrodette et al. 2018, Boyd et al. 2019), grupos de toninha tendem a ter o seu tamanho subestimado durante a realização de sobrevoos em aviões. Uma potencial razão é o fato de nem todos os indivíduos do grupo estarem disponíveis juntos para serem contados. Actis et al. (2018), ao avaliar a sincronia entre toninhas, não encontraram relação entre o tamanho do grupo e a sincronia dos animais, o que indicaria que a probabilidade de não terem animais disponíveis aumenta com o tamanho do grupo. Outra potencial razão para a subestimativa do tamanho de grupo estaria relacionada a presença de filhotes no grupo. Além de serem difíceis de detectar a partir da aeronave, os filhotes tendem a permanecer cobertos pela "mãe" quando estão em superfície (obs. pessoal autor), o que os torna indisponíveis para contagem. Adicionalmente, com o aumento da distância perpendicular que o grupo é detectado, a probabilidade de um indivíduo cobrir outro indivíduo próximo aumenta (Boyd et al. 2019). Por fim, a velocidade do avião reduz o tempo que o observador tem para contabilizar o número total de indivíduos o que invariavelmente afeta a estimativa final.

A utilização do fator de correção computado no presente estudo para corrigir futuras estimativas de abundância de toninha deve ser feita sempre que o modelo do avião e a altura e velocidade de voo sejam similares. A presença de janelas-bolha maximiza a capacidade de detecção e a contagem do número de animais, uma vez que aumenta a janela de tempo que um grupo permanece no campo de busca do observador. Adicionalmente, ao estar com o campo visual totalmente focado para o lado externo do avião, ou seja no mar, o observador potencialmente está mais atento e, assim, sua probabilidade de detectar um grupo aumentará. A experiência dos observadores também deve ser levada em consideração, visto que observadores menos experientes apresentam maior taxa de perda de grupos (e.g. Laake et al. 1997) e, portanto, ao utilizar o presente fator de correção o tamanho da população estará subestimando.

A utilização do helicóptero *Robinson R44* demonstrou-se efetiva para a realização de amostragens no ambiente marinho-costeiro. O amplo campo de visão, resultado da retirada das portas, associado à baixa velocidade de voo tornam essa plataforma muito eficaz para detectar grupos de toninha e contar o número de indivíduos. A autonomia de voo do helicóptero *Robinson R44*, não somente em relação ao tempo total, mas também em relação à distância máxima da costa, limita o potencial de amostrar áreas mais afastadas da costa com essa aeronave. Novos experimentos, como os apresentados no presente estudo e em Sucunza et al. (2018), com outros modelos de helicóptero que permitam maior autonomia de voo deveriam ser realizados. É importante notar a aparente falta de reação comportamental dos indivíduos ao ruído do helicóptero, mas evidente reação à sombra da aeronave. Ao ser coberto pela sombra do helicóptero, todos os indivíduos do grupo mergulham. Assim, recomenda-se observar a posição da sombra da aeronave no mar em relação ao seu deslocamento, com o objetivo de evitar a reação dos animais em frente à faixa de busca dos observadores.

A reanálise dos dados apresentados por Zerbini et al. (2010), considerando os novos limites propostos para as FMAs e as potenciais subdivisões na FMA II (FMA IIa e IIb), indicaram a alta vulnerabilidade da toninha frente a captura acidental em redes de pesca. Levando em consideração estimativas pretéritas de captura acidental em redes de emalhe, a mortalidade de toninhas é considerada insustentável para toda a FMA II. A implementação efetiva da INI 12/2012 (MPA/MMA 2012) representa um desafio para o manejo na área, contudo o seu potencial de redução da sobreposição entre as pescarias de emalhe e a toninha é elevado e certamente fundamental para garantir a conservação da toninha. A FMA II apresenta a maior ocupação da região de costa ao longo de toda a distribuição da espécie, o que agrava o risco de extinção das populações de toninha na FMA II.

