SC/66b/SH/29

Mid-summer abundance estimates of fin whales around the South Orkney Islands and Elephant Island

Sacha Viqueart, Helena Herr

INTERNATIONAL WHALING COMMISSION

Mid-summer abundance estimates of fin whales around the South Orkney Islands and Elephant Island

Sacha Viquerat[1)], Helena Herr[1)]

1) Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Foundation, Werftstrasse 6, D-25761 Buesum, Germany. sacha.viquerat@tiho-hannover.de

Abstract

We conducted a line-transect distance sampling survey between the 24th of January and the 7th of February 2016 around Elephant Island and the South Orkney Islands on board a Chilean fishing vessel. The aim of this survey was an assessment of fin whales (*Balaenoptera physalus*) densities in the area. A single observer collected distance sampling data from the bridge along 463 km of effort, recording 44 fin whale groups. Using a generalized additive model of segmented data that included the spatial smooth of segment midpoints as covariate, we produced a fine scale distribution map of fin whales around the South Orkney Islands and Elephant Island. The minimum average density of fin whales was estimated at 0.0268 ± 0.0183 animals / km² in a 19,750 km² area around Elephant Island, resulting in a minimum abundance estimate of 528 ± 362 fin whales. For the 13,550 km² area around the South Orkney Islands, we estimated a minimum density of 0.0588 ± 0.0381 fin whales / km² and a minimum abundance of 796 ± 516 animals. The highest predicted densities were found south west of Coronation Island, coinciding with the shelf break. This study confirms the area of the Antarctic islands to be a new hotspot that might host a substantial part of the Southern Hemisphere fin whales.

Keywords: Western Antarctic Peninsula, *Balaenoptera physalus* fin whale, population status, cetacean abundance.

Introduction

The Southern Ocean is a high productivity area with a diverse biogeography. A decisive feature between the east Pacific and Atlantic sector of the southern Ocean is the Western Antarctic Peninsula (WAP), extending the Antarctic continent far into the north. The area is characterised by multiple islands directly on or close to the shelf, mainly the South Orkney Islands, Elephant Island and the South Shetland Islands. These geological features create dynamic slopes on the otherwise relatively flat shelf surface, which leads to local, nutrient rich upwellings (PREZELIN ET AL. 2000, DINNIMAN ET AL. 2004).

While there have been various fisheries related studies around the western flank of the WAP under the auspices of CCAMLR and the IWC, most of these studies date back to the 90s or used fixed strip surveys to produce population numbers for a number of marine species (e.g. JOIRIS & DOCHY 2013). There is still very little knowledge on the fin whales (*Balaenoptera physalus*) of the southern hemisphere. Having suffered substantially from commercial whaling activities up until 1986 (with casualties totalling at about 700,000 animals), fin whales are still listed by the IUCN as critically endangered (REILLY ET AL. 2011). There is only sparse information on their population status, ecology, migration patterns and ecological role within the Southern Ocean, and, with the exception of analysis of the circumpolar IDCR-SOWER datasets collected between 1978/1979 and 2004 (LEAPER & MILLER 2011), there are no recent population estimates for the Southern Hemisphere.

Increasing sighting numbers of fin whales in the area of the WAP over the past few years (JOIRIS & DOCHY 2013, SANTORA ET AL. 2014) provided first indication for the Southern Hemisphere population potentially to be recovering. The WAP seems to play a key role as an emerging hotspot area where a substantial number of fin whales seem to aggregate during the austral summer months (HERR ET AL. 2016). In contrast, only few sightings of fin whales were reported from the same area just a couple of decades back (see for example SCHEIDAT ET AL. 2011). A dedicated aerial survey conducted in 2013 within the Bransfield Strait and Drake Passage produced the first density estimates for fin whales in the area and found minimum densities of 0.117 animals / km² (95% CI: 0.053 – 0.181). A minimal abundance of fin whales within an approximately 42,000 km² area in the Drake Passage was estimated at 4,898 (95%CI: 2,221 – 7,575) animals (HERR ET AL. 2016). The most recent circumpolar abundance estimate for fin whales south of 60°S was 5,445 (95% CI: 2,000 – 14,500) animals (based on an analysis of IDCR/SOWER survey data collected between 1978/1979 and 2004; LEAPER & MILLER 2011). These findings suggest that either a major proportion of fin whales of the

Southern Hemisphere use the area west of the WAP at least temporarily or that there has been a considerable growth in the total abundance of fin whales in the Southern Hemisphere since the IDCR/SOWER cruises.

As a designated area for increased effort by the krill fisheries industry, WAP is thus worthy of increased survey efforts to monitor and confirm this apparently important area for the Southern Hemisphere fin whale population as well as to assess the potential for conflict management between industry demands and the needs of a recovering population.

