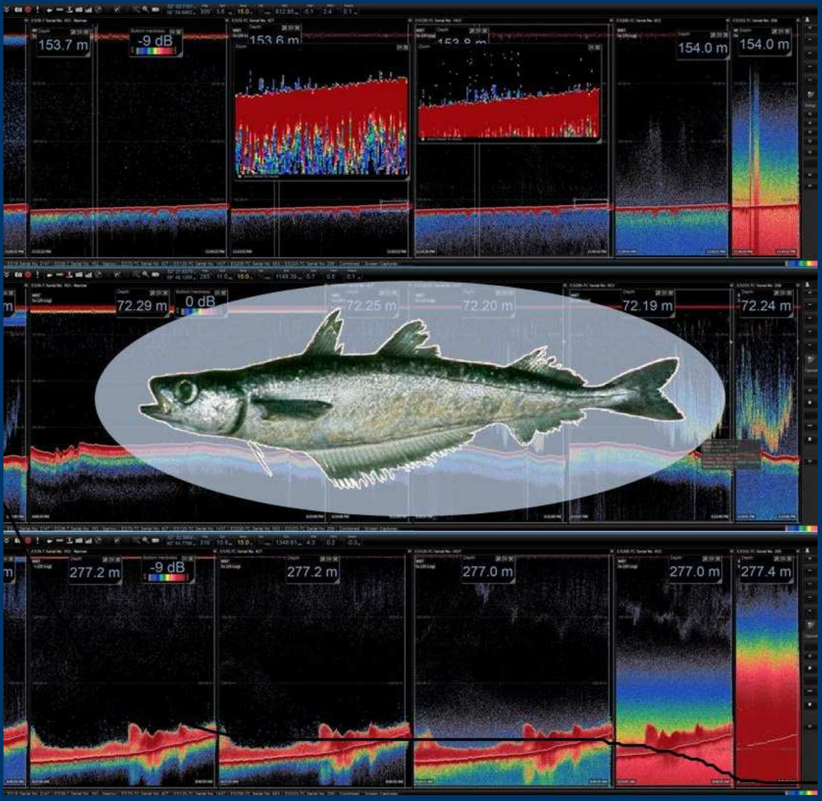
2019 Acoustic – Trawl Survey

S Blue Whiting

Micromesistius a. australis



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Abstract

An acoustic-trawl survey for southern blue whiting, *Micromesistius australis australis*, was undertaken south of the Falkland Islands from September 9th to September 17th 2019, during the season of pelagic spawning. Southern blue whiting was the predominant trawl catch (97.2% of the total), followed by Falkland sprat (0.8%), common hake (0.5%), and Falkland calamari (0.2%). Acoustic sign was scrutinized by INIDEP survey personnel, and the echo-integration classified to southern blue whiting gave an estimate of 224,132.8 tonnes biomass in an area of 19,513 km^2, of which biomass 99% was concentrated within roughly 1.7% of the area. The accuracy of this estimate is qualified by the target-strength model and by the subjectivity of acoustic classification, and may best be regarded as a relative index of areal distribution. Age determination of 32 southern blue whiting otoliths gave a modal age of 6 years (range 5 to 9 years), indicating that the main proportion of spawning individuals belonged to the 2012-2014 cohorts.

Introduction

Southern blue whiting *Micromesistius australis australis* (Inada and Nakamura 1975) is a commercially important gadoid of the south-west Atlantic. In Falkland Islands waters southern blue whiting was previously the most important finfish catch (FIG 2005), but has declined to a minor bycatch in recent years (Ramos and Winter 2019a).

An acoustic trawl-survey for southern blue whiting was undertaken south of the Falkland Islands from September 9th to September 17th 2019, on-board the RV *Victor Angelescu*. The survey was scheduled to take place during the season of pelagic spawning (Arkhipkin et al. 2012). This survey continued the series of joint UK-Argentine surveys for southern blue whiting that had been conducted in the 1990s and early 2000s (e.g., Madirolas 1996, Madirolas et al. 2001, FIG 2004).

Methods

Operational and technical procedures of the survey are summarized in Cabreira et al. (2019). Continuous acoustic data were collected by the survey vessel at 18, 38, 70, 120, 200 and 333 kHz. The data were integrated to track units averaging 1847 m horizontal resolution (6-minute intervals) and full-column vertical resolution. Echo-integration was scrutinized during the survey in LSSS post-processing software (Korneliussen et al. 2006) and classified to biota by correspondence with trawl catches and visual comparison of the acoustic sign (A. Cabreira, INIDEP, pers. comm.). Scrutinized echo-integration was reported as the nautical area scattering coefficient (s_A, m^2 nmi^{-2}), then scaled to area backscattering coefficient (s_a, MacLennan et al. 2002) as:

$$s_a \quad = \quad s_A / 4\pi\,(1852)^2 \qquad (\mathrm{m}^2\ \mathrm{m}^{-2}). \qquad (1)$$

Acoustic data were quantified at 38 kHz, as most modelling work for fish has been carried out at this frequency (NOAA 2004, Korneliussen 2010, Kang 2014). Mean target strength (TS) of southern blue whiting as a function of fish fork length (FL) was calculated from the regression equation of Dunford and Macaulay (2006):

$$\mathrm{TS} \quad = \quad 38.0 \cdot \log_{10} \mathrm{FL} - 97.0 \qquad (\mathrm{dB\ re\ 1\ m^2}), \qquad (2)$$

Three other species were also evaluated, that contributed to the survey catch and acoustic classification. For these three other species, the most recent target strength models or approximations found in the literature were used (Appendix Table A1). Target strength is converted to backscattering cross-section (σ_{bs}) as:

$$\sigma_{bs} \quad = \quad 10^{TS/10} \qquad (m^2) \tag{3}$$

and therefore the numbers (N) of fish corresponding to a given average TS, per area unit, are:

$$N\ m^{-2} \quad = \quad s_a / \sigma_{bs} \qquad (m^2\ m^{-2} / m^2 \ = \ m^{-2}). \tag{4}$$

Numbers per area unit (m^2) were converted to biomass (kg) per area unit from the average individual lengths / weights of specimens sampled in the survey trawls. For species with sufficient sample data in the survey, the length / weight relationship was calculated as:

$$W \quad = \alpha \cdot L^{\beta} \qquad \text{(Froese 2006)} \tag{5}$$

For species with insufficient samples the length / weight relationship was inferred from literature sources (Table A2). Length / weight averages per trawl were proportioned to track units by inverse distance weighting (Shepard 1968). Then, densities per track unit were extrapolated to the survey area, also by inverse distance weighting. Acoustic fishery surveys are commonly analysed with geostatistical methods such as kriging (Petitgas 1996), but the general sparsity of classified echo-integrations in this survey (see below) would be poorly suited to kriging. As with other recent surveys (e.g., Ramos and Winter 2019b, Winter 2019a), the survey area was gridded for analysis on a scale of 5 km^2.

