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Research Article

Antarctic demersal finfish around the Elephant and the South Orkney islands: distribution, abundance and biological characteristics

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ABSTRACT. A research survey for demersal finfish was completed using bottom trawl fishing gear, following a random stratified sampling design, between 50 and 500 m on shelf areas of Subarea 48.1 (Elephant Island) and Subarea 48.2 (South Orkney Island). An acoustic survey was simultaneously carried out to enhance knowledge of bathymetry and the distribution of fish and krill in the studied area. The cruise took place between the 6 and 27 January 2018. A total of 36 hauls were carried out, 15 around Elephant Island and 21 around the South Orkney Islands. A total of 37 fish species were caught with a total biomass of 19,112 kg. The main species encountered included *Notothenia rossii* and *Champsocephalus gunnari*, with nominal catches weighing 16,204 (85%) and 876 kg (5%), respectively. Other species of fish accounted noticeably for lower amounts (11%), such as *Gobionotothen gibberifrons* (330 kg), *Chaenocephalus aceratus* (322 kg), and *Pseudochaenichthys georgianus* (299 kg). Indicative estimates of standing stock biomass suggested that in this cruise, *N. rossii* was the most abundant demersal finfish species in the Elephant Island area, followed by *C. gunnari*. Differently, on the South Orkney Islands shelf, the most abundant species was *G. gibberifrons*, followed by *P. georgianus*. The study provides biological data (length frequency distribution, median size, sex ratio, gonad maturity stages, length-weight relationship) on the main species captured during the survey, and the oceanographic characteristics (depth profiles of temperature, salinity, density) obtained with CTD around the South Orkney Islands.

Keywords: Antarctica; finfish; relative abundance; biological characteristics; acoustic; environment

INTRODUCTION

The marine flora and fauna that inhabit Antarctica, as well as their delicate ecological relationships, are of interest to many countries regarding research and promotion of their survival and conservation (Hempel, 2007; Griffiths, 2010; Murphy, 2014). However, the remote and hard-to-access nature of this region limit the knowledge of the mechanisms that underlie these marine ecosystems and, although expanding current knowledge is presented as a major objective for research activities, still requires further development to contribute adequately to the implementation of conservation measures (Constable *et al*., 2000). Thus, Antarctic living marine organisms are a valuable source of scientific interest and, at the same time, they represent a considerable challenge to achieve an appropriate management approach that will allow the commercial exploitation of some species (Constable *et al*., 2000; Fabra & Gascón, 2008).

For many years the waters surrounding the Antarctic continent were subject to marine mammal exploitation, later giving way pursuing Antarctic fish and Antarctic krill (*Euphausia superba*) (Nicol &

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Endo, 1997; Tin *et al*., 2009). Fishing activities, specifically in the Scotia Sea region of the Southern Ocean (Statistical subareas 48.1, 48.2 and 48.3), started almost half a century ago. Catches were carried out by USSR vessels targeting mainly Nototheniidae (*Notothenia rossii*) and Channichthyidae (*Champsocephalus gunnari*, *Chaenocephalus aceratus* and *Chaenodraco wilsoni*) (CCAMLR, 1990a,b). Due to the drastic decrease of these species, especially in subareas 48.1 and 48.2 (Kock, 1991), the Commission for the Conservation of the Antarctic Marine Living Resources (CCAMLR) imposed a moratorium on finfish fishing since the 1989/90 season. This Conservation Measure (CM 32-02) is still in force.

In recent decades, special attention has been given to monitoring the status and recovery of fish stocks on shelf areas of subareas 48.1 and 48.2. Until recently, these surveys recorded little increase in terms of fish biomass and abundance levels (*e.g*., Jones *et al*., 2003; Kock *et al*., 2007; Jones, 2009; Marschoff *et al*., 2012; CCAMLR, 2013a; Barrera-Oro *et al*., 2017). However, in the investigation carried out by Kock & Jones (2012a) onboard the RV Polarstern in the South Shetland Islands during March-April 2012, *N. rossii* and *C. gunnari* showed a clear signal of recovery in contrast with a previous survey (Kock *et al*., 2007).

In the present study, we provide additional insight into the state of fish populations around Elephant Island (Subarea 48.1) and the South Orkney Islands (Subarea 48.2) from a bottom trawl research survey suggesting appropriate measures for the management of subareas 48.1 and 48.2. The present investigation was authorized by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) and by the Under-secretariat for Fisheries of Chile (SUBPESCA).

MATERIALS AND METHODS

General aspects

The study area comprised the continental shelf around Elephant Island and the South Orkney Islands (subareas 48.1 and 48.2) (Fig. 1). Sampling activities were carried out between 50 and 500 m depth, between January 10 and 21, 2018.

Acoustic survey

The acoustic information was obtained with a SIMRAD EK80 wide band scientific echosounder, at a frequency of 38 kHz (ES38B), and a SIMRAD ES70 fishing echosounder equipped with a 120 kHz frequency transducer (ES120-7C). The time varied gain (TVG) used corresponded to 20 LOG for the detection of shoals (Reid *et al*., 1998; MacLennan *et al*., 2002; Simmonds & MacLennan, 2006; ICES, 2007). The ES70 equipment can detect individual targets and estimate the size of the observed organisms as an option available on the echosounder screen, which allows visualizing the lengths of the detected specimens in a frequency histogram (in centimeters) and thus allow to discriminate between Antarctic krill (*Euphausia superba*) and fish.

The acoustic survey covered the approximate area of the 50 and 500 m isobaths of depth, with a pulse length of 1,024 μs. The information was recorded during all navigation and fishing operations, and these tasks were complemented during the night for seabed recognition for the next day and shoal detection (fish and krill). Some identification hauls were carried out at the time of resource detection to reduce the spatio-temporal uncertainty in the allocation of the echo-integration units.

The geo-referenced acoustic information (raw) was stored in magnetic files that were processed and analyzed on land. Data were analyzed through the Sonardata computer program; data referred to SA (m^2 mn^{-2}) will be associated with each species identified in the echograms. Krill concentrations were detected considering their bathymetric distribution, shoal shape and individuals size structure, provided by the echosounder, and samples obtained with a midwater net. It is important to note that in some cases, the mackerel icefish *Champsocephalus gunnari* and pelagic finfish ("other finfish") shoals were identified exclusively through expert judgment. Concerning the echogram characteristics, the predominant use of bottom trawling nets resulted in a lack of the pelagic environment sampling.

Fishing hauls

Demersal finfish sampling was carried out using bottom trawl fishing gear, according to a stratified random sampling design. All hauls were carried out with an effective trawling time of 30 min during daylight hours. (nautical twilight to nautical sunset). Trawling was conducted only during daylight hours when fishes were known to concentrate on the bottom or in near-bottom layers, to be comparable with results of previous investigations, carried out in this way, in this same region (*e,g*., Jones *et al*., 1999a, 2001, 2003; Kock *et al*., 2002, 2007; Jones & Kock, 2009; Kock & Jones, 2012a). A hardbottom snapper trawl net (length 45 m, horizontal mouth opening 11 m, vertical mouth height of 8-9 m, and 40 mm mesh size in the codend) (Net Systems, Inc., Bainbridge Island, WA), was used for the hauls; gear previously used in this area by the US AMLR Program, Southwest Fisheries Science Center, National Marine Fisheries Service, USA.