In this study, we conducted a distance sampling survey for fin whales around the South Orkneys and Elephant Island from a platform of opportunity. Collected data were used for model based abundance estimation of fin whales around the South Orkneys and Elephant Island.

Materials & Methods

We conducted a line transect distance sampling survey with a single observer from the bridge (11.2 m elevation above sea level) of the Chilean fishing vessel *Cabo de Hornos* from January 27th until February 7th around the South Orkney Islands and Elephant Island. The observer was stationed at a central location, allowing an unobstructed field of view (*FOV*) of 60° to each side of the ship. Data were gathered on transits between fishing trawl sites.

Using and a survey computer hooked up to a GPS device to record survey parameters and detections, the observer recorded all sightings within his *FOV*, focussing on the 90° sector around the transect line (45° to each side of the transect). After initial naked eye detection, a binocular with reticule display for distance measurements (Fujinon MTRC-SX) was used to measure the distance to the sighting and, if necessary, to confirm species identification. Observer shifts were limited to 1 1/2 hour stretches of continuous effort, followed by 1/2 hour break to prevent observer fatigue. Total effort time within any 24 hour period was limited to 8 hours. The environmental parameters sea state (measured in the Beaufort scale), swell, ice coverage, and glare were recorded at the beginning of each effort period and whenever any change therein occurred. To limit the distraction from the target species, no seals or bird species were recorded.

Sighting conditions were rated as 'good', 'moderate', 'poor' or 'unacceptable' (quality was assessed based on fin whale sighting conditions) separately for the port and starboard portion of the *FOV*. In case of unacceptable conditions (such as fog, very strong glare etc.), observation of that side was discontinued.

All cetacean sightings included the horizontal angle and the radial distance to the sighting, the species identification (allowing for unidentified animals), group size estimate and, if deferrable, the general swim direction. The radial distance was measured using calibrated reticules that are specific for the binoculars in use.

Horizontal angles were measured using an angle board in relation to the ships heading. The perpendicular distance to the track line was then calculated via:

$$(1) \qquad d_{perp} = \sin\theta \times d_{rad}$$

Where d_{perp} is the perpendicular distance to the track line, θ is the horizontal angle and d_{rad} is the radial distance, calculated by converting δ (the declination angle measured in reticules).

We defined two strata post survey by designing a 20 km buffer around the covered track lines, divided by each Island group. These strata were used in the modelling step for predicting densities (see Figure 1).

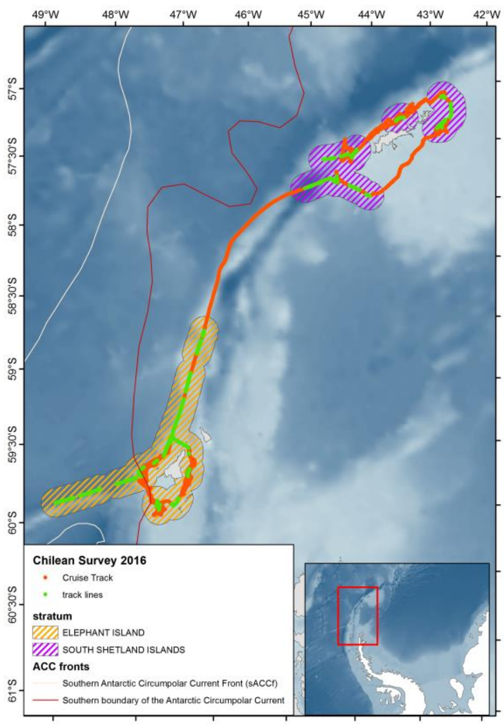

Figure 1: Overview of cruise track and survey effort between 27th of January and 7th of February 2016; the red line indicates ship track; the light green line marks effort periods; the shaded polygons mark the strata defined for latter analysis. ; ACC fronts: abbreviated boundaries of the Antarctic circumpolar currents system (sACCf: Southern Antarctic Circumpolar Current Front, sBACC: southern boundary of the Antarctic Circumpolar Current) (data source: CCAMLR GIS repository); Background bathymetry from ETOPO (Amante & Eakins 2009).

From the collected sighting data, we produced multiple covariate detection functions for fin whales (*MCDS,* see BUCKLAND ET AL. 2004). Half normal models of fin whale sightings, including the environmental parameters sea state, swell, ice coverage, glare conditions, group size and subjective sighting conditions were tested against models without covariates. The best detection function model was chosen based on the Akaike Information Criterion (*AIC*, AKAIKE 1974).