The inverse distance weighting of trawls combined both the spatial proximity from trawls to track units, and the temporal proximity between when a trawl was taken and when the track unit was echo-sounded. Spatial proximity from trawls to track units was measured as the closest distance from either end of the trawl, or from the linear segment between ends. That way, longer trawls were automatically weighted more on average as some point of their extent would always be closer to any given track unit. Spatial and temporal proximities were standardized to a maximum of 1 and added in Euclidean space. The inverse distance weighting of track units did not include temporal proximity as track units were regular and consecutive.

Given the determinism of the echo-integration scrutiny, no variability computation was undertaken for species' biomass estimates.

A subsample of 32 southern blue whiting otoliths was age-read to determine which cohorts were primarily contributing to the spawning aggregation. The otoliths (16 female, 16 male) were selected from the principal mode of the length-frequency distribution. Ages were determined by two readers: T.A.J. Busbridge and Z. Shcherbich, and compared using R package FSA (Ogle et al. 2019). The average percent error (APE) between readers was calculated as:

$$APE \quad = \frac{\sum_{j=1}^{n} APE_j}{n}, \quad APE_j \ = 100 \times \frac{\sum_{i=1}^{R} \frac{(x_{ij} - \bar{x}_j)}{\bar{x}_j}}{R} \tag{6}$$

where APE_j is the APE of the jth fish, x_{ij} is the ith age estimate on the jth fish, $\bar{x}_j$ is the mean age estimate for the jth fish, R is the number of times that each fish was aged, and n is the number of aged fish in the sample (Beamish and Fournier 1981).

Southern blue whiting maturities were assessed according to the INIDEP (Argentina) maturity scale (Macchi and Acha 1998).

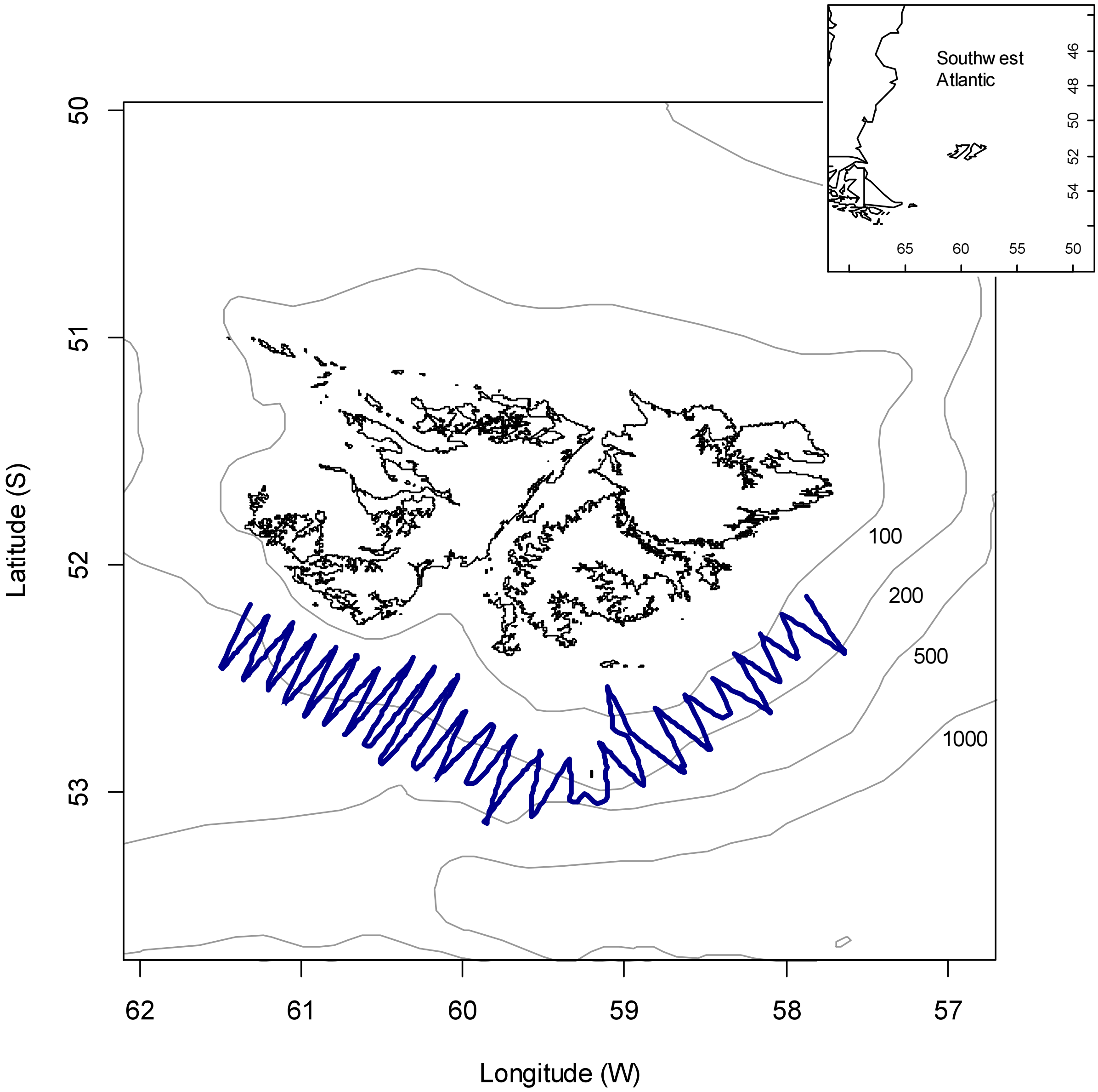

Figure 1. Acoustic track of the September 2019 southern blue whiting survey (blue). Bathymetry lines are in metres.

Results

For analysis the survey track was edited to 915 units following a zig-zag course mainly between 100 m and 300 m depth (Figure 1); covering a total distance of 1650.75 km. A survey area was defined that contoured around the survey track at roughly the same distance as the distance between track turn-points, and was bounded by the 100 m isobath inshore and around Beauchêne Island. The survey area occupied approximately 19,513 km^2 (gridded as 782 units of 5 km^2). Eight trawls were taken opportunistically during the survey (Figure 2). Coordinates and catches of these trawls are summarized in Tables A3 and A4.

Southern blue whiting

Southern blue whiting, being the objective of the survey, represented by far the greatest total proportion of trawl catches (Table A4), and the highest number of acoustic classifications (40 of the 915 survey track units). Area backscattering was concentrated heavily in the western part of the survey area (Figure 2), with a maximum s_a of $6.46e^{-3}$ m^2 m^{-2}.