A população mais ao norte de toninhas FMA Ia provavelmente está isolada demograficamente das demais populações da espécie, possui a menor disponibilidade de habitat e a menor densidade entre todas as populações de toninha, sendo sugerida a sua classificação como "em perigo" segundo a *IUCN Red List Categories and Criteria* (IUCN 2012). Recentemente um dos maiores desastres ambientais do Brasil, o rompimento da barragem de Fundão (Magris et al. 2019), causou o deságue de toneladas de rejeitos na área marinha adjacente a foz do Rio Doce, sendo esta a mesma área onde foi observada a maior densidade de toninhas ao longo da FMA Ia. A degradação do já reduzido habita disponível para as toninhas em sinergia com as capturas acidentais em redes de pesca representam os principais riscos para a conservação dessa população. Eliminar o impacto advindo da degradação do habitat requer estratégias complexas de manejo e muitas vezes grande investimentos econômicos, contudo, o manejo da pesca pode ser obtido com estratégias mais viáveis economicamente e mais fáceis de implementar. A INI 12/2012 apresenta relevante potencial de proteção para a toninha, precisando ainda ser avaliada a efetiva implementação da legislação.

Embora o monitoramento aéreo tripulado apresente alta eficácia para realizar registros de grupos de toninha e, assim, produzir resultados sobre a distribuição e abundância da espécie, o uso integrado de diferentes métodos de amostragem deve ser sempre estimulado, uma vez que invariavelmente irá agregar informações importante para a conservação e manejo. Experimentos direcionados, como os apresentados no presente estudo, são recomendados para avaliar o potencial de utilizar plataformas aéreas não tripuladas para realizar o registro e contagem de toninhas. A validação desta emergente técnica (e.g. Brack et al. 2018) é muito importante, uma vez que possibilitará reduzir os riscos associados a necessidade da presença humana nos sobrevoos tripulados. Métodos acústicos (e.g. Barlow et al. 2013) também apresentam elevado potencial para o monitoramento das populações de toninha, uma vez que possibilitam registrar informações de forma contínua durante longos períodos. Amostragens acústicas e visuais simultâneas poderiam contribuir para os avanços relacionados a estimativa de abundância de toninha a partir de métodos acústicos. Além disso, a implementação de ações de conservação concomitante com a continuidade do monitoramento da abundância e de tendências nas populações de toninha deve ser encorajada.

6 REFERÊNCIAS

Actis, P. S., D. Danilewicz, M. J. Cremer & G. A. Bortolotto. 2018. Breathing synchrony in franciscana (*Pontoporia blainvillei*) and Guiana dolphins (*Sotalia guianensis*) in southern Brazil. Marine Mammal Science XX: XXX-XXX.

Alpizar-jara, R. & K. H. Pollock 1996. A combination line transect and capture recapture sampling model for multiple observers in aerial surveys. Environmental and Ecological Statistics 3: 311-327.

Andriolo, A., P. G. Kinas, M. H. Engel, C. C. A. Martins & A. M. Rufino. 2010. Humpback whales within the Brazilian breeding ground: Distribution and population size estimate. Endangered Species Research 11:233-243.

Barbato, B. H. A., E. R. Secchi, A. P. M. Di Beneditto, et al. 2013. Geographical variation in franciscana (*Pontoporia blainvillei*) external morphology. Journal of the Marine Biological Association of the United Kingdom 92:1645-1656.

Barlow, J., C. W. Oliver, T. D. Jackson & B. L. Taylor. 1988. Harbor porpoise, Phocoena phocoena, abundance estimation for California, Oregon, and Washington: II. aerial surveys. Fishery Bulletin 86: 433-444.

Barlow, J., P. L. Tyack, M. Johnson, R. W. Baird, G. S. Schorr & R. D. Andrews. 2013. Trackline and point detection probabilities for acoustic surveys of Cuvier's and Blainville's beacked whales. The Journal of the Acoustical Society of America 134: 2486-2496.

Barlow J. 2015. Inferring trackline detection probabilities, g(0), for cetaceans from apparent densities in different surveys conditions. Marine Mammal Science 31: 923-943.