The dataset was segmented into continuous effort stretches of app. 5 km. With the effective half strip width (*esw*) from the detection function, we calculated the effectively covered area per 5 km segment using:

$$(2) \qquad A_{eff} = 2 \times esw \times L_{segment}$$

With A_{eff} being the effectively covered area within the segment, *esw* the effective half strip width for fin whales and $L_{segment}$ the total effort within the segment.

Using the number of group sightings, we then calculate the density of fin whales for each segment as:

$$(3) \qquad \widehat{D}_{segment} = {}^{G_{segment}}\big/_{A_{eff}} \times \hat{s}_{segment}$$

with $D_{segment}$ the density of fin whales per km², $G_{segment}$ = the number of recorded fin whale groups along the segment, A_{eff} = the effectively covered area of the segment and $\hat{s}_{segment}$ = the average group size of fin whales for the segment.

We used generalised additive models (*gam*) to produce a density surface model based on the segmented dataset associated with environmental covariates (see Table 1 for a summary of the tested covariates).

Table 1: covariates used in the modelling process. name denotes the identifier of respective covariate used in the modelling and is later used as a substitute in the text; unit informs on the SI unit the respective covariate is measured in; source denotes the origin of the data.

covariate	Name	unit	Source
Bathymetry	*Depth*	Meters [m]	ARNDT ET AL. 2013
Aspect of seafloor	*Aspect*	Degree [angular]	Calculated in R (R CORE DEVELOPMENT TEAM 2015) from ARNDT ET AL. 2013 using the *terrain* function from package *raster* (HIJMANS 2015)
Slope of seafloor	*Slope*		
Distance to southern Boundary of Antarctic circumpolar Current	*dist2sBACC*	Kilometers [km]	CCAMLR online GIS repository (*http://gis.ccamlr.org/home*)
Coordinates of segment midpoint	*(x, y)*	Meters [m]	Coordinate of segment midpoint in *WGS84 / Antarctic Polar Stereographic projection* (EPSG: 3031)

A *tweedie* error distribution (TWEEDIE 1956) was used in all models to compensate for the typically high number of false zeroes during cetacean surveys (see MILLER 2013). We used the decadal log of the segment length as sample weights for the modelling stage. The dimensions of the thin plate smoothing functions (see WOOD 2003) were restricted to four dimensions in each covariate to avoid unrealistic overfitting of the data. The best model was chosen based on the Restricted Maximum Likelihood score (*REML*).

The model was applied to a set of prediction grids in 5x5 km resolution that covered the strata (South Orkney Islands and Elephant Island) to produce distribution maps as well as density and abundance estimates for fin whales in each stratum.

All analyses were performed in R 3.2.2 (R CORE DEVELOPMENT TEAM 2015) using the packages *Distance* (MILLER ET AL. 2015), *rgdal* (BIVAND ET AL. 2015), *rgeos* (BIVAND & RUNDEL 2015), *maptools* (BIVAND & LEWIN-KOH 2015), *raster* (HIJMANS 2015) and *mgcv* (WOOD 2011).

Results

The stratum around Elephant Island was surveyed between 27th of January and the 1st of February 2016. A total of 299 km of track lines were observed on effort within this stratum, with 27 group sightings of 29 fin whales, averaging a group size of 1.07 fin whales / group. The South Orkney Islands stratum was surveyed between the 2nd of February and the 7th of February 2016. A total of 164 km of track lines were observed on effort, with 17 group sightings of 32 fin whales, averaging a group size of 1.88 fin whales / group (see Table 2 & Figure 2).

Table 2: Summary of cetacean records on effort between 27th of January and 7th of February 2016. stratum: subset of survey area; G: Number of cetacean groups recorded on effort. I: Total number of cetaceans recorded (asterisk indicate calf sighting); ŝ: average group size of encounters; table gives detections for fin and humpback whales, respectively.

		Fin whales				**Humpback whales**			
stratum	Effort [km]	G	I	C	ŝ	G	I	C	ŝ
Elephant Island	299	27	29	0	1.07	16	18	1	1.13
South Orkney Islands	164	17	32	0	1.88	12	21	0	1.75
Total	**463**	**44**	**61**	**0**	**1.39**	**28**	**39**	**1**	**1.39**