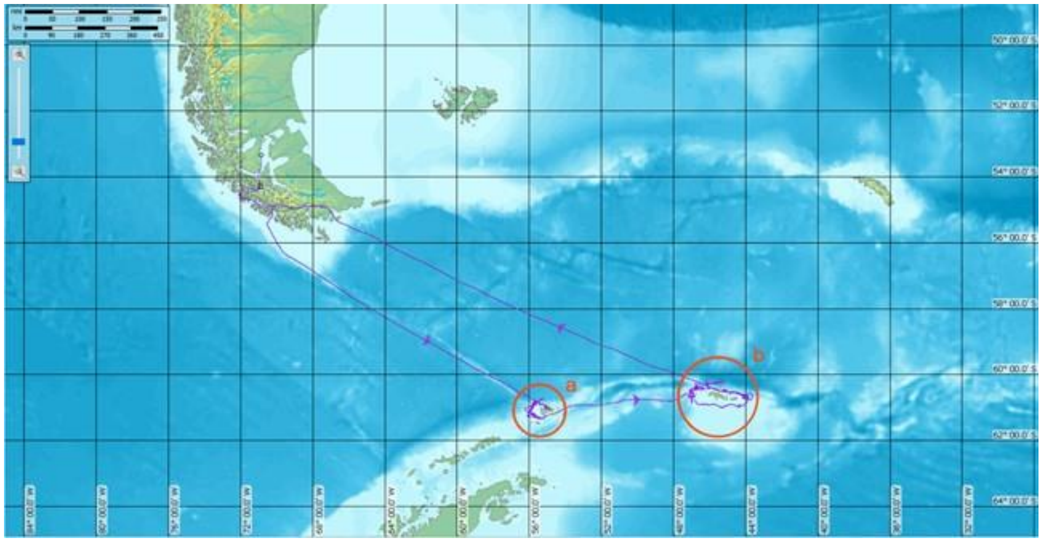

Figure 1. Navigation route of the research cruise. a) Elephant Island (Subarea 48.1), b) South Orkney Islands (Subarea 48.2).

After each haul, fishes were identified and sorted for species. Species identification was carried out to the most precise taxonomic level possible. Identification guides for the identification criteria were used for fish and other species (Fisher & Hureau, 1985; CCAMLR, 2011a, 2013b; Dongwon, 2015) and fish juveniles and larvae (Iwami, 1995; Iwami & Naganobu, 2007). Catch composition was recorded in terms of weight and number of individuals caught. In each haul, the catch per unit of effort (CPUE) was estimated as catch by haul (kg $haul^{-1}$), catch by time (kg h^{-1}), and catch by distance covered (kg km^{-1}).

The seabed area surveyed during the haul was determined by the latitude/longitude coordinates taken as a straight line from the start to the end of the trawl's bottom contact, and the average of the trawl mouth width. We assumed a gear catchability of 100%.

Length and sex compositions

Fish size was measured as total length (TL) in cm (from the tip of snout to end of caudal fin) and its total weight (Wt) in grams. The length-frequency distributions were grouped per species and sampling area. Length-weight relationships were expressed using the standard allometric equation $Wt = a \times TL^b$. The Student's *t*-test ($t_{\alpha/2}$, n-2) was applied to establish the type of relative growth (allometric-isometric) characterizing the different species (Dixon & Massey, 1957).

Sex and gonad maturity were determined using the five-point scale (immature, in development, developed, mature and post-spawning) of Kock & Kellermann (1991). In the case of large catches, a representative sub-sample was randomly selected to determine the size and sex composition. Additionally, gonad and otolith samples were taken for reproductive and aging purposes.

Environmental conditions

Depth profiles of temperature and salinity were obtained in 19 trawling hauls around the South Orkney Islands by attaching a Seabird SBE 37SMP MicroCAT CTD to the upper part of the net.

RESULTS

General aspects

The cruise conducted between January 6 and 27, 2018, covering a total distance of approximately 3,496 nm. The port of departure and return was Punta Arenas, Chile. The research was conducted aboard the Chilean factory ship Cabo de Hornos, an 80 m-long stern trawler with 2,140 GRT, belonging to the fishing company Deris S.A. This vessel was equipped with two echo sounders (Simrad ES80, 38 kHz, and a Simrad ES70, 120 kHz frequency) and a multi-frequency sonar (Furuno, FSV30, 21-27 kHz).

The bottom trawl survey included 36 hauls: 15 around Elephant Island (Subarea 48.1) and 21 around the South Orkney Islands (Subarea 48.2) (Fig. 2).

In Subarea 48.1 trawling depth ranged between 92 m and 415 m, with the most frequent fishing hauls within 101-200 m (Fig 3a). In Subarea 48.2, trawling depth ranged between 106 and 425 m, with the most frequent fishing hauls within 201-300 m (Fig. 3b).

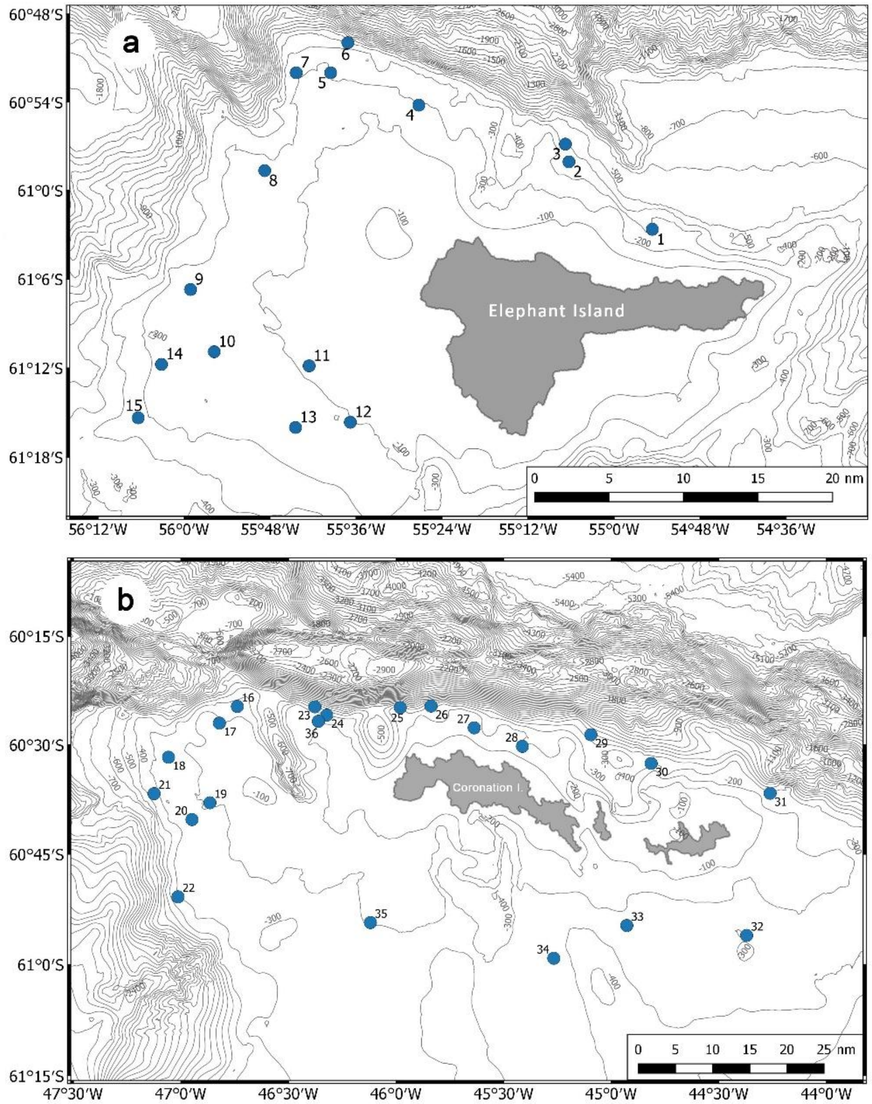

Figure 2. Bottom trawl sampling stations for the demersal finfish survey. a) Stations around the Elephant Island (Subarea 48.1), and b) stations around the South Orkney Islands (Coronation, Signy, Powell and Laurie islands) (Subarea 48.2).

Acoustic survey

The acoustic survey was carried out across the whole study area. The navigation route totaled 579 nm around Elephant Island and 1,120 nm (Fig. 4a) around the South Orkney Islands (Fig. 4b).