Bertozzi, C. P. & A. N. Zerbini. 2002. Incidental mortality of Franciscana (*Pontoporia blainvillei*) in the artisanal fishery of Praia Grande, São Paulo State Brazil. Latin American Journal of Aquatic Mammals 1:153-160.

Borchers, D. L., J. L. Laake, C. Southwell & C. G. M. Paxton. 2006. Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. Biometrics 62:372-378.

Bordino, P., G. Thompson & M. Iñíguez. 1999. Ecology and behaviour of the franciscana (*Pontoporia blainvillei*) in Bahía Anegada, Argentina. Journal of Cetacean Research and Management 1:213-222.

Boyd, C., Hobbs, R. C., Punt, A. E., Shelden, E. W., Sims, C. L. & P. R. Wade. 2019. Bayesian estimation of group size for a costal cetacean using aerial survey data. Marine Mammal Science XX:1-25.

Brack, I. V., Kindel, A., & Oliveira L. F. 2018. Detection errors in wildlife abundance estimates from unmanned aerial systems (UAS) surveys: Synthesis, solutions, and challenges. Methods in Ecology and Evolution 9: 1864-1873.

Brook, B. W., N. S. Sodhi & C. J. A. Bradshaw. 2008. Synergies among extinction drivers under global change. Trends in Ecology and Evolution 23:453-460.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers & L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of wildlife populations. Oxford University Press.

Committee on Taxonomy. 2018. List of marine mammal species and subspecies. Society for Marine Mammalogy. Disponível em www.marinemammalscience.org. Accessado 25 julho 2019.

Costa-Urrutia, P., C. Abud, E. R. Secchi, E. P. Lessa. 2012. Population genetic structure and social kin association of franciscan dolphin, Pontoporia blainvillei. Journal of Heredity 103: 92-102.

Corcuera, J. 1994. Mortality of Pontoporia blainvillei in Northern Buenos Aires Province: the threat of small fishing camps. Páginas 291-294 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan & J. Barlow. International Whaling Commission, Special Issue 15.

Cremer, M. J. & P. C. SIMÕES-LOPES. 2005. The occurrence of Pontoporia blainvillei (Gervais & d'Orbigny) (Cetacea, Pontoporiidae) in a estuarine area in southern Brazil. Revista Brasileira de Zoologia 22: 717-723.

Cremer, M. J. & P. C. Simões-Lopes. 2008. Distribution, abundance and density estimates of franciscanas, *Pontoporia blainvillei* (Cetacea: Pontoporiidae), in Babitonga bay, southern Brazil. Revista Brasileira de Zoologia 25:397-402.

Cremer, M. J., C. M. Sartori, A. C. Holz, B. Schulze, N. Z. dos Santos, A. K. de M. Alves & R. L. Paitach. 2013. Franciscana strandings on the north coast of Santa Catarina State and insights into birth period. Biotemas 26:133-139.

Crespo, E. A., J. F. Corcuera & A. L. Cazorla. 1994. Interactions between marine mammals and fisheries in some coastal fishing areas of Argentina. Páginas 269-282 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan & J. Barlow. International Whaling Commission, Special Issue 15.

Crespo, E. A., G. Harris & R. González. 1998. Group size and distributional range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845-849.

Crespo, E. A., E. R. Secchi, L. D. Rosa, P. G. Kinas, D. Danilewicz & P. Bordino. 2002. Report of the working group on abundance estimates. Latin American Journal of Aquatic Mammals 1:65-66.

Crespo, E. A. 2009. Franciscana dolphin Pontoporia blainvillei. Páginas 466-469 *in* Encyclopedia of marine mammals, 2nd ed, eds. Perrin, W. F., B. Würsig & J. G. M. Thewissen. Academic Press.

Crespo, E. A., S. N. Pedraza, M. F. Grandi, S. L. Dans & G. V. Garaffo. 2010. Abundance and distribution of endangered Franciscana dolphins in Argentine waters and conservation implication. Marine Mammal Science 26:17-35.