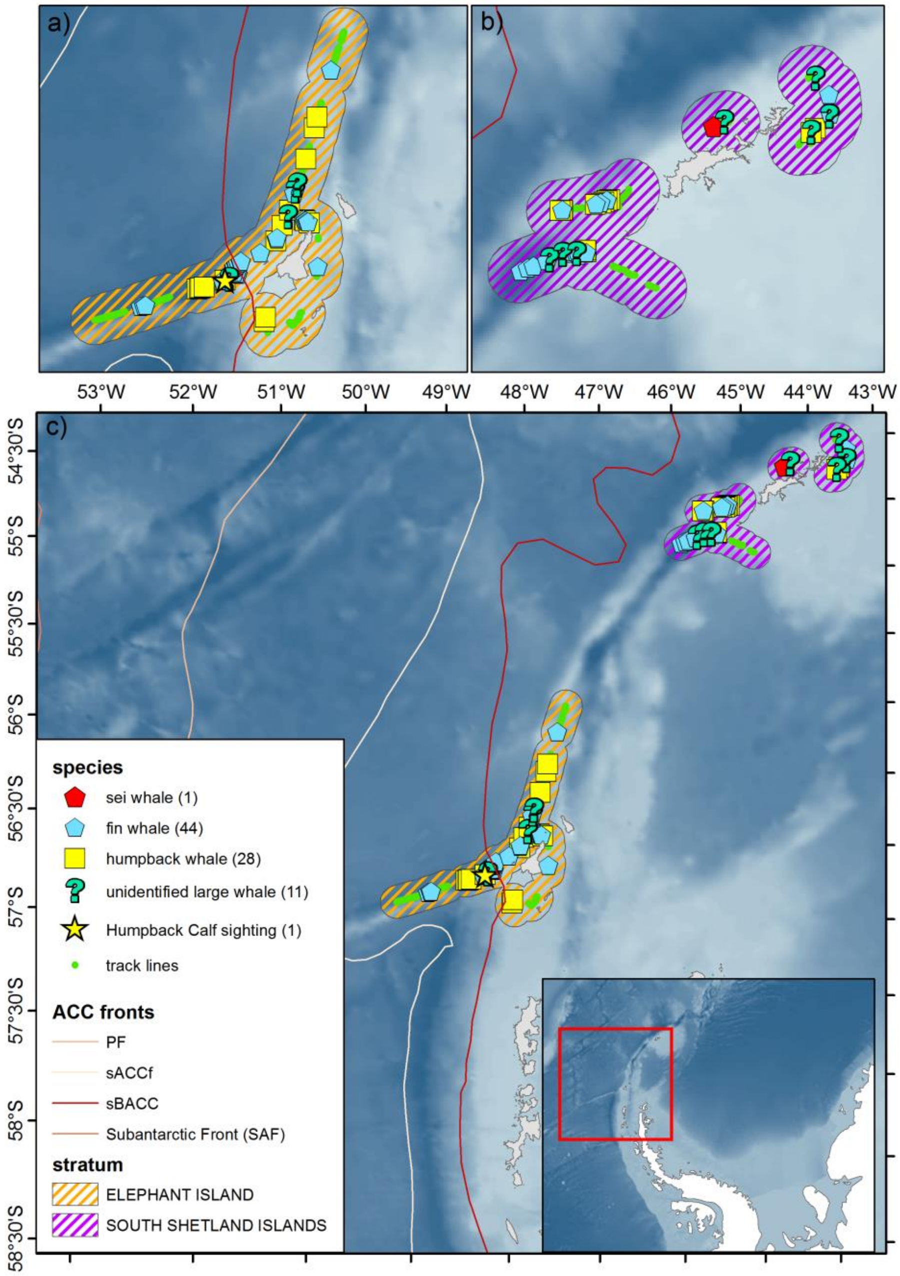

Figure 2: Overview of cetacean records near a) Elephant Island; b) the South Orkney Islands (on effort between 2nd of February -7th of February 2016); and c) complete survey period; effort stretches are marked in green; strata as designed for the modelling step are marked as dashed polygons; ACC fronts: abbreviated boundaries of the Antarctic circumpolar currents system (PF: Polar front; sACCf: Southern Antarctic Circumpolar Current Front, sBACC: southern boundary of the Antarctic Circumpolar Current) (data source: CCAMLR GIS repository); Background bathymetry from ETOPO (Amante & Eakins 2009).

Sea states 2 and 4 on the Beaufort scale were the most common sea states encountered during the survey (Table 3).

Table 3: Summary of sea states encountered during the survey. Sea state denotes the perceived strength of wind force measured in Beaufort.

Sea state	Effort [km]	Percentile
1	80.6	17.41%
2	158.7	34.26%
3	83.9	18.11%
4	124.2	26.81%
5	15.8	3.40%

Only data recorded at sea states ≤ 4 were included in the final dataset. After right truncation at 2,500 meters from the track line, 38 fin whale groups were available for the detection function modelling step. A straightforward detection function using no additional covariates (fw_1) was chosen for the subsequent analyses in fin whales (see Table 4 and Figure 3).