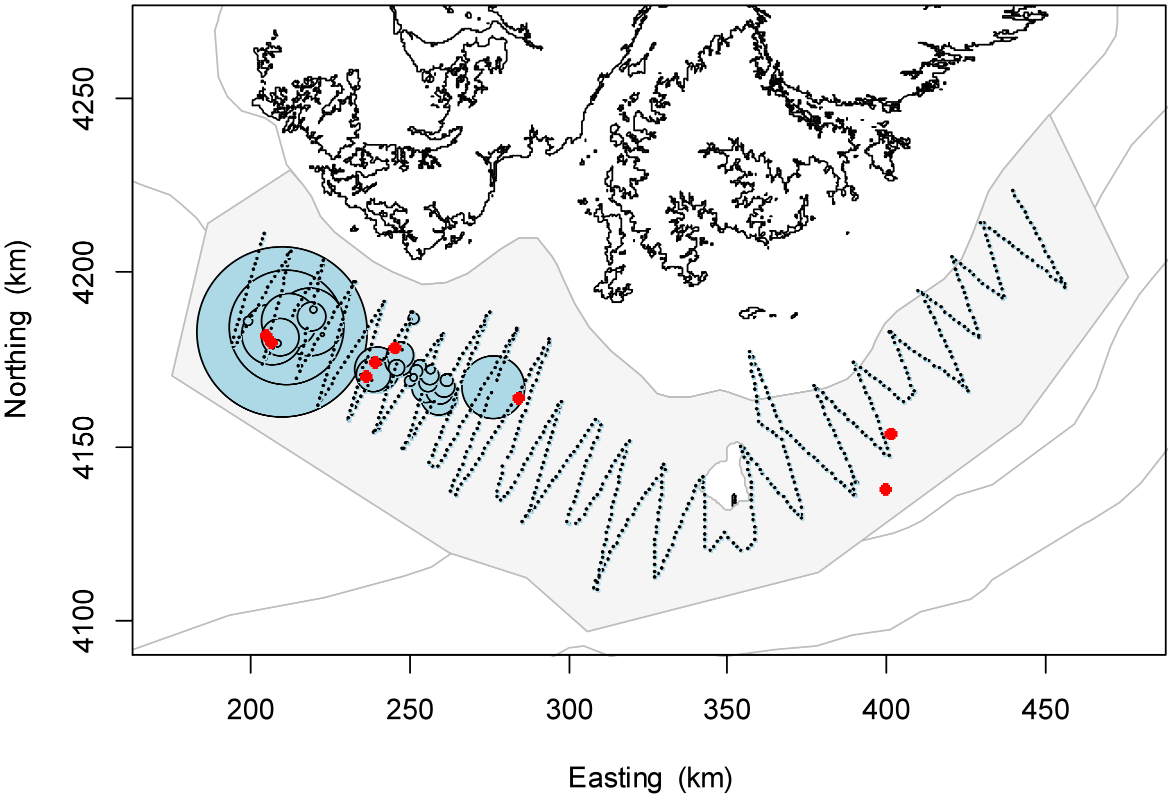

Figure 2. Defined survey area for southern blue whiting (grey field), area backscattering coefficients per track unit scaled to relative magnitude (light blue), and mean trawl positions (red).

1178 southern blue whiting length samples (446 female, 732 male) and 346 length-weight samples (161 female, 185 male) were taken, at four of the 8 trawl stations. Length-frequency distributions differed between males (mean total length 44.59 cm ± 0.16 cm (1 std. error) and females (mean total length 48.81 cm ± 0.17 cm (Figure 3). Length / weight relationships were not significantly different between males and females (df = 1, F = 3.12, p = 0.08). The combined length / weight fit (Figure 4) obtained $W = 0.0014 \cdot L^{3.3895}$ (Table A2).

The combined size range for female and male southern blue whiting was 44 to 50 cm FL. No systematic differences were observed between readings by T.A.J. Busbridge and Z. Shcherbich (McNemar's test: df = 1, Chi = 0.8181, p = 0.366), with readers agreeing on 21 of 32 otoliths (65.6%). A 1-year difference between readers was found on 7 of 32 otoliths (21.9%), possibly resulting from difficulties in determining the first winter annulus in otoliths of this species. Overall comparison obtained an APE of 3.3%, indicating similar age determinations between readers. Determined ages ranged from 5 to 9 years; modal age = 6 years (Figure 5); all age determinations are summarized in Table A5. These ages indicate that the main proportion of the spawning individuals sampled belonged to cohorts 2012-2014.

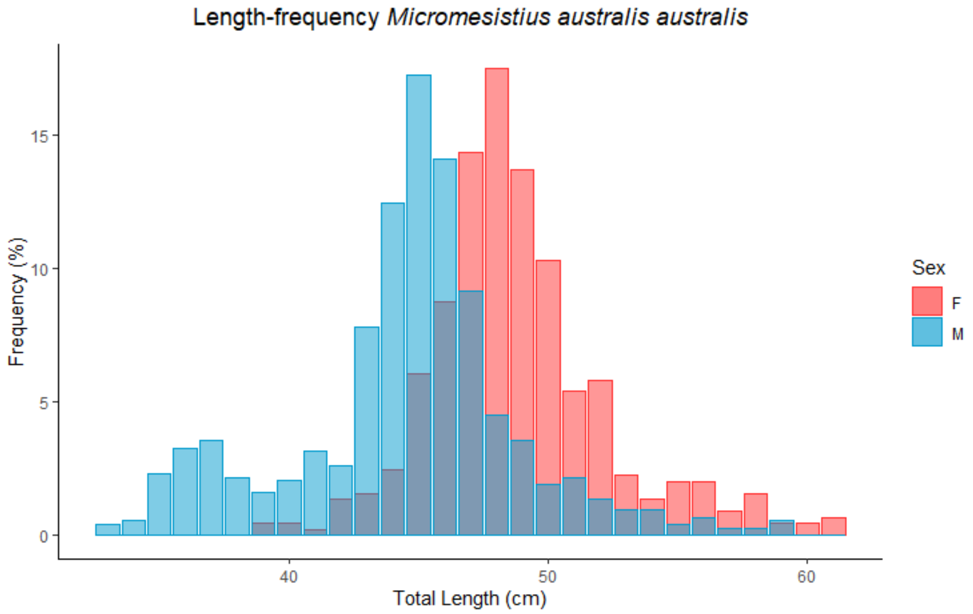

Figure 3. Length frequency distributions of male and female southern blue whiting measured during the survey.