Cunha, H. A., B. V. Medeiros, L. A. Barbosa, M. J., et al. 2014. Population structure of the endangered franciscana dolphin (*Pontoporia blainvillei*): Reassessing management units. PLOS ONE 9:e85633.

Danilewicz, D. 2003. Reproduction of female franciscana (Pontoporia blainvillei) in Rio Grande do Sul, southern Brazil. Latin American Journal of Aquatic Mammals 2: 67-78.

Danilewicz, D., E. R. Secchi, P. H. Ott, I. B. Moreno, M. Bassoi & M. Borges-Martins. 2009. Habitat use patterns of franciscana dolphins (Pontoporia blainvillei) off southern Brazil in relation to waters depth. Journal of the Marine Biological Association of the United Kingdom 89:943-949.

Danilewicz, D., I. B. Moreno, P. H. Ott, M. Tavares, A. F. Azevedo, E. R. Secchi & A. Andriolo. 2010. Abundance estimate for a threatened population of franciscana dolphins in southern coastal Brazil: Uncertainties and management implications. Journal of the Marine Biological Association of the United Kingdom 90:1659-1666.

Danilewicz, D., A. N. Zerbini, A. Andriolo, *et al.* 2012. Abundance and distribution of an isolated population of franciscana dolphins (*Pontoporia blainvillei*) in southeastern Brazil: Red alert for FMA I?. International Whaling Commission, Scientific Committee Paper SC/64/SM17.

Denuncio, P., R. Bastida, M. Dassis, G. Giardino, M. Gerpe, D. Rodríguez. 2011. Plastic ingestion in franciscana dolphins, Pontoporia blainvillei (Gervais and d'Orbigny, 1844), from Argentina. Marine Pollution Bulletin 62: 1836-1841.

Di Beneditto, A. P. M., R. M. A. Ramos & N. R. W. Lima. 1998. Fishing activity in northern Rio de Janeiro State (Brazil) and its relation with small cetaceans. Brazilian Archives of Biology and Technology 41: 296-302.

Ferreira, E. C., M. M. C. Muelbert & E. R. Secchi. 2010. Distribuição espaço-temporal das capturas acidentais de toninhas (Pontoporia blainvillei) em redes de emalhe e dos ecalhes ao longo da costa sul do Rio Grande do Sul, Brasil. Atlântica 32: 183-197.

Forcada J. 2009. Distribution. Páginas 316-321 *in* Encyclopedia of marine mammals, 2nd ed, eds. Perrin, W. F., B. Würsig & J. G. M. Thewissen. Academic Press.

Gales, N., M. Hindell & R. Kirkwood eds. 2003. Marine mammals: Fisheries, tourism and management issues. CSIRO Publishing.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364-1372.

Gerrodette, T., Perryman, W. L. & C. S. Oedekoven. 2018. Accuracy and precision of dolphin group size estimates. Marine Mammal Science XXX:XX-XX.

Hiby, A. R. & P. S. H. 1989. Survey techniques for estimating abundance of cetaceans. Reports of the International Whaling Commission (Special Issue 11) p. 47-80.

Hiby, L. 1999. The objective identification of duplicate sightings in aerial survey for porpoise *in* Marine Mammal Survey and Assessment Methods. Garner, G. W., S. C. Amstrup, J. L. Laake, et al. eds. A. A. Balkema.

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1., second edition. IUCN.

Kinas, P. G. 2002. The impact of incidental kills by gill nets on the franciscana dolphin (*Pontoporia blainvillei*) in southern Brazil. Bulletin of Marine Science 70:409-421.

Kinas, P. G., E. R. Secchi, R. Ramos, D. Danilewicz & E. A. Crespo. 2002. Report of the Working Group on Vital Parameters and Demography. Latin American Journal of Aquatic Mammals 1:43-46.

Laake, J. L., J. Calambokidis, S. D. Osmek & D. J. Rugh. 1997. Probability of detecting harbour porpoise from aerial surveys: Estimating g(0). Journal of Wildlife Management. 61:63-75.