Table 4: Detection function modelling results; model: name of the model used throughout the analysis and as substitute in the text; covariate: indicates the environmental covariate used in the detection function model; AIC: Akaike Information Criterion (the smaller the value, the better the fit); N_{trunc}: Number of sightings analysed after right truncation at 2500 m. Model in bold indicates the final chosen model for all subsequent analysis.

Model	covariate	AIC	N_{trunc}
fw1	*no covariate*	*582*	*38*
fw2	sea state	584	38
fw3	ice coverage	584	38
fw4	sighting conditions	584	38
fw6	group size	583	38

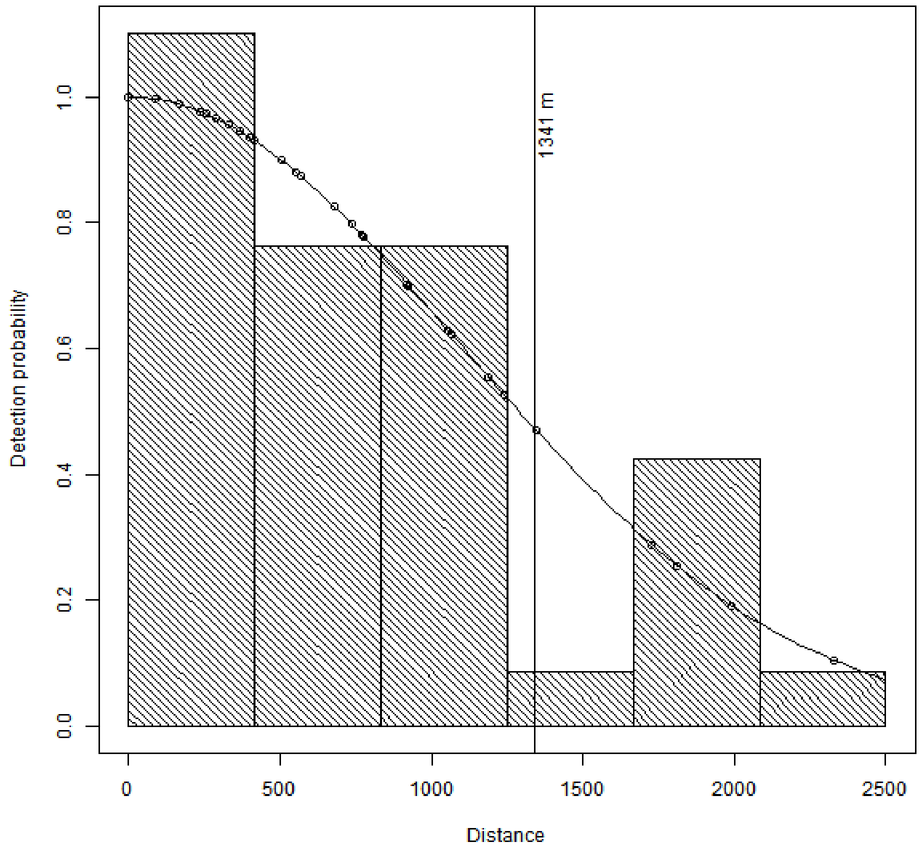

Figure 3: detection function fw_1 for fin whales using no additional covariates based on 38 records (after right truncation at 2,500 m). The vertical line indicates the estimated effective strip width (*esw*) at a width of 1,341 meters.

The segmentation process of the survey dataset yielded 119 individual segments. The results of the additive modelling are given in Table 5. The best model was m_{14} including a spatial smoother (*x*, *y*), explaining 66.23% of the observed deviance. Introducing additional covariates inflated predictions unrealistically and did not contribute substantially to the robustness and scope of the models.

Table 5: Summary statistics of tested models in the additive modelling process of the segmented data; model: identifier for model used throughout the analysis and as substitute in the text; covariate: indicates the covariate combination tested in the model (multiple covariates within brackets indicate interactions); θ: dispersion factor for the tweedie family; dev: deviance explained by the model; REML score: Restricted Maximum Likelihood score of respective model; selected model is highlighted in bold font.

model	**covariate**	**θ**	**Dev**	**REML score**
m_0	1	0.53	0.00%	69.48
m_1	dist2sBACC , slope, depth, aspect	0.31	29.63%	52.94
m_2	dist2sBACC, slope, aspect	0.37	22.23%	57.36
m_3	dist2sBACC, slope	0.36	20.46%	57.06
m_4	slope, aspect, depth	0.31	28.71%	52.74
m_5	slope, aspect	0.36	22.23%	56.63
m_6	slope, depth	0.31	28.36%	52.44
m_7	(x, y), dist2sBACC, slope, depth, aspect	0.14	71.82%	37.46