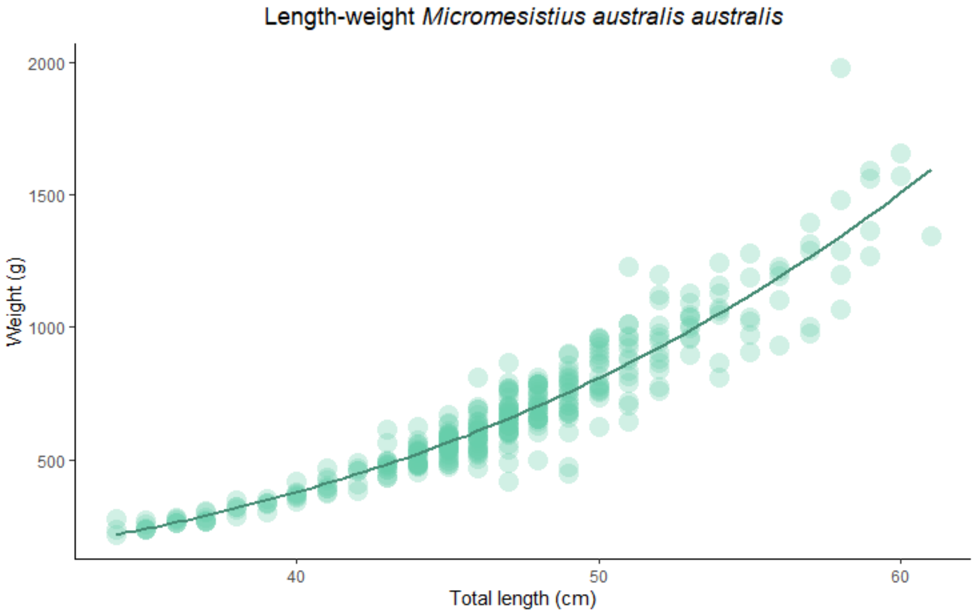

Figure 4. Length / weight relationship (black line) of southern blue whiting sampled during the survey. Green-scale is proportional to the sampling density per length interval.

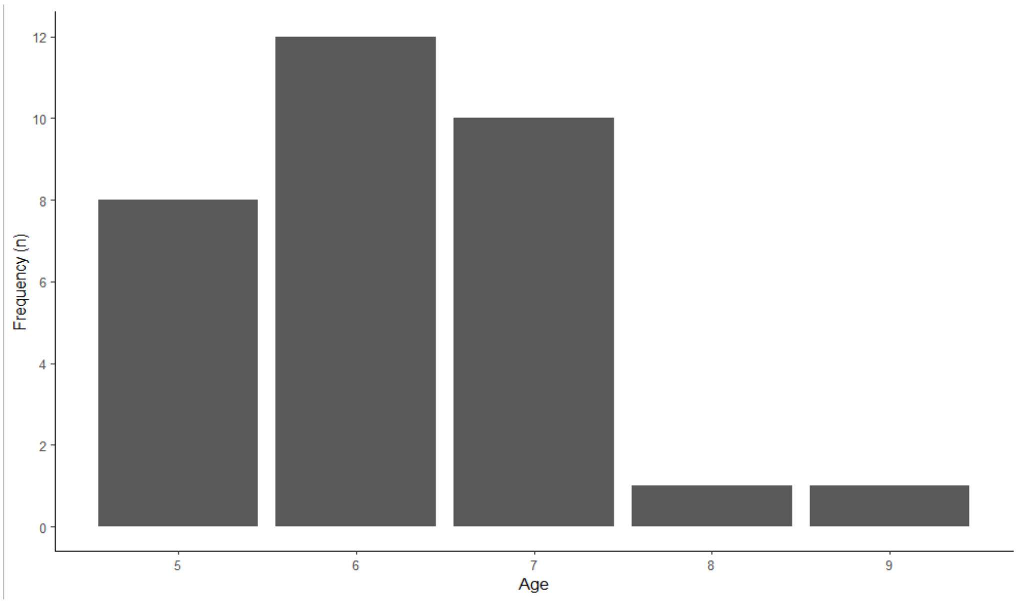

Figure 5. Age determination distribution of 32 southern blue whiting otoliths.

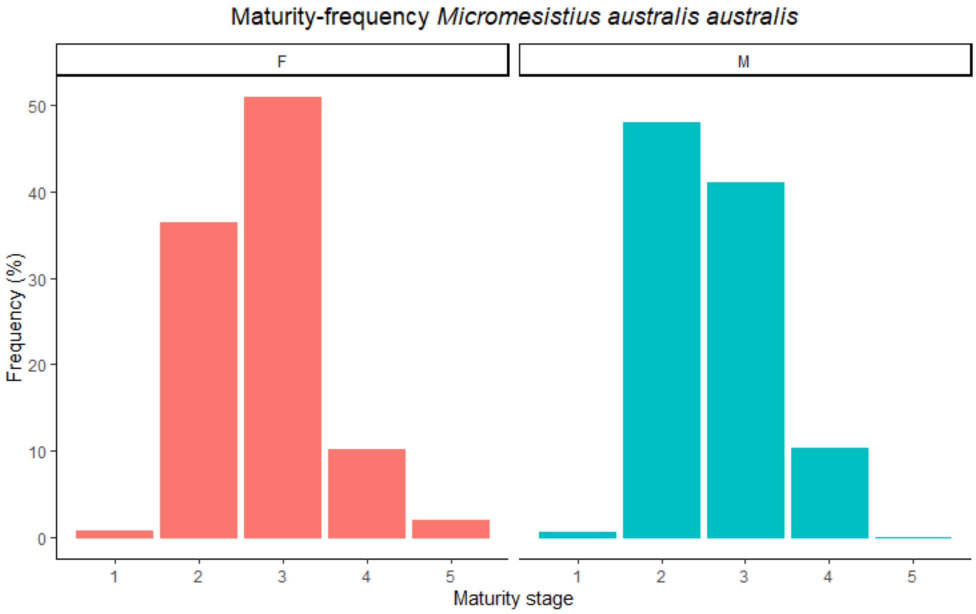

Figure 6. Maturity frequency distributions of female and male southern blue whiting sampled during the survey.

The majority of southern blue whiting sampled were either "maturing" (stage 2) or "mature" (stage 3), with progressively smaller proportions "post-spawning" (stage 4) or "resting" (stage 5). Females were on average further advanced in the maturation process than males (Figure 6).

The inverse-distance weighting algorithm combining acoustic backscatter and length / weight measurements obtained an overall southern blue whiting mean density of 11.5 t km^{-2}. Mean density multiplied by the survey area resulted in a biomass estimate of 19,513 km^2 × 11.5 t km^{-2} = 224,132.8 t (Table 1). The distribution of this biomass estimate was very highly concentrated (Figure 7) with one single of the 782 grid units accounting for 46.8% of the biomass, seven of the grid units accounting for >90% of the biomass, and thirteen of the grid units accounting for >99% of the biomass.