Laake, J. L., D. L. Borchers. 2004. Methods for incomplete detection at distance zero. Páginas 108-189 *in* Advanced Distance Sampling: estimating abundance of biological populations. Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers & L. Thomas. eds. New York: Oxford University Press.

Lailson-Brito, J., P. R. Dorneles, C. E. Azevedo-Silva, et al. 2011. Organochlorine concentrations in franciscana dolphins, *Pontoporia blainvillei*, from Brazilian waters. Chemospehere 84:882-887.

Lavandier, R., J. Arêas, N. Quinete, et al. 2016. PCB and PBDE levels in a highly threatened dolphin species from the southeastern Brazilian coast. Environmental Pollution 208:442-449.

Lázaro, M., E. P. Lessa & H. Hamilton. 2004. Geographic genetic structure in the franciscana dolphin (Pontoporia blainvillei). Marine Mammal Science 20: 201-214.

Magris, R. A., M. Marta-Almeida, J. A. F. Monteiro & N. C. Ban. 2019. A modelling approach to assess the impact of land mining on marine biodiversity: Assessment in coastal catchments experiencing catastrophic events (SW Brazil). Science of Total Environment 659:828-840.

Marsh, H. & D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management. 53:1017-1024.

McLellan W. A., R. J. McAlarney, E. W. Cummings, A. J. Read, C. G. M. Paxton, J. T. Bell & D. A. Pabst. 2018. Distribution and abundance of beaked whales (Family Ziphiidae) off Cape Hatteras, North Carolina, U.S.A. Marine Mammal Science 34:997-1017.

Mendez, M., H. C. Rosenbaum, A. Subramaniam, C. Yackulic & P. Bordino. 2010. Isolation by environmental distance in mobile marine species: Molecular ecology of franciscana dolphins at their southern range. Molecular Ecology 19:2212-2228.

MMA. 2014. Lista nacional oficial de espécies da fauna ameaçada de extinção—Mamíferos, aves, répteis, anfíbios e invertebrados terrestres. In: Portaria MMA no. 444, de 17 de dezembro de 2014, Brasil. Disponível em http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2014/p_mma_444_2014_lista_esp%C3%A9cies_ame%C3%A7adas_extin%C3%A7%C3%A3o.pdf. Acessado 27 julho 2017.

MPA/MMA. 2012. Instrução Normativa Interministerial MPA/MMA Nº 12, de 22 de agosto de 2012. Disponível em http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Instrucao_normativa/2012/in_inter_mpa_mma_12_2012_redesemalhe_se_s.pdf. Acessado 27 julho 2017.

Myers, R. A., J. K. Baum, T. D. Shephered, S. P. Powers & C. H. Peterson. 2007. Cascadian effects of the loss of apex predatory sharks from a coastal ocean. Science 315:1846-1850.

Perrin, W. F. 1991. Why are there so many kinds of whales and dolphins? BioScience 41:460-461.

Ott, P. H., E. R. Secchi, I. B. Moreno, et al. 2002. Report of the Working Group on Fishery Interactions. Latin American Journal of Aquatic Mammals 1:55-64.

Perrin, W. F., G. P. Donovan & J. Barlow eds. 1994. Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps. Report of the International Whaling Commission, Special Issue 15.

Pimm, S. T., G. J. Russell, J. L. Gittleman & T. M. Brooks. 1995. The future of biodiversity. Science 269: 347-350.

Pinedo, M. C., R. Praderi & R. L. Brownell Jr. 1989. Review of the biology and status of the franciscana *Pontoporia blainvillei* (Gervais & D'Orbigny, 1844). Páginas 46-51 *in* Biology and conservation of the river dolphins, eds. Perrin, W. F., R. L. Brownell Jr., K. Zhou & L. Jiankang. IUCN.

Pinedo, M. C. 1995. Development and variation in external morphology of the franciscana, Pontoporia blainvillei. Revista Brasileira de Biologia 55: 85-96.

Pollock, K. H., H. Marsh, I. R. Lawler & M. W. Alldredge. 2006. Estimating animal abundance in heterogeneous environments: An application to aerial surveys for dugongs. Journal of Wildlife Management 70:255–262.