m_8	(x, y) , dist2sBACC, slope, aspect	0.14	71.07%	38.31
m_9	(x, y), dist2sBACC, slope	0.14	67.97%	40.33
m_{10}	(x, y) , slope	0.14	67.63%	42.40
m_{11}	(x, y), slope, depth	0.14	67.85%	41.90
m_{12}	(x, y), slope, depth, aspect	0.14	71.41%	39.70
m_{13}	(x, y), depth	0.14	66.44%	45.11
$\boldsymbol{m_{14}}$	***(x, y)***	***0.14***	***66.23%***	***45.75***
m_{15}	(x, y), dist2sBACC, slope, depth	0.14	68.18%	39.79
m_{16}	(x, y), dist2sBACC, depth	0.14	66.66%	42.79
m_{17}	(x, y), dist2_sBACC	0.14	66.46%	43.49

Based on model m_{14}, the average density of fin whales was predicted at 0.0268 ± 0.0183 (95%CI: 0 - 0.0627) fin whales / km² for the Elephant Island stratum and at 0.0588 ± 0.0381 (95%CI: 0 - 0.1334) fin whales / km² for the South Orkney Islands stratum. Abundance was estimated at 528 ± 362 (95%CI: 0 – 1,238) fin whales around Elephant Island and 796 ± 516 (95%CI: 0 – 1,807) fin whales around the South Orkney Islands (Table 6).

Table 6: prediction of fin whale densities and abundance; Area: area of stratum; D: animal density [fin whales / km²]; D_{se}: Standard error of D; D_{95CI}: 95% Confidence Interval of D; N: number of fin whales in respective stratum; N_{se}: Standard error of N; N_{95CI}: 95% Confidence Interval of N.

stratum	Area	D	D_{se}	D_{95CI}	N	N_{se}	N_{95CI}
Elephant Island	19,750	0.0268	0.0183	0 - 0.0627	528	362	0 - 1238
South Orkney Islands	13,550	0.0588	0.0381	0 - 0.1334	796	516	0 - 1807

The highest density of fin whales was predicted within the South Orkney Islands stratum, along the shelf edge at about 50 km south west of the shoreline of Coronation Island (Figure 4).

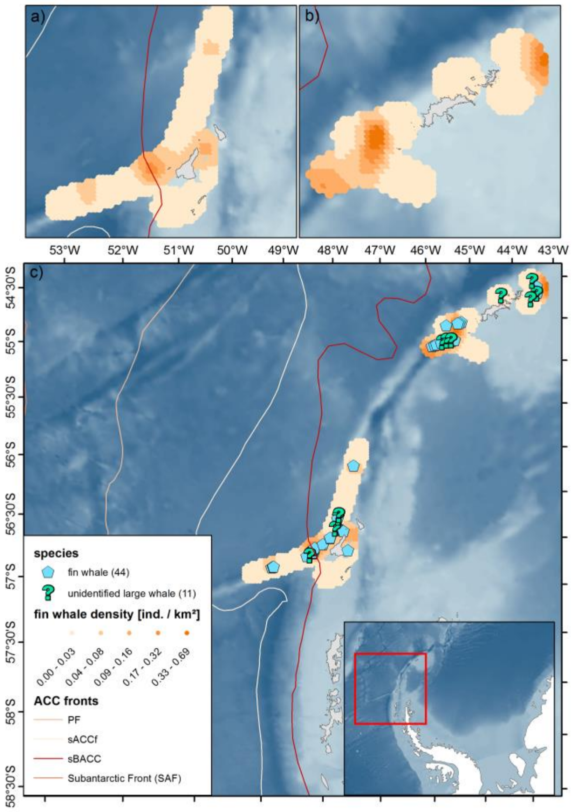

Figure 4: Model prediction of fin whale density around Elephant Island (a), the South Orkney Islands (b) and the whole survey area (c). Fin whale sightings recorded on effort are marked as blue pentagons. Unidentified large whale sightings are marked as question marks; ACC fronts: abbreviated boundaries of the Antarctic circumpolar currents system (PF: Polar front; sACCf: Southern Antarctic Circumpolar Current Front, sBACC: southern boundary of the Antarctic Circumpolar Current) (data source: CCAMLR GIS repository); Background bathymetry from ETOPO (Amante & Eakins 2009).