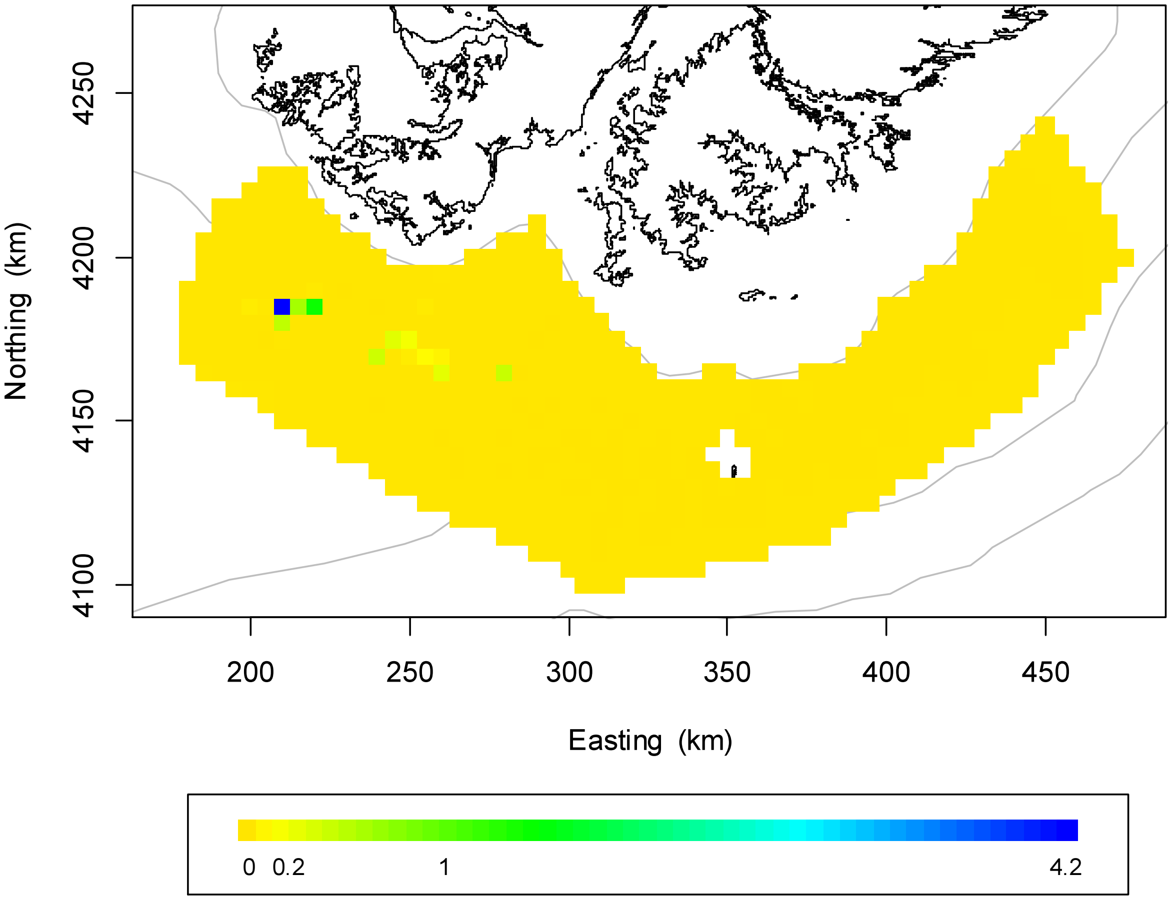

Figure 7. Density distribution of southern blue whiting per 5 km^2 grid, in kg m^{-2}.

Falkland sprat

Falkland sprat (*Sprattus fuegensis*) was the second-most abundantly caught species during the survey, albeit taken at only one trawl station (Table A4). Falkland sprat was classified to backscatter at 14 of the 915 survey track units, maximum s_a = 4.77e^{-4} m^2 m^{-2}, and closely concentrated in the area of the one trawl they were caught in (Figure A1). 245 sprat lengths were measured, but no weights.

The inverse-distance weighting algorithm obtained an overall mean density of 0.28 t km^{-2}, resulting in a biomass estimate of 5477.1 t for the survey area (Table 1). Like southern blue whiting, the distribution of the sprat biomass estimate was highly concentrated (Figure A1) with one single of the 782 grid units accounting for 47.0% of the biomass, and 60 grid units accounting for >90% of the biomass.

Common hake

Common hake (*Merluccius hubbsi*) was the one finfish species caught at >4 trawl stations (Table A4). Common hake was classified to backscatter at 2 of the 915 survey track units, about 51 km east of Beauchêne Island (Figure A2), with maximum $s_a = 2.55e^{-7}$ m^2 m^{-2}. (The one small catch of southern hake, *Merluccius australis*, Table A4, was presumably indiscriminate from common hake, but this is not otherwise evaluated). 54 common hake lengths were measured, at 5 trawl stations, of which 5 specimens were also weighed.

The inverse-distance weighting algorithm obtained an overall mean density of 0.0009 t km^{-2}, resulting in a biomass estimate of 17.1 t for the survey area (Table 1).

Falkland calamari

Falkland calamari (*Doryteuthis gahi*) was the species reported caught in the most trawls (6 of 8), and the only invertebrate classified to backscatter; at 9 of the 915 survey track units, with two separate areas of concentration (Figure A3). Maximum $s_a = 4.64e^{-7}$ m^2 m^{-2}. 333 Falkland calamari mantle lengths were measured, at 5 trawl stations, of which 210 were also weighed. Thus, no specimens were measured at one of the six trawl stations where calamari catch was recorded (Trawl 4). An average length was assigned to Trawl 4 as the distance-weighted mean of the other five trawl stations.

The inverse-distance weighting algorithm obtained an overall mean density of 0.002 t km^{-2}, resulting in a biomass estimate of 40.4 t for the survey area (Table 1).

Summary

The four species southern blue whiting, Falkland sprat, common hake and Falkland calamari together comprised >99% of area backscatter classified during the survey and >98% of trawl catch; southern blue whiting alone was >93% of area backscatter and >97% of trawl catch (Table 1). The remaining <1% of backscatter was classified as either lanternfish (Myctophidae), which obtained minimal catch, or grenadier (*Coelorinchus fasciatus* / *Macrourus carinatus*), for which we presently found no suitable target-strength model. The remaining <2% of trawl catch included mostly skates, benthic-demersal fish, and invertebrates (Table A4), which have appreciably little acoustic profile.