In the area around Elephant Island, the highest numbers of *Champsocephalus gunnari* were detected primarily around the west and northwestern sectors of the island and mostly associated with steep bathymetry (Fig. 4b). Only one haul allowed the positive identification of an icefish school (33.6 t). In the other four hauls, only some individuals of *Pseudochaenichthys georgianus* and *Euphausia superba* were detected. Other finfish without a clear definition of the species were recorded in the southwestern and south sectors of Elephant Island (Fig. 4d). Krill aggregations were observed along almost the entire navigation route of the ship, with more in the north and northwestern sector of the island (Fig. 4c).

Around the South Orkney Islands, the acoustic identification of *C. gunnari* concentrations was carried out based on expert judgment only, given that the largest number of aggregations were relatively far off the bottom (>8 m), and above the mouth of the net used in the research. On this basis, the probable aggregations of mackerel icefish distributed primarily in the north and northwestern sectors of these islands (Fig. 5b). Krill concentrations were observed throughout the navigation route, especially in the northwestern and northeastern sectors (Fig. 5c). Records of possible other finfish were determined in two sectors, the first to the west-northwestern of these islands and the second to the east (Fig. 5c).

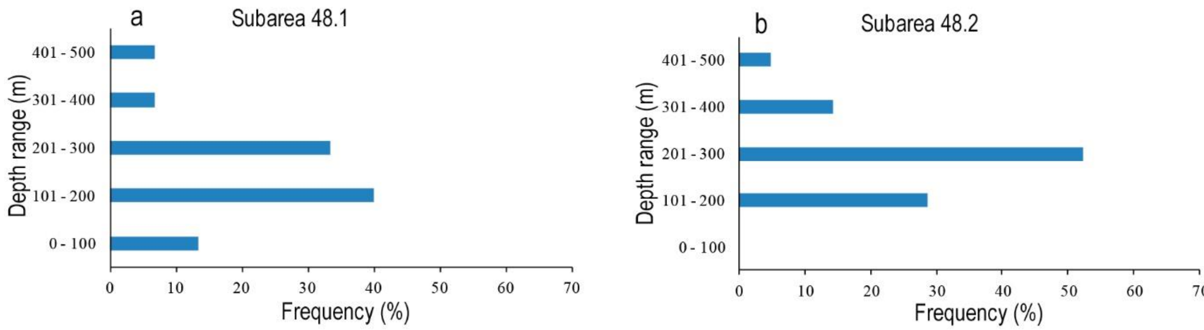

Figure 3. Distribution of trawling hauls by depth range for the demersal finfish survey. a) Subarea 48.1, b) Subarea 48.2.

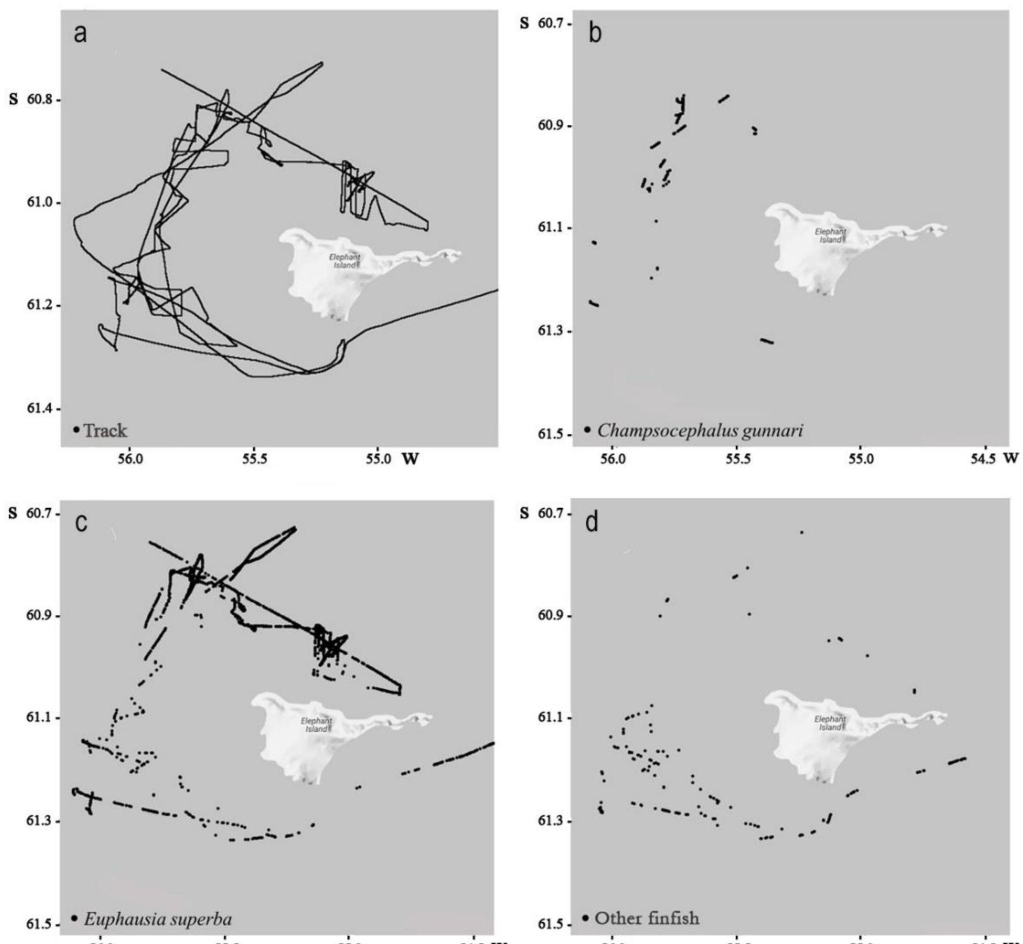

Figure 4. Spatial distribution of acoustic records of demersal fish and krill around Elephant Island. a) Acoustic track survey, b) mackerel icefish *(Champsocephalus gunnari)*, c) Antarctic krill (*Euphausia superba*), d) other finfish.

The effort, catch, and CPUE

The total catch of all finfish species during the bottom trawl survey was 19,112.28 kg; in Subarea 48.1, the amount was 17,305.7 kg and 1,806.58 kg in Subarea 48.2 (Table 1). A total of 37 fish species were identified, and size and sex were determined for 2,294 specimens.

Grouping catches obtained in both subareas, the main species caught were *N. rossii* and *C. gunnari*, with catches accounting for 16,204.38 and 875.69 kg, respectively. Other species recorded were *Gobionotothen gibberifrons* (329.97 kg), *Chaenocephalus aceratus* (321.91 kg) and *Pseudochaenichthys georgianus* (299.39 kg).