Discussion

Our study provides the first mid-summer minimal density and abundance estimates for fin whales around Elephant Island and the South Orkney Islands based on a dedicated cetacean line transect distance sampling survey. Compared to other studies, our average minimal density estimate of 0.0268 ± 0.0183 (95%CI: 0 - 0.0627) fin whales / km² for the 19,750 km² stratum around Elephant Island and at 0.0588 ± 0.0381 (95%CI: 0 - 0.1334) fin whales / km² for the 13,550 km² stratum around the South Orkney Islands is well within the range of published values. JOIRIS & DOCHY 2013 reported estimated densities of 0.03 fin whales / km² near Elephant Island between March and April 2012 from a mixed species fixed strip survey. HERR ET AL. 2016 report fin whale densities of 0.114 animals / km² within an area further to the southwest, including Elephant Island and the South Shetlands. JOIRIS & DOCHY 2013 also mention the area north-west of Elephant Island to be associated with high density estimates, which we associate with higher densities as well. Both sources report that many of the large fin whale groups were spatially separated but usually associated with other marine wildlife (such as marine birds and seals), which we could also observe in this survey. Elephant Island in particular is known for free floating patches of high krill concentrations when ice free (see for example HEWITT & DEMER 1993, NOWACEK ET AL.2011). There are strong indications that the main driver for most species encountered near the WAP is the prey availability in krill (FRIEDLAENDER ET AL. 2006, NOWACEK ET AL. 2011, HERR ET AL. 2016). Acoustic surveys for fin whales indicate that the area might only be temporarily used by fin whales between the months of February–July, with peak calling in May (SIROVIC ET AL. 2004, SIROVIC ET AL. 2009). The decrease in calling activity is attributed to the beginning formation of ice, thus resulting in a potential migration of fin whales out of the area due to the marginal availability of prey items (SIROVIC ET AL. 2004).

Our minimum abundance estimated was 528 ± 362 fin whales around Elephant Island and 796 ± 516 fin whales around the South Orkney Islands. While there is some debate about the current population status of the fin whales of the southern hemisphere (around 5,500 animals, LEAPER & MILLER 2011), a total of 1200 animals within the spatially constrained area around Elephant Island and the South Orkney Islands has to be considered a substantial proportion of the total population, thus rendering this area at least temporarily very vulnerable to any disturbances. As there is no information on current trends in the southern hemisphere fin whale population, we cannot discern whether the results from this study reflect a general increase in fin whale abundance since the late 90's or if this truly is an emerging hotspot that has been utilised by fin whales only since the early 2000's.

As there is no information on the availability bias of fin whales, we expect the actual numbers to be higher. Also, the high number of unidentified animals (one of the major drawbacks of a single observer setup) could even further increase the population estimates, as most of these animals were probably fin whales but were described as unidentified large whales to ascertain data quality. We can therefore expect the actual numbers to be even higher on average. The high number of on effort sightings and observations made during fishing trawls of humpback whales, sei whales and the high number and diversity of observed multi species feeding aggregations of marine vertebrate (including marine birds and seals) emphasize the ecological significance of the area.

This survey proves that straightforward setups using a dedicated line transect methodology can yield robust snapshots of local populations with high efficiency. The high and reliable encounter rates especially for large whales in the area make these CCAMLR surveys a feasible platform of opportunity for cetacean research. The ease of access to the area, the proximity to facilities on the mainland (such as the Falklands or South America) and the high conflict potential with increased efforts in krill fisheries in the area should make this a designated target for future survey efforts.

Acknowledgement

We would like to thank the cruise leader Patricio Arana, the scientific team of the Chilean finfish survey and the head of our department Ursula Siebert. We would also like to express our gratitude to the crew of the *Cabo de Hornos* for welcoming us on board and helping us set up during the survey amidst their own duties.

References

Amante, C., Eakins, B.W. (2009) ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. *doi:10.7289/V5C8276M* [Access on 1st of June 2015].

Arndt J.E., Schenke H.W., Jakobsson M., Nitsche F., Buys G., Goleby B., Rebesco M., Bohoyo F., Hong J.K., Black J., Greku R., Udintsev G., Barrios F., Reynoso-Peralta W., Morishita T., Wigley R. (2013) The international bathymetric chart of the Southern Ocean (IBCSO) version 1.0: a new bathymetric compilation covering circum-Antarctic waters. Geophys Res Lett 40:3111–3117. *doi:10.1002/grl.50413*

Bivand, R.S., Keitt, T., Rowlingson, B. (2015) rgdal: Bindings for the Geospatial Data Abstraction Library. R package version 1.0-4. http://CRAN.R-project.org/package=rgdal

Bivand, R.S., Lewin-Koh, N. (2015) maptools: Tools for Reading and Handling Spatial Objects. R package version 0.8-36. http://CRAN.R-project.org/package=maptools

Bivand, R.S., Rundel, C. (2015) rgeos: Interface to Geometry Engine - Open Source (GEOS). R package version 0.3-11. http://CRAN.R-project.org/package=rgeos

Branch, T.A., Butterworth, D.S. (2001) Southern hemisphere minke whales: standardized abundance estimates from the 1978/79 to 1997/98 IDCR_SOWER surveys. Journal of Cetacean Research and Managmenet 3(2): 143-174

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L. (2001) Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, UK.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., and Thomas, L. (2004) Advanced Distance Sampling. Oxford University Press. Oxford, UK.