Table 1. Survey summaries of the four principal species evaluated.

Species	Trawl catch (KG)	s_A (m^2 nmi^{-2})	Survey area biomass (T)
S. blue whiting	14918.2	690210	224132.8
Falkland sprat	122.5	45043	5477.1
Common hake	76.9	13	17.1
Falkland calamari	24.7	43	40.4
Total	15346.9	735321	

Discussion

Acoustic surveying is an efficient and well-established methodology for estimating the abundance of commercial fish stocks, with some known limitations (Thorne 1983). In a mixed assemblage, classifying backscatter to biota still requires partly subjective judgment (Fernandes 2009, Charef et al. 2010), and near-bottom fish may be confounded with backscatter from the seabed (Ona and Mitson 1996). Furthermore, the choice of acoustic target strength model may be a significant source of difference in estimation. Dunford and Macaulay's (2006) equation for southern blue whiting, used in this analysis (Table A1), replaced an earlier equation that used parameters $\alpha = 25.05$ and $\beta = -81.35$ (McClatchie et al. 1998). At the median FL of 46 cm sampled in this survey, backscattering cross-section σ_{bs} according to either the 2006 or 1998 equation would be respectively $4.15e^{-4}$ m^2 and $1.07e^{-4}$ m^2, i.e. a difference ratio of 3.9×. The disparity may be even higher for target strengths that have to be 'borrowed' from related species. The median FL of Falkland sprat sampled in this survey was 16 cm, equivalent to $\sigma_{bs} = 5.13e^{-5}$ m^2 according to the equation of Didrikas and Hansson (2004) for Baltic Sea sprat, Table A1. In contrast, a study of Black Sea sprat obtained $\alpha = 15.7$ and $\beta = -86.5$ (Marinova and Panayotova 2015), equivalent to $\sigma_{bs} = 1.74e^{-7}$ m^2 at 16 cm; a difference ratio of 295× that would translate directly to the density estimate. Notably however, none of the sprat specimens analysed by Marinova and Panayotova (2015) were actually as big as 16 cm, underlining the importance of data that are directly compatible with the research objective.

Recognizing these caveats, interpretation of the results invites some caution. The survey area estimate of 224,132.8 t for southern blue whiting is higher than the 201,974 t estimated for the entire south-west Atlantic fishery by Ramos and Winter (2019a), and is conspicuous for its very skewed densities. Conversely, the survey area estimate of 40.4 t Falkland calamari is a fraction of the 5076 t escapement biomass estimated by Winter (2019b) in the southern part of the Loligo Box. Calamari biomass normally recedes at the end of a season as the squid migrate to spawn (and coincidentally the most recent calamari season was closed – by emergency order – on the day this survey started), but the difference would not plausibly be this great. The primary utility of this acoustic-trawl survey may fundamentally be to provide indices of areal distribution, and relative biomass estimates comparable to future surveys.

Acknowledgement

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Appendix

Table A1. Target-strength model parameters in the format TS = $\alpha \cdot \log_{10}(L) + \beta$, at 38 kHz, L in cm; fork length for fish, mantle length for squid.

Species	α	β	Reference
Micromesistius australis	38.0	–97.00	Dunford and Macaulay (2006)
Sprattus fuegensis	25.5	–73.60	Didrikas and Hansson (2004)[1]
Merluccius hubbsi	23.6	–74.00	Lillo et al. (1996)[2]
Doryteuthis gahi	20.0	–71.52	Soule et al. (2010)[3]

[1] Actually modelled on Baltic Sea *Sprattus sprattus*.

[2] Actually modelled on Chilean hake *Merluccius gayi*.

[3] Actually modelled on chokka squid *Loligo reynaudii*; re-calculated from Table 4 in Soule et al. (2010), Algoa data only, truncated TS (n = 7).

Table A2. Length / weight model parameters in the format $W = \alpha \cdot L^{\beta}$, W in g and L in cm.

Species	α	β	Reference
Micromesistius australis	0.0014	3.3895	This survey.
Sprattus fuegensis	0.0027	3.0900	Froese and Pauly 2019
Merluccius hubbsi	0.0103	2.8926	FIG 2019
Doryteuthis gahi	0.1777	2.1648	This survey.

Table A3. Survey trawl coordinates.

Trawl	Station	Date	Start			End		
			Time	Latitude	Longitude	Time	Latitude	Longitude
1	764	8/9/2019	19:20	52° 26.79	61° 19.58	19:26	52° 27.05	61° 19.11
2	768	9/9/2019	16:00	52° 31.46	60° 50.04	16:15	52° 30.59	60° 51.74
3	770	9/9/2019	22:05	52° 29.12	60° 45.17	22:20	52° 29.12	60° 45.17
4	775	10/9/2019	21:45	52° 37.88	60° 11.69	21:49	52° 37.86	60° 11.67
5	780	13/9/2019	20:28	52° 54.39	58° 58.84	20:49	52° 53.43	58° 00.31
6	783	14/9/2019	12:36	52° 44.97	58° 27.06	13:02	52° 45.88	58° 29.02
7	790	17/9/2019	6:44	52° 33.18	60° 53.42	6:51	52° 32.90	60° 53.92
8	791	17/9/2019	16:25	52° 26.09	61° 20.49	16:37	52° 25.72	61° 21.15

Table A4. Catches by trawl.

Species group	Catch (KG)							
	Trawl 1	Trawl 2	Trawl 3	Trawl 4	Trawl 5	Trawl 6	Trawl 7	Trawl 8
Micromesistius australis	7299	0	272.42	0	0	0	5256.60	2090.16
Sprattus fuegensis	0	0	0	122.52	0	0	0	0
Merluccius hubbsi	0.820	0	0.688	0	0	73.18	1.46	0.760
Macrourus carinatus	0	0	0	0	0	64.98	3.16	1.94
Munida	0	0	0	29.92	0.136	0	0	0
Salilota australis	1.016	0	26.42	0	0	0	0.94	0
Bathyraja brachyurops	0	3.60	24.02	0	0	0	0	0
Dipturus chilensis	3.98	1.90	0	0	0	18.24	0	0
Doryteuthis gahi	0	0.146	0.300	0.438	15.44	7.38	1.50	0
Schroederichthys bivius	0	4.280	2.14	0	0	0	1.00	0
Patagonotothen sp.	0.008	0	0.36	0.118	0	3.694	0	0
Desmonema chierchianum	0	0	0	1.30	2.14	0	0.22	0
Coelorinchus fasciatus	0	0	0	0	0	0.160	0	0.114
Zygochlamys patagonica	0	0	0	0	1.72	0	1.86	0
Bathyraja albomaculata	0	0	0	0	0	1.22	0	0
Merluccius australis	0	0	0	0	0	1.04	0	0
Cottoperca gobio	0	0	0	0.826	0	0	0	0
Genypterus blacodes	0	0	0	0	0	0	0	0.800
Bathyraja scaphiops	0.560	0	0	0	0	0	0	0
Myxine sp.	0	0	0	0.170	0	0	0	0
Iluocoetes fimbriatus	0	0	0	0	0	0.068	0	0
Myctophidae	0	0	0	0	0.012	0.052	0	0

Table A5. Southern blue whiting otolith age determinations and corresponding measurements.