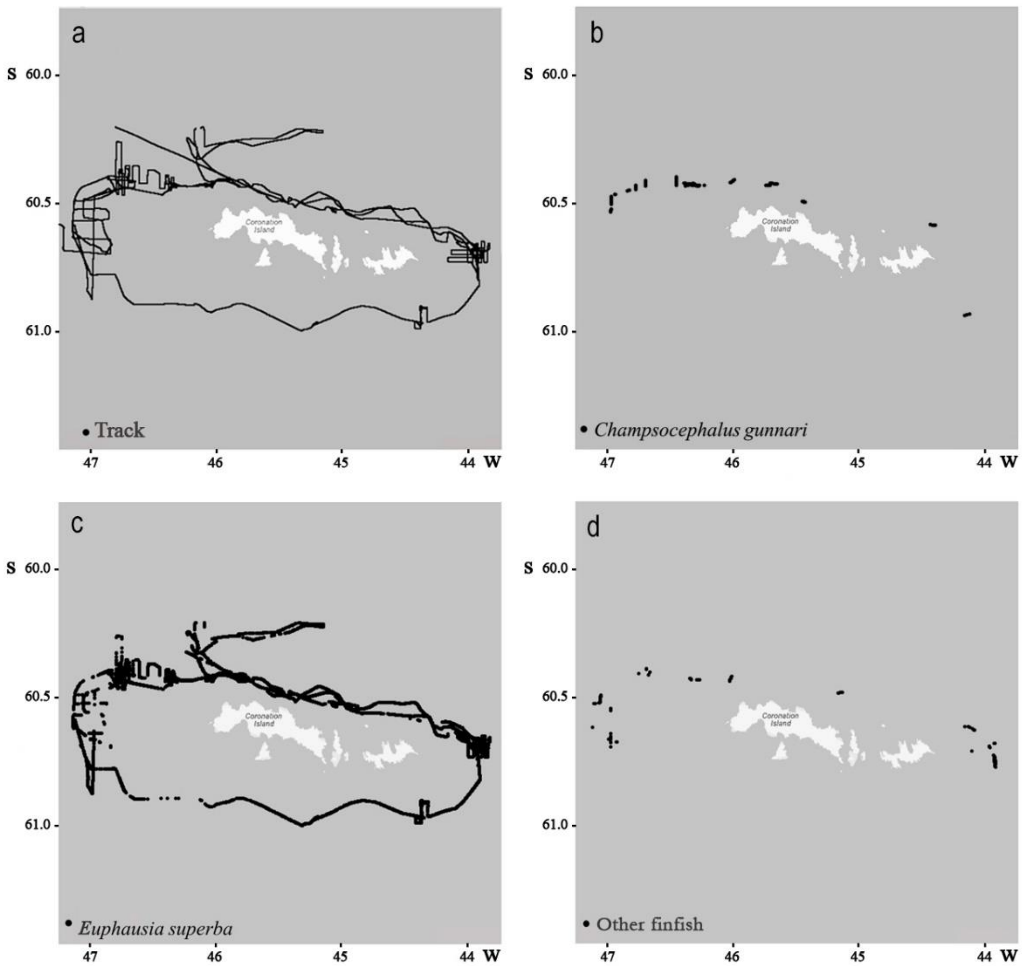

Figure 5. Spatial distribution of acoustic records of demersal fish and krill in the vicinity of the South Orkney Islands. a) Acoustic track survey, b) mackerel icefish (*Champsocephalus gunnari*), c) Antarctic krill (*Euphausia superba*), d) other finfish.

In terms of biomass, the main species caught in Subarea 48.1 were *N. rossii* and *C. gunnari*, which yielded a total of 16,197.81 and 704.74 kg, respectively. In Subarea 48.2, the catches mainly composed of *G. gibberifrons* (306.83 kg), *P. georgianus* (299.39 kg), *C. aceratus* (242.93 kg) and *C. gunnari* (170.95 kg).

Catch per unit effort, in terms of kilograms per trawling hour (kg h^{-1}), showed marked differences between subareas (Table 2). In Subarea 48.1, the CPUE of *N. rossii* reached 2,159 kg h^{-1}, while in Subarea 48.2, this amount dropped to 0.62 kg h^{-1}. *C. gunnari* showed a similar trend, decreasing from 93.96 kg h^{-1} in Subarea 48.1 to 16.25 kg h^{-1} in Subarea 48.2. An inverse evidence trend was recorded for *G. gibberifrons*, *P. georgianus* and *C. aceratus*, with the CPUE increasing in Subarea 48.2. By grouping both subareas, the highest CPUE values were obtained for *N. rossii* and *C. gunnari*, reaching 899.24 and 48.6 kg h^{-1}, respectively (Table 2).

The CPUE expressed as catch per trawling kilometer (kg km^{-1}) showed a similar pattern. In Subarea 48.1, the CPUE reached 319.84 kg km^{-1} for *N. rossii*, decreasing to 0.10 kg km^{-1} in Subarea 48.2. The CPUE of *C. gunnari* was 13.92 kg km^{-1} in Subarea 48.1 and to 2.52 kg km^{-1} in Subarea 48.2. By pooling together both subareas, the CPUE for *N. rossii* and *C. gunnari* reached 136.72 and 7.39 kg km^{-1}, respectively (Table 2). Considering all species the species caught, the CPUE accounted for 2,307.43 kg h^{-1} in Subarea 48.1 and 171.73 kg h^{-1} in Subarea 48.2. CPUE per trawling km in Subarea 48.1 reached 341.72 kg km^{-1} and only 26.61 kg km^{-1} in Subarea 48.2.

Table 1. Catch (kg) and specimens sampled by species, obtained with bottom trawling (Hardbottom Snapper Trawl) in subareas 48.1 and 48.2. Code: CCAMLR species code.

Species	Code	Subarea 48.1			Subarea 48.2			Total		
		Catch (kg)	Sampling (kg)	n	Catch (kg)	Sampling (kg)	n	Catch (kg)	Sampling (kg)	n
Notothenia rossii	NOR	16,197.81	794.42	326	6.57	6.57	2	16,204,38	800.99	328
Chaenocephalus aceratus	SSI	78.98	74.78	62	242.93	236.30	224	321.91	311.08	286
Lepidonotothen squamifrons	NOK	8.13	3.29	7	112.95	59.07	107	121.08	62.36	114
Parachaenichthys charcoti	PCH	1.55	1.19	8	0	0	0	1.55	1.19	8
Champsocephalus gunnari	ANI	704.74	180.73	494	170.95	98.62	317	875.69	279.35	811
Lepidonotothen larseni	NOL	3.63	0.66	16	22.02	1.25	19	25.64	1.90	35
Chionodraco rastrospinosus	KIF	7.17	3.37	7	70.68	52.38	103	77.85	55.75	110
Dissostichus mawsoni	TOA	53.26	3.77	3	0	0	0	53.26	3.77	3
Octopodidae	OCT	16.75	0	0	12.13	0	0	28.88	0	0
Gymnoscopelus nicholsi	GYN	48.62	0	0	20.23	0.04	1	68.85	0.04	1
Bathyraja eatonii	BEA	0	0	0	0.96	0.96	2	0.96	0.96	2
Trematomus eulepidotus	TRL	0	0	0	19.82	2.63	13	19.82	2.63	13
Bathyraja maccaini	BAM	3.25	0	0	15.20	0.46	1	18.45	0.46	1
Bathyraja spp.	BHY	2.18	0	0	0	0	0	2.18	0	0
Ophthalmolycus amberensis	LYA	1.81	0.82	2	0	0	0	1.81	0.82	2
Muraenolepis microps	MOY	1.64	1.64	4	4.60	2.30	7	6.24	3.94	11
Gobionotothen gibberifrons	NOG	23.14	20.43	25	306.83	42.39	186	329.97	62.81	211
Notothenia coriiceps	NOC	50.92	48.88	36	11.41	11.12	6	62.34	60.01	42
Pachycara brachycephalum	PHB	0.10	0	0	0	0	0	0.1	0	0
Nototheniops nudifrons	NOD	0.60	0.60	12	0.92	0.81	8	1.51	1.40	20
Cryodraco antarcticus	FIC	0.38	0.38	10	1.44	1.22	14	1.82	1.60	24
Cephalopoda	CEP	1.18	0	0	0	0	0	1.18	0	0
Notothenia acuta	NOA	0.16	0.16	1	0	0	0	0.16	0.16	1
Pseudochaenichthys georgianus	SGI	0	0	0	299.39	294.02	242	299.39	294.02	242
Notothenia squamifrons	NOS	0	0	0	1.71	1.71	12	1.71	1.71	12
Pogonophryne marmorata	PGM	0	0	0	0.35	0.35	1	0.35	0.35	1
Trematomus hansoni	TRH	0	0	0	3.93	3.93	6	3.93	3.93	6
Pleuragramma antarcticum	ANS	0	0	0	4.56	0	0	4.56	0	0
Trematomus newnesi	TRW	0	0	0	0.11	0.11	1	0.11	0.11	1
Neopagetopsis ionah	JIC	0	0	0	0.43	0.43	2	0.43	0.43	2
Bathydraco antarcticus	BDN	0	0	0	0.18	0.18	1	0.18	0.18	1
Pogonophryne spp.	POG	0	0	0	0.41	0.41	1	0.41	0.41	1
Raja spp.	RAJ	0	0	0	0.02	0	0	0.02	0	0
Paraliparis spp.	PVZ	0	0	0	0.02	0.02	1	0.02	0.02	1
Pogonophryne scotti	SZT	0	0	0	0.30	0.30	1	0.30	0.30	1
Racovitzia glacialis	RGG	0	0	0	0.24	0.24	2	0.24	0.24	2
Macrourus whitsoni	WGR	0	0	0	0	0	0	0	0	0
Anotopterus pharao	ANH	0	0	0	0.60	0.60	1	0.60	0.60	1
Macrourus holotrachys	MCH	0	0	0	0	0	0	0	0	0
Bentos	BEN	99.75	0	0	474.73	0	0	574.47	0	0
Total		17,305.70	1,135.10	1.013	1,806.58	818.35	1281	19,112.28	1,953.45	2294