Ramos, R. M. A., A. P. M. Di Beneditto, S. Siciliano, et al. 2002. Morphology of the franciscana (Pontoporia blainvillei) off southeastern Brazil: Sexual dimorphism, growth and geographic variation. Latin American Journal of Aquatic Mammals 1: 129-144.

Rosas, F. C. W., E. L. A. Monteiro-Filho & M. R. de Oliveira. 2002. Incidental catches of Franciscana (*Pontoporia blainvillei*) on the southern coast of São Paulo State and the coast of Paraná State, Brazil. Latin American Journal of Aquatic Mammals 1:161-167.

Read, A. J., Drinker P. & S. Northridge. 2006. Bycatch of marine mammals in US and global fisheries. Conservation Biology 20: 163-69.

Read, A. J. 2008. The looming crisis: Interactions between marine mammals and fisheries. Journal of Mammalogy 89:541-548.

Reeves, R. R., B. D. Smith, E. Crespo & N. G. Di Sciara. 2003. Dolphins, whales, and porpoises: 2002-2010 conservation action plan for the world's cetaceans. IUCN Species Survival Commission.

Reeves, R. R., K. McClellan & T. B. Werner. 2013. Marine mammal bycatch in gillent and other entangling net fisheries, 1990 to 2011. Endangered Species Research 20:71-97.

Sala, O. E., F. S. Chapin, J. J. Armesto, et al. 2000. Global biodiversity scenarios for the year 2100. Science 287:1770-1774.

Secchi E. R., A. N. Zerbini, M. Bassoi, L. Dalla Rosa, L. M. Moller & C. C. Rocha-Campos. 1997. Mortality of franciscanas, *Pontoporia blainvillei*, in coastal gillnets in southern Brazil: 1994-1995. Report International Whaling Commission. 47:653–658.

Secchi, E. R., J. Y. Wang, B. W. Murray, C. C. Rocha-Campos & B. N. White. 1998. Population differentiation in the franciscana (Pontoporia blainvillei) from two geographic locations of Brazil as determined from mitochondrial DNA control region sequences. Canadian Journal of Zoology 76: 1622-1627.

Secchi, E. R., P. H. Ott, E. A. Crespo, P. G. Kinas, S. N. Pedraza & P. Bordino. 2001 A first estimate of franciscana (*Pontoporia blainvillei*) abundance off southern Brazil. Journal of Cetacean Research and Management 3:95-100.

Secchi, E. R., D. Danilewicz & P. H. Ott. 2003a. Applying the phylogeographic concept to identify franciscana dolphin stocks: Implications to meet management objectives. Journal of Cetacean Research and Management 5:61-68.

Secchi, E. R., P. H. Ott & D. S. Danilewicz. 2003b. Effects of fishing by-catch and conservation status of the Franciscana dolphin, *Pontoporia blainvillei*. Páginas 174-191, *in* Marine mammals: Fisheries, tourism and management issues, eds. Gales, N., M. Hindell & R. Kirkwood. CSIRO Publishing.

Secchi E. R. 2006. Modelling the population dynamics and viability analysis of franciscana (*Pontoporia blainvillei*) and Hector's dolphins (*Cephalorhynchus hectori*) under the effects of bycatch in fisheries, parameter uncertainty and stochasticity. Tese de doutorado, University of Otago.

Secchi E. R. 2010. Review on the threats and conservation status of franciscana, *Pontoporia blainvillei* (Cetacea, Pontoporiidae). Páginas 323-339, *in* Biology, evolution and conservation of river dolphins within south America and Asia, eds. Ruiz-Garcia M. & J. M. Shostell. Nova Science Publishers Inc.

Seixas, T. G., H. D. A. Kehrig, G. Fillmann, et al. 2007. Ecological and biological determinants of trace elements accumulation in liver and kidney of Pontoporia blainvillei. Science of the Total Environment 385: 208-220.