Trawl*	Sex	Fork length (cm)	Weight (g)	Age determination (years)
3	F	44	546	5
1	F	45	594	6
1	F	45	640	5
1	F	46	668	7
1	F	46	646	6
3	F	46	564	5
8	F	47	678	6
8	F	47	708	7
8	F	47	642	6
1	F	47	769	7
7	F	48	682	5
7	F	48	630	6
8	F	48	786	6
8	F	49	674	7
8	F	49	679	5
1	F	50	814	5
8	M	44	558	7
1	M	45	586	7
1	M	45	598	5
1	M	46	538	7
1	M	46	630	6
3	M	46	627	7
3	M	47	658	8
1	M	47	697	6
1	M	47	604	6
1	M	47	630	6
7	M	48	740	5
7	M	48	653	7
7	M	48	695	7
3	M	49	770	9
8	M	49	658	6
1	M	50	880	6

* Corresponding to Tables A3 and A4.

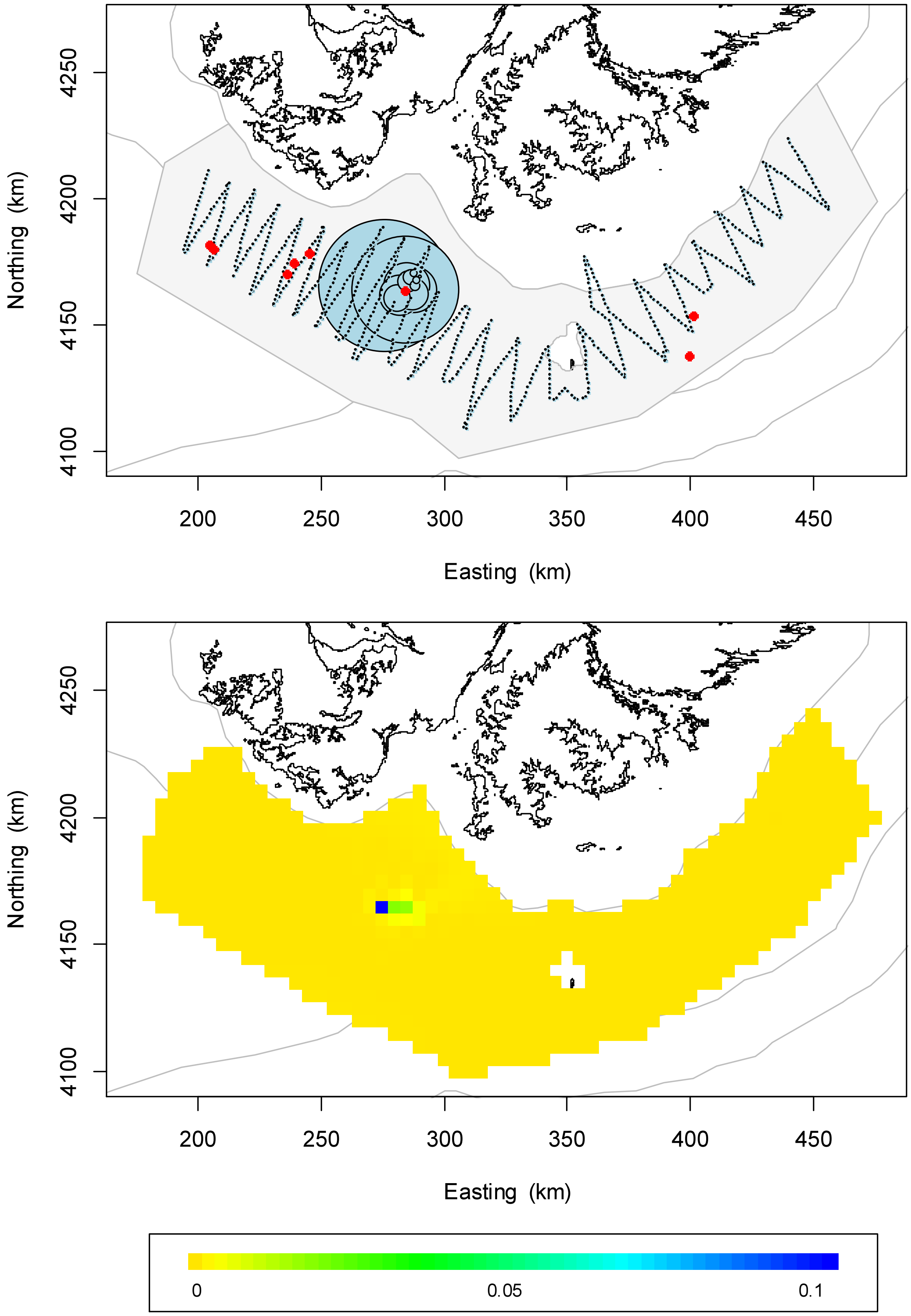

Figure A1. Falkland sprat: relative area backscattering coefficients (top) and density kg m^{-2} (bottom).