Standing stock biomass

In both subareas, we were unable to complete the planned number of stations because of limited ship time and ice conditions, which resulted in a low number of sampling stations from which to estimate standing stock biomass (Elephant Island: 13 stations; South Orkney Islands: 21 stations). For this reason, the results presented in Table 3 should be taken only as indicative.

Estimates of standing stock biomass were computed using the Delta log normal maximum likelihood estimator (De la Mare, 1994; Pennington, 1996). Seabed areas of the Elephant Island shelf were drawn from Jones *et al*. (1999), and seabed areas on the South Orkney Islands shelf were drawn from Jones (2000).

Indicative estimates of demersal finfish standing stock biomass, around Elephant Island and the South

Table 2. Catch per unit of effort (CPUE) of *Champsocephalus gunnari*, *Notothenia rossii*, *Chaenocephalus aceratus*, *Pseudochaenichthys georgianus* and *Gobionotothen gibberifrons* in subareas 48.1 and 48.2.

Species	Subarea	Catch (kg)	CPUE (kg h^{-1})	CPUE (kg km^{-1})
Champsocephalus gunnari	48.1	704.74	93.96	13.92
	48.2	170.95	16.25	2.52
	Total	875.69	48.60	7.39
Notothenia rossii	48.1	16,197.81	2,159.71	319.84
	48.2	6.57	0.62	0.097
	Total	16,204.38	899.24	136.72
Chaenocephalus aceratus	48.1	78.98	10.53	1.56
	48.2	242.93	23.09	3.58
	Total	321.91	17.86	2.72
Pseudochaenichthys georgianus	48.1	0	0	0
	48.2	299.39	28.46	4.41
	Total	299.39	16.61	2.53
Gobionotothen gibberifrons	48.1	23.14	3.09	0.46
	48.2	306.83	29.17	4.52
	Total	329.97	18.31	2.78

Table 3. Indicative estimates of total stock biomass (t) for eight primary demersal species from the 2018 bottom trawl surveys of Elephant Island and the South Orkney Islands.

Area	Species	Abundance (t)	Standard error	95% Confidence interval
Elephant Island	*Chaenocephalus aceratus*	453	189	
	Champsocephalus gunnari	6.333	4.134	1,615-79,662
	Chionodraco rastrospinosus	54	28	17-123
	Gobionotothen gibberifrons	167	91	52-885
	Lepidonotothen larseni	23	10	9-88
	Lepidonotothen squamifrons	103	75	21-2,861
	Notothenia coriiceps	318	184	95-2,422
	Notothenia rossii	376.229	302.509	55,362-16,526,300
South Orkney Islands	*Chaenocephalus aceratus*	6.716	2.391	3,482-18,373
	Champsocephalus gunnari	4.242	1.572	2,149-12,318
	Gobionotothen gibberifrons	11.145	4.568	5,248-37,693
	Lepidonotothen larseni	654	283	288-2,421
	Lepidonotothen squamifrons	3.936	2.062	1,388-22,266
	Notothenia coriiceps	309	214	67-4,821
	Notothenia rossii	161	113	28-466
	Pseudochaenichthys georgianus	1.061	5.323	4,073-53,329

Orkney Islands, suggest that *N. rossii*, followed by *C. gunnari*, are the most abundant finfish species in the Elephant Island area sampled as part of the bottom trawl survey. Conversely, the most abundant species on the South Orkney Island shelf was *G. gibberifrons* followed by *P. georgianus* (Table 3).

Length frequency distribution

In Subarea 48.1, the total lengths (TL) of *N. rossii* males reached an average of 52.16 cm with a range between 23 and 71 cm. The females of this species were larger, reaching an average size of 57.35 cm with a range between 35 and 79 cm TL (Figs. 6a-b). There were no distinct modes in the length distributions of this species.

Regarding *C. gunnari*, males caught in Subarea 48.1 varied between 18 and 53 cm TL with an average of 34.56 cm. The size of females ranged between 18 and 55 cm, with an average size of 33.67 cm TL (Figs. 7a-b). Both sexes present a strong modal between 32 and 34 cm TL, likely representing a three years class. There was also evidence of a mode at around 48-50 cm TL, which could indicate the existence of another annual class in that length range.

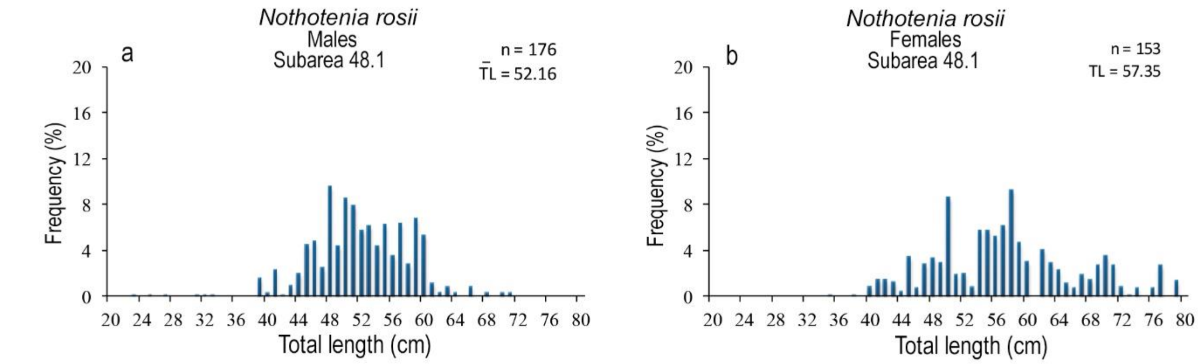

Figure 6. Total length (TL, cm) frequency distributions of *Notothenia rossii* in Subarea 48.1. a) male, b female).