Siciliano S. 1994. Review of small cetacean and fishery interaction in coastal waters of Brazil. Páginas 241-450 *in* Gillnets and cetaceans: Incorporating the proceedings of the symposium and workshop on the mortality of cetaceans in passive fishing nets and traps, eds. Perrin, W. F., G. P. Donovan & J. Barlow. International Whaling Commission, Special Issue 15.

Siciliano, S., A. P. M. DI BENEDITTO, R. M. A. 2002 A toninha, Pontoporia blainvillei, (Gervais & d'Orbigny, 1844) (Mammalia, Cetacea, Pontoporiidae), nos estados do Rio de Janeiro e Espírito Santo, costa sudeste do Brasil: caracterização dos hábitats e fatores de isolamento das populações. Boletim do Museu Nacional, Zoologia 476: 1-5.

Slooten, E., S. Dawson, W. Rayment & S. Childerhouse. 2006. A noew abundance estimate for Maui's dolphin: What does it mean for managing this critically endangered species? Biological Conservation 28:576-581.

Slooten, E., J. Y. Wang, S. Z. Dungan, et al. 2013. Impacts of fisheries on the critically endangered humpback dolphin *Sousa chinensis* population in the eastern Taiwan Strait. Endangered Species Research 22:99-114.

Southwell, C. J., Paxton, C. G. M., D. L. Borchers, et al. 2008. Estimating population status under conditions of uncertainty: The Ross seal in east Antarctica. Antarctic Science 20:123-133.

Stapleton, S., S. Atkinson, D. Hedman & D. Garshelis. 2014. Revisiting western Hudson bay: Using aerial surveys to update polar bear abundance in a sentinel population. Biological Conservation 170:38-47.

Sucunza, F., D. Danilewicz, M. Cremer, A. Andriolo & A. N. Zerbini. 2018. Refining estimates of availability bias to improve assessment of the conservation status of an endangered dolphin. PLOS ONE 13:e0194213.

Taylor, B. L. & T. Gerrodette. 1993.The use of statistical power in conservation biology: The vaquita and northern spotted owl. Conservation Biology 7:489-500.

Taylor, B. L., P. R. Wade, D. P. De Master & J. Barlow. 2000. Incorporating uncertainty into management models for marine mammals. Conservation Biology 14:1243-1252.

Taylor, B. L., L. Rojas-Bracho, J. Moore, et al. 2016. Extinction is imminent for Mexico's endemic porpoise unless fishery bycatch is eliminated. Conservation Letters XX:1-8.

Thomas, L., S. T. Buckland, E. Rexstad, *et al.* 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.

Turvey, S. T., R. L. Pitman, B. L. Taylor, et al. 2007. First human-caused extinction of a cetacean species? Biology Letters 3:537-540.

Van Erp I. 1969. In quest of the La Plata dolphin. Pacific Discovery 22:18-24.

Wade, P. R. & T. Gerrodette. 1992. Estimates of dolphin abundance in the eastern tropical Pacific: Preliminary analysis of five years of data. Report of the International Whaling Commission 42:533-539.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14:1-37.

Williams, B. K. 2001. Uncertainty, learning, and the optimal management of wildlife. Environmental and Ecological Statistics 8: 269-288.

Yogui, G. T., M. C. O. Santos, C. P. Bertozzi & R. C. Montone. 2010. Levels of persistent organic pollutants and residual pattern of DDTs in small cetaceans from the coast of São Paulo, Brazil. Marine Pollution Bulletin 60:1862-1867.

Zerbini, A. N., E. R. Secchi, D. Danilewicz, A. Andriolo, J. L. Laake & A. Azevedo. 2010. Abundance and distribution of the franciscana (*Pontoporia blainvillei*) in the Franciscana Management Area II (southeastern and southern Brazil). International Whaling Commission, Scientific Committee paper SC/62/SM7.

Zerbini, A. N., E. Secchi, E. Crespo, D. Danilewicz & R. Reeves. 2017. *Pontoporia blainvillei*. In: IUCN 2017. The IUCN Red List of Threatened Species. 2017. Disponível em www.iucnredlist.org. Acessado 30 janeiro 2018.