Dinniman, M.S., Klinck, J.M. (2004) A model study of circulation and cross-shelf exchange on the west Antarctic Peninsula continental shelf. Oceanography 51(17–19), pp. 2003–2022

Friedlaender, A.S., Halpin, P.N., Qian, S.S., Lawson, G.L., Wiebe, P.H., Read, A.J. (2006) Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. Mar Ecol Prog Ser 317: pp. 297-310

Herr, H., Viquerat, S., Siegel, V., Kock, K.H., Dorschel, B., Huneke, W.G.C., Bracher, A., Schröder, M., Gutt, J. (2016) Horizontal niche partitioning of humpback and fin whales around the West Antarctic Peninsula: evidence from a concurrent whale and krill survey. Polar Biol 39:799–818. *doi 10.1007/s00300-016-1927-9*

Hewitt, R.P., Demer, D.A. (1993) Dispersion and abundance of Antarctic krill in the vicinity of Elephant Island in the 1992 austral summer. Mar Ecol Prog Ser 58:29–39

Hijmans, R.J. (2015) raster: Geographic Data Analysis and Modeling. R package version 2.4-18. http://CRAN.R-project.org/package=raster

Joiris, C.R., Dochy, O. (2013) A major autumn feeding ground for fin whales, southern fulmars and grey-headed albatrosses around the South Shetland Islands, Antarctica. Polar Biol 36(11), pp 1649-1658

Leaper R. & Miller, C. (2011) Management of Antarctic baleen whales amid past exploitation, current threats and complex marine eco systems. Antarct Sci 23:503–529. *doi:10.1017/S0954102011000708*

Miller, D.L. (2015) Distance: distance sampling detection function and abundance estimation. R package version 0.9.3.http://CRAN.Rproject.org/package=Distance

Miller, D.L., Burt, M.L., Rexstad, E.A., Thomas, L. (2013) Spatial models for distance sampling data: recent developments and future directions. Methods Ecol. Evol. **4**, 1001–1010.

Nowacek, D.P., Friedlaender, A.S., Halpin, P.N., Hazen, E.L., Johnston, D.W., Read, A.J., Espinasse, B., Zhou, M., Zhu, Y. (2011) Super-aggregations of krill and humpback whales in Wilhelmina Bay, Antarctic Peninsula. PLoS ONE 6(4):e19173. *doi:10.1371/journal.pone.0019173*

Prézelin, B.B., Hofmann, E.E., Mengelt, C., Klinck, J.M. (2000) The linkage between Upper Circumpolar Deep Water (UCDW) and phytoplankton assemblages on the west Antarctic Peninsula continental shelf. J Mar Re, 58(2), pp. 165-202

R Core Team (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. & Zerbini, A.N. (2013) The IUCN Red List of Threatened Species: Balaenoptera physalus – published in 2013. http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T2478A44210520.en

Santora, J.A., Reiss, C.S., Cossio, A.M., Veiti, R.R. (2009b) Interannual spatial variability of krill (Euphausia superba) influences seabird foraging behavior near Elephant Island, Antarctica. Fish Oceanogr 18:20–35

Santoro, J.A., Schroeder, I.D., Loeb, V. (2014) Spatial assessment of fin whale hotspots and their association with krill within an important Antarctic feeding and fishing ground. Marine Biology 161(10):2293-2305 DOI: 10.1007/s00227-014-2506-7

Scheidat, M., Friedlaender, A., Kock, K.H., Lehnert, L., Boebel, O., Roberts, J., Williams, R. (2011) Cetacean surveys in the Southern Ocean using icebreaker-supported helicopters. Polar Biol 34: 1513-1522

Sirovic, A., Hildebrand, J.A., Wiggins, S.M., McDonald, M.A., Moore, S.E., Thiele, D. (2004) Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. Deep-Sea Res Pt II 51: pp. 2327–2344. do*i:10.1016/j.dsr2.2004.08.005*

Sirovic, A., Hildebrand, J.A., Wiggins, S.M., Thiele, D. (2009) Blue and fin whale acoustic presence around Antarctica during 2003 and 2004. Mar Mam Sci, 25(1): 125–136. *doi: 10.1111/j.1748-7692.2008.00239.x*

Tweedie, M.C.K. (1956) Some statistical properties of inverse Gaussian distributions. Virginia J. Sci. (N.S.) 7: 160–165.

Wood, S.N. (2003) Thin-plate regression splines. Journal of the Royal Statistical Society (B) 65(1):95-114.

Wood, S.N. (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73(1):3-36