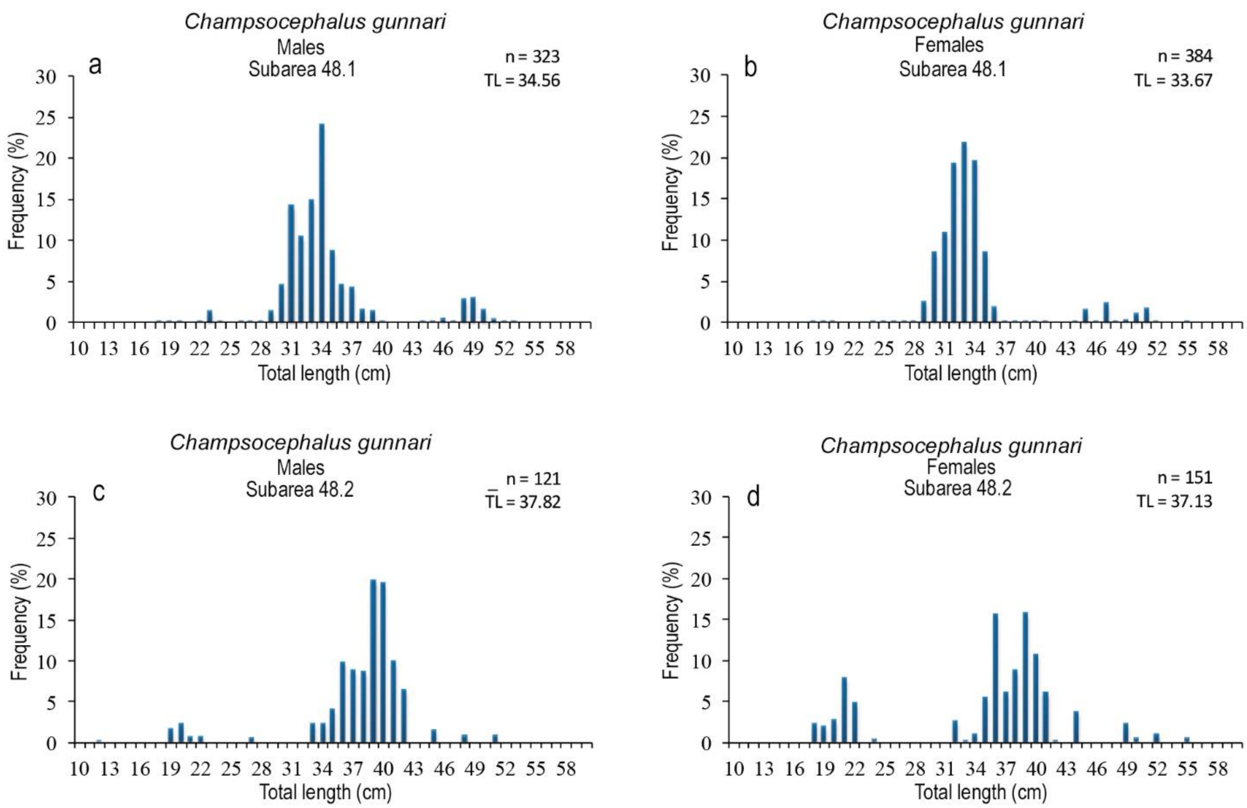

Figure 7. Total length (TL, cm) frequency distributions (male and female) of *Champsocephalus gunnari*. a-b) Subarea 48.1, c-d) Subarea 48.2.

In Subarea 48.2, the males of *C. gunnari* measured between 12 and 51 cm with an average of 37.82 cm TL, while the females showed a length range of 18 to 55 cm with an average of 37.13 cm (Figs. 7c-d). As in the previous subarea, the size of males roughly follows a normal distribution with a peak between 36 and 40 cm TL, and in females, a lesser peak between 18 and 22 cm TL is distinguished.

It should be noted that in hauls 11-13, carried out between 92 and 135 m to the southwestern of Elephant Island (Fig. 2), the catch was almost exclusively composed of juveniles. The TL in these hauls was between 5 and 13 cm, with an average of 8.27 cm of TL, clearly different from the average already previously indicated in adjacent areas of this same subarea (Fig. 8).

The size range of *C. aceratus* males was between 19 and 65 cm, with an average of 44.10 cm TL. The females showed a larger size, with total lengths of 14 to 71 cm and an average of 57.2 cm TL (Figs. 9a-b).

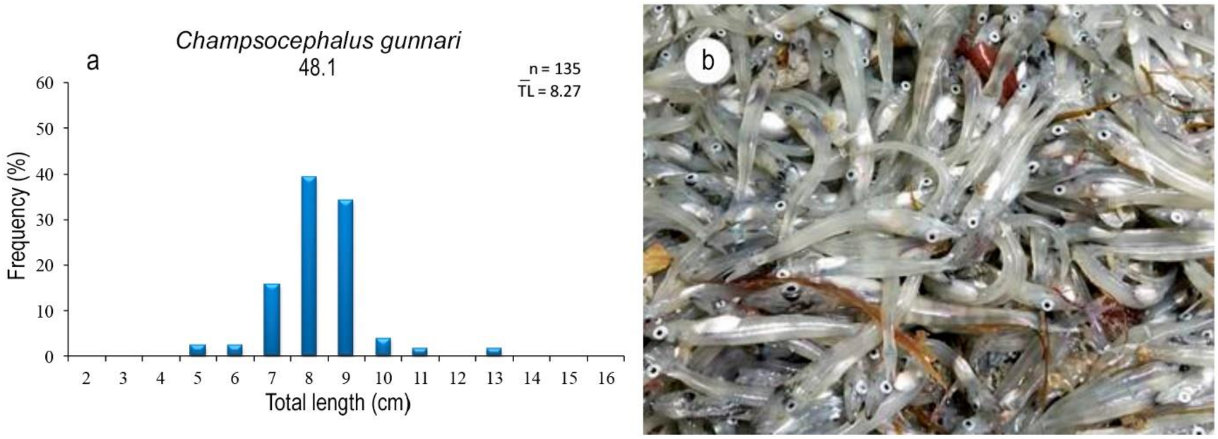

Figure 8. a) Total length (TL, cm) frequency distributions of *Champsocephalus gunnari* between 92 and 135 m deep in the SW of Elephant Island (hauls 11-13), b) small specimens captured (Photo: C.D. Jones).

Specimens of *Pseudochaenichthys georgianus* were only obtained in Subarea 48.2. The total length range in males was 14 to 58 cm, with an average of 47.54 cm, and in females was 25 to 63 cm with an average of 49.35 cm TL (Figs. 9c-d).

Due to the limited number of individuals of *Gobionotothen gibberifrons* captured, samples obtained in both subareas were grouped for their analysis. Size for both sexes ranged between 17 and 50 cm TL, with averages of 35.31 cm for males and 29.95 cm for females. Noteworthy in these distributions is the presence of a mode of large males between 48 and 50 cm TL (Figs. 9e-f).

The total length range (TL, cm) of the different species of fish caught on the cruise is shown in Table 4.

Sex ratio

The analysis of the catch records of *N. rossii* in Subarea 48.1 shows that 53.5% of the specimens were males, and 46.5% were females.

In the case of *C. gunnari*, females predominated in the sample carried out in Subarea 48.1, with 54.3% of the examined specimens and the remaining 45.7% corresponding to males. The same situation was observed in Subarea 48.2, where the total of females reached 55.5% and the males 44.5%.

Regarding *G. gibberifrons*, when grouping the samples obtained in both subareas, a relative predominance of males was observed (53.6%). The same situation was observed in *P. georgianus* (58.6%). The sex ratio recorded for *C. aceratus* was close to 1:1, being 49.6 and 50.4% of males and females, respectively.

Gonad maturity stages

The 5-point scale described by Kock & Kellerman (1991) for nototheniids and channichthyids was used to determine the maturity stages of the species captured during the cruise. In the case of *C. gunnari*, the majority (between 60 and 70%) of specimens were in a developing stage and only a few specimens in the developed and mature stage (Fig. 10a).

Regarding *C. aceratus*, differences in maturity between sexes were observed; approximately 50% of males and 21% of females exhibited developing gonads, while females showed the highest preponderance (50%) in the developed stage (Fig. 10b).

On the other hand, males and females of *N. rossii* were mainly found in developing and developed stage, the latter constituting between 58 and 68% of the total (males and females, respectively) (Fig. 10c).

In *P. georgianus*, developing males were approximately 65% of the total, followed by the immature stage (20%). In females, developed specimens were 48% of the total and 37.6% in the developing stage (Fig. 10d).

The species *G. gibberifrons* exhibited similar patterns, with both sexes reaching 70% of the specimens in the developing stage and other (20%) in the immature stage (Fig. 10e).