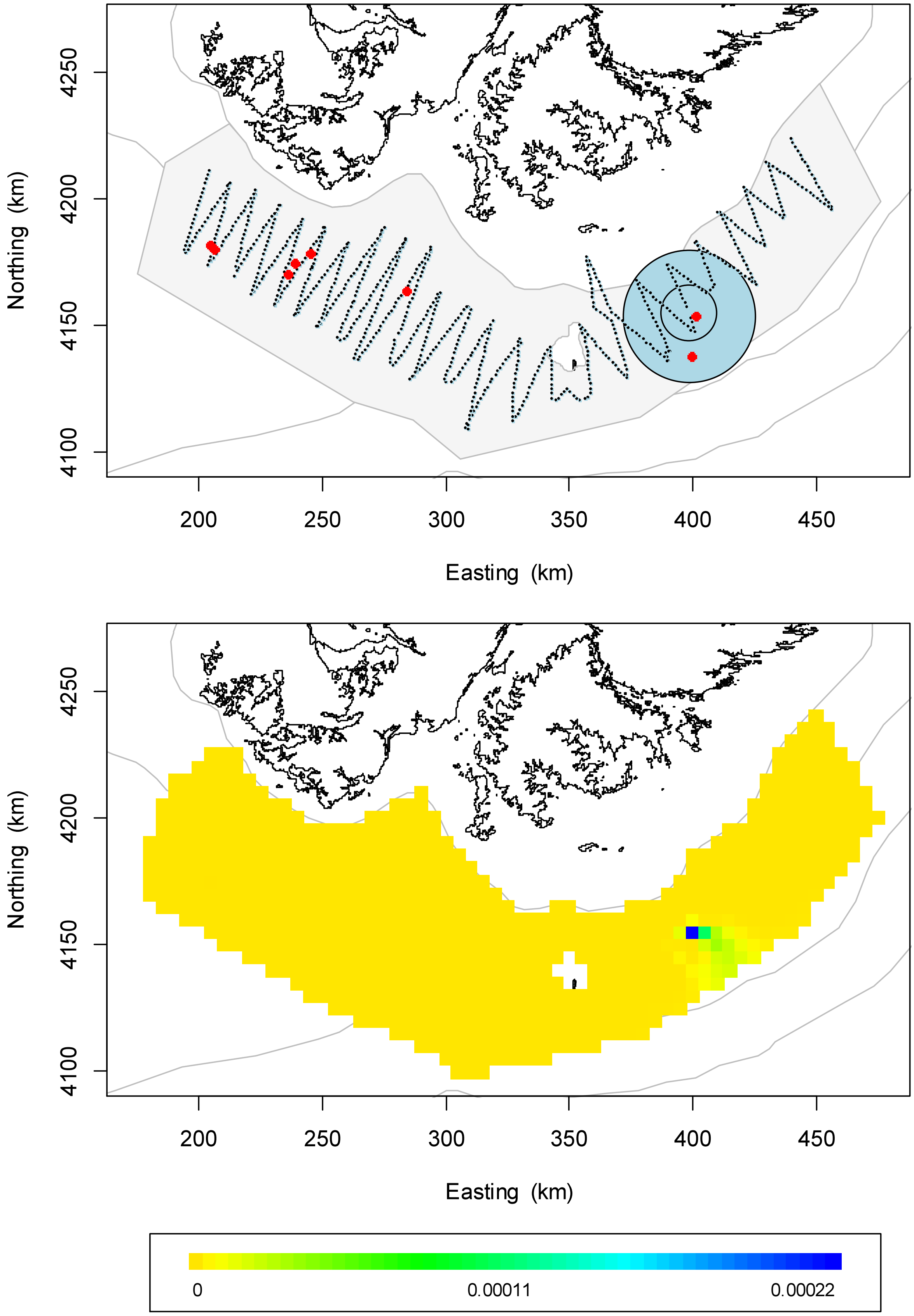

Figure A2. Common hake: relative area backscattering coefficients (top) and density kg m^{-2} (bottom).

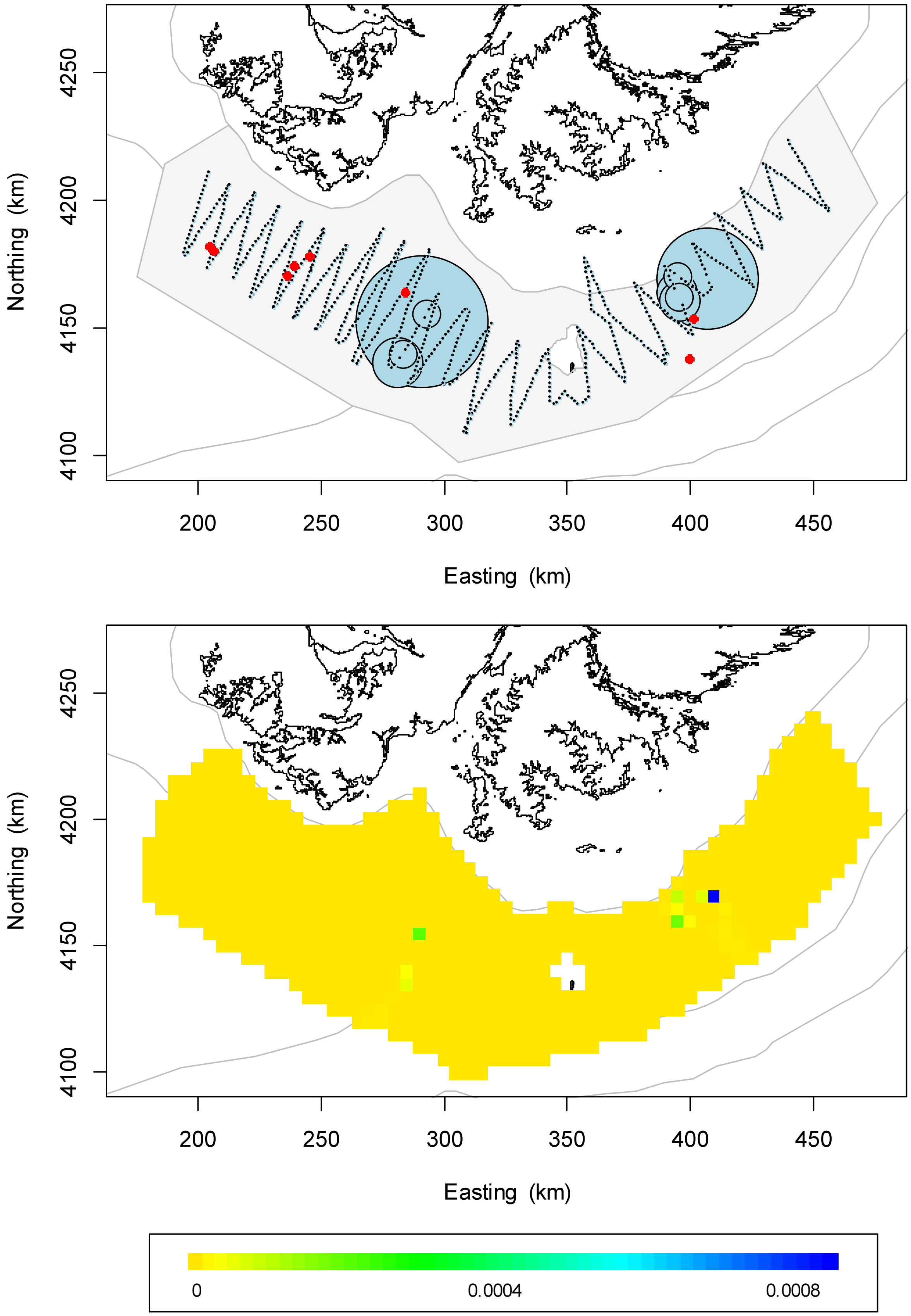

Figure A3. Falkland calamari: relative area backscattering coefficients (top) and density kg m^{-2} (bottom).