Length-weight relationship

The total length (TL) and total weight (Wt) records of the species with the highest catch biomass from both subareas (48.1 and 48.2) were grouped for *C. gunnari*, *N. rossii*, *C. aceratus*, *P. georgianus*, and *G. gibberifrons*.

A total of 964 specimens of *C. gunnari* were measured and weighed (437 males and 527 females). In

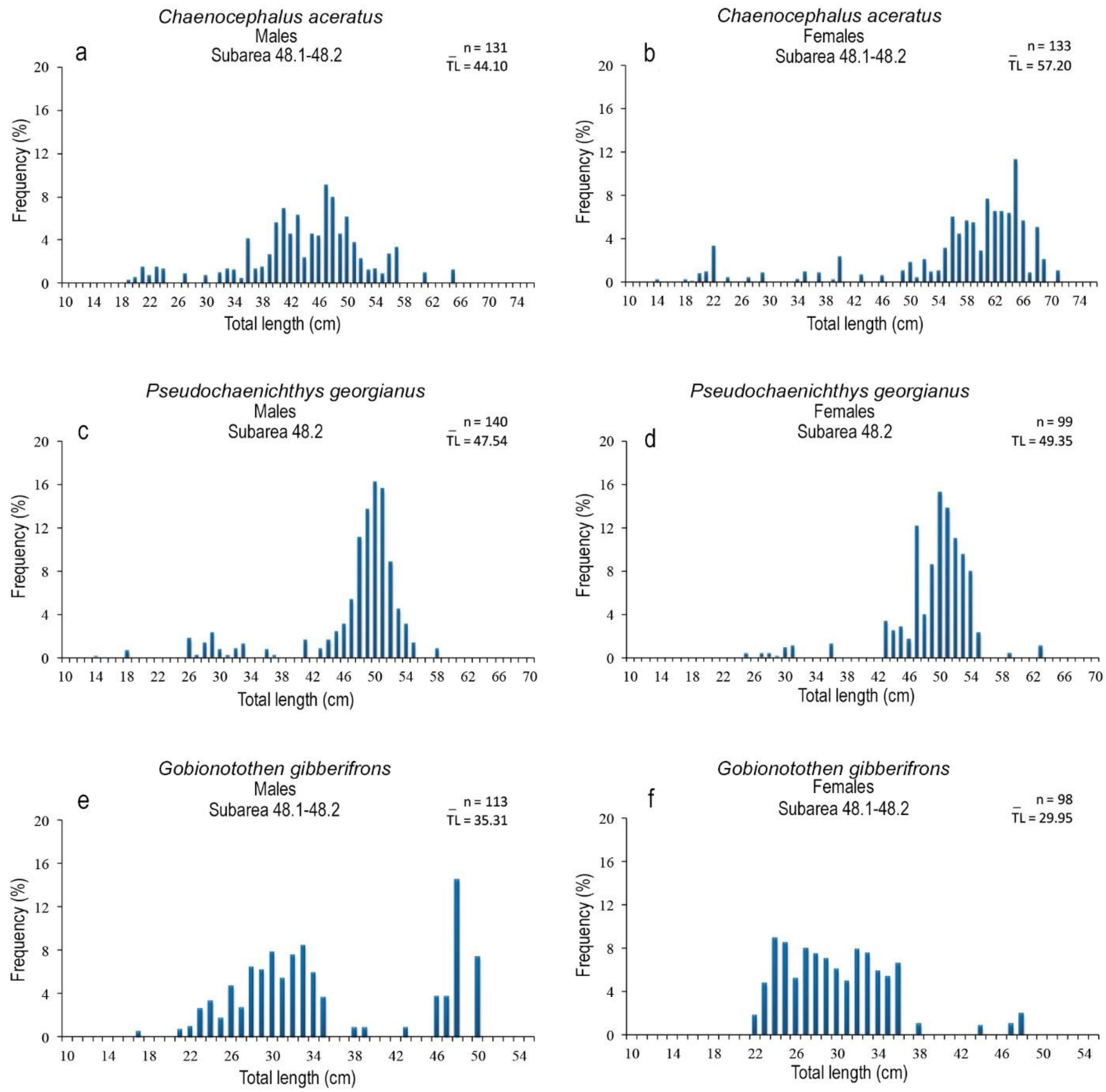

Figure 9. Total length (TL, cm) frequency distribution of males and females of a-b) *Chaenocephalus aceratus* grouped in both subareas, c-d) *Pseudochaenichthys georgianus* in Subarea 48.2, e-f) *Gobionotothen gibberifrons* grouped in both subareas.

the length-weight relationships, the coefficients of determination were 0.96 (males) and 0.94 (females), and the parameter *b* was 3.289 and 3.112 in males and females, respectively. Males presented positive allometry (*b* > 3), and whereas females showed isometry (*b* = 3) (Table 5, Figs. 11a-b).

In the case of *N. rossii*, a total of 178 males and 153 females were measured and weighed. In the length-weight relationships, the coefficients of determination were 0.97 and 0.96 for males and females, respectively, and the parameter *b* was 3.018 in males and 2.935 in females. Both sexes exhibit and isometric growth (*b* = 3) (Table 5, Figs. 11c-d).

Regarding *C. aceratus*, 131 males and 133 females were analyzed, with coefficients of determination corresponding to 0.98 and 0.99, respectively. The parameter *b* was 3.754 in males and 3.590 in females. Positive allometric growth (*b* > 3) was observed in both sexes (Table 5, Figs. 11e-f).

For the length-weight relationship analysis in *P. georgianus*, 140 males and 99 females were sampled.

Table 4. Total length range (TL, cm) of the different species of fish caught on the cruise.

Species	Minimum length (cm)	Maximum length (cm)
Notothenia rossii	23	79
Chaenocephalus aceratus	14	71
Lepidonotothen squamifrons	12	51
Parachaenichthys charcoti	17	39
Champsocephalus gunnari	5	55
Lepidonotothen larseni	12	28
Chionodraco rastrospinosus	14	52
Dissostichus mawsoni	24	101
Gymnoscopelus nicholsi	16	
Bathyraja eatonii	31	38
Trematomus eulepidotus	18	29
Bathyraja maccaini	38	
Ophthalmolycus amberensis	19	28
Muraenolepis microps	22	44
Gobionotothen gibberifrons	17	50
Notothenia coriiceps	32	55
Nototheniops nudifrons	10	28
Cryodraco antarcticus	15	35
Notothenia acuta	23	
Pseudochaenichthys georgianus	14	63
Notothenia squamifrons	17	23
Pogonophryne marmorata	27	
Trematomus hansoni	26	44
Trematomus newnesi	21	
Neopagetopsis ionah	20	25
Bathydraco antarcticus	20	
Pogonophryne spp.	29	
Paraliparis spp.	11	
Pogonophryne scotti	27	
Racovitzia glacialis	23	33
Macrourus whitsoni	14	
Anotopterus pharao	40	101
Macrourus holotrachys	7	9.5

The coefficient of determination was 0.95 in males and 0.97 in females, while the parameter b was 3.257 and 3.699, respectively. Positive allometric growth ($b > 3$) was determined for both sexes (Table 5, Figs. 11g-h).

For *G. gibberifrons* a total of 113 males and 98 females were measured and weighed. The respective coefficients of determination were 0.97 and 0.96, while the parameter b was of 3.521 and 3.304, respectively. Positive allometric growth was found in both sexes ($b > 3$) (Table 5, Figs. 11i-j).

The average weights determined for the different species caught during the survey are set out in Table 6.

Environmental conditions

Depth profiles of temperature, salinity, and density and the average curve for these parameters are shown around the South Orkney Islands (Fig. 12). In the depth range at which the trawls were carried out, it is worth noting that at 200 m depth waters were characterized by average values of temperature of -0.6°C and salinity of 34.45, whereas at 500 m average values were 0.45°C and 34.68, respectively.

DISCUSSION

Since the 1989/1990 season, direct fishing of *Champsocephalus gunnari*, *Dissostichus eleginoides*, *Dissostichus mawsoni*, *Electrona carlsbergi*, *Gobionotothen gibberifrons*, *Lepidonotothen squamifroms*, *Notothenia rossii*, *Patagonotothen guntheri*, *Pseudochaenichthys georgianus* and other species of finfish has been prohibited in several subareas and divisions of the Southern Ocean (CCAMLR Conservation measure 32-02). This measure also indicates that this prohibition shall not apply to the taking of specified taxa for scientific research under Conservation Measure 24-01. Since then, several investigations have been carried out in subareas 48.1 and 48.2, to monitor the recovery and status of Antarctic fish populations. Kock & Jones (2005) published a comprehensive review of the results obtained from historical research surveys carried out on demersal fish around the South Shetland Islands, Elephant Island, and the South Orkney Islands.

The present survey was carried out following the general guidelines recommended by the CCAMLR Scientific Committee, which consist of using the same bottom trawl net used previously in the evaluation of the demersal fish community (Hardbottom Snapper Trawl). For comparative purposes, the sampling station was set at approximately the same geographic coordinates used previously.

It is noticeable that a substantial diversity of species was caught using a bottom trawl net, with a total of 36 species of fish caught during the cruise, 15 of them present on the Elephant Island shelf, and 27 around the South Orkney Islands. Likewise, the difference in species composition and relative abundance was evident when comparing the catches made between the two surveyed areas (Table 1).

Catches composition by species was dependent on the depth strata at which the haul was made, and on geographical location. Interestingly, the marbled rockcod (*N. rossii)* was the only species that showed a considerable abundance around Elephant Island. However, it was almost enterally absent in the samples collected around the South Orkney Islands, registering only the presence of two individuals. A lower abundance of the mackerel icefish (*C. gunnari)* around Elephant Island was observed, while it was practically

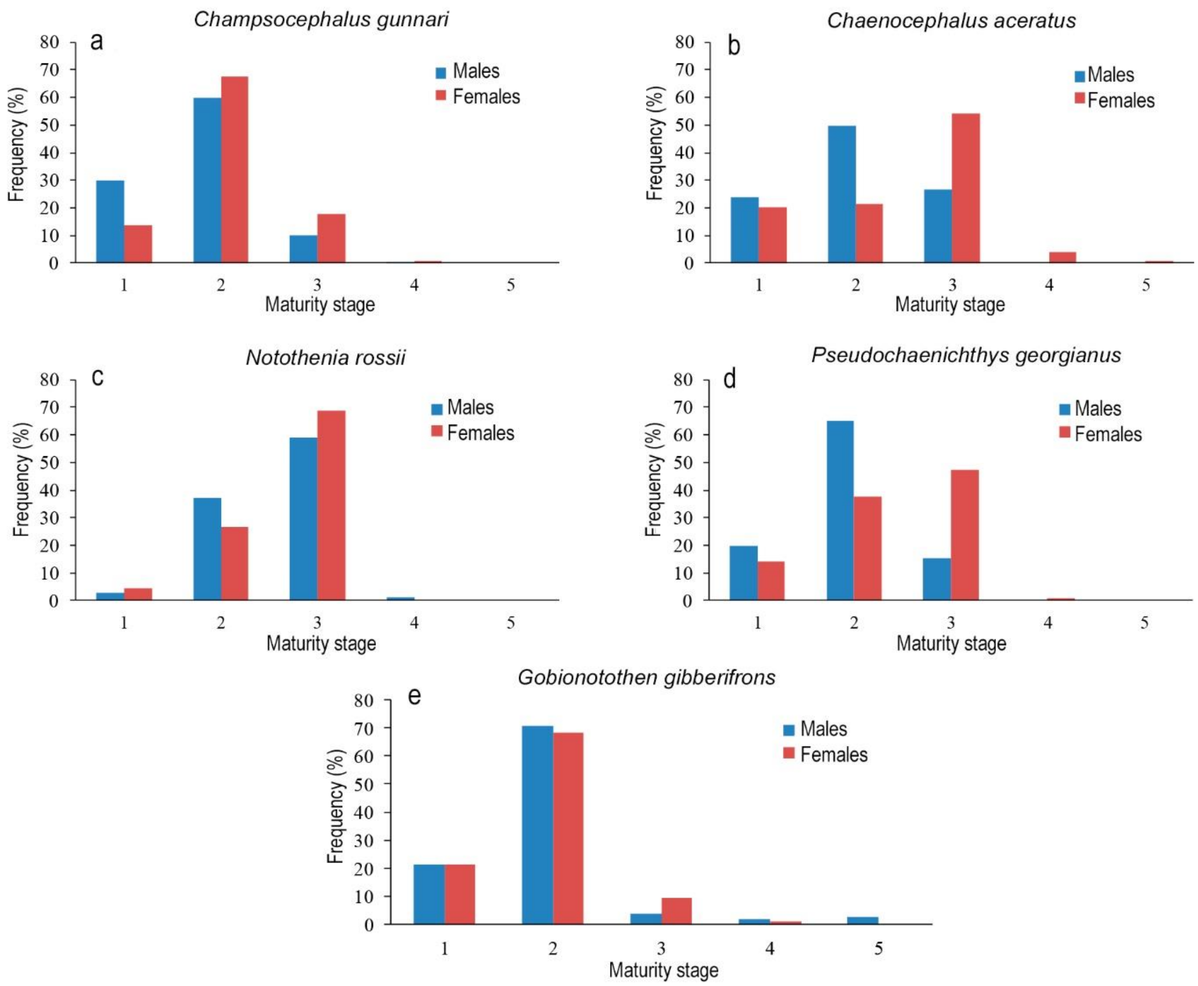

Figure 10. Maturity stage distribution of a) *Champsocephalus gunnari*, b) *Chaenocephalus aceratus*, c) *Notothenia rossii*, d) *Pseudochaenichthys georgianus*, and e) *Gobionotothen gibberifrons*. 1: immature; 2: developing or resting; 3: developed; 4: mature; 5: post-spawning (Kock & Kellerman, 1991).

Table 5. Total length-total weight relationship of the principal species caught on the cruise. a: intercept, b: slope, R^2: coefficient of determination.

Species	Subarea	Males				Females			
		Sample (n)	a	b	R^2	Sample (n)	a	b	R^2
Champsocephalus gunnari	48.1 - 48.2	437	2.21×10^{-6}	3.29	0.96	527	4.18×10^{-6}	3.11	0.94
Notothenia rossii	48.1 - 48.2	178	1.36×10^{-5}	3.02	0.97	153	1.90×10^{-5}	2.93	0.96
Chaenocephalus aceratus	48.1 - 48.2	131	3.95×10^{-7}	3.75	0.98	133	7.11×10^{-7}	3.59	0.99
Pseudochaenichthys georgianus	48.2	140	4.06×10^{-6}	3.26	0.95	99	6.82×10^{-7}	3.70	0.97
Gobionotothen gibberifrons	48.1 - 48.2	113	1.57×10^{-6}	3.52	0.97	98	3.16×10^{-6}	3.30	0.96

absent in the waters surrounding the South Orkney Islands. This situation during a survey undertaken in 2016 was different, where a great abundance of this species was observed around both islands. However, this survey was conducted using a mid-water trawl and a different sampling design (Arana *et al*., 2016). Differences in the values obtained from CPUE and in the acoustic records between both expeditions should be verified in the future.

N. rossii tends to aggregate in high numbers in somewhat limited areas, as was noted by Jones *et al*. (2001). On this occasion, the highest concentrations were recorded between 100 and 400 m of depth to the north and northwest of Elephant Island with high yields. During a single half-hour trawl, the catch reached a maximum of 3,569 kg. Previously, Jones *et al*. (2001) also documented dense aggregations of marbled rockcod at 230-320 m depth north of this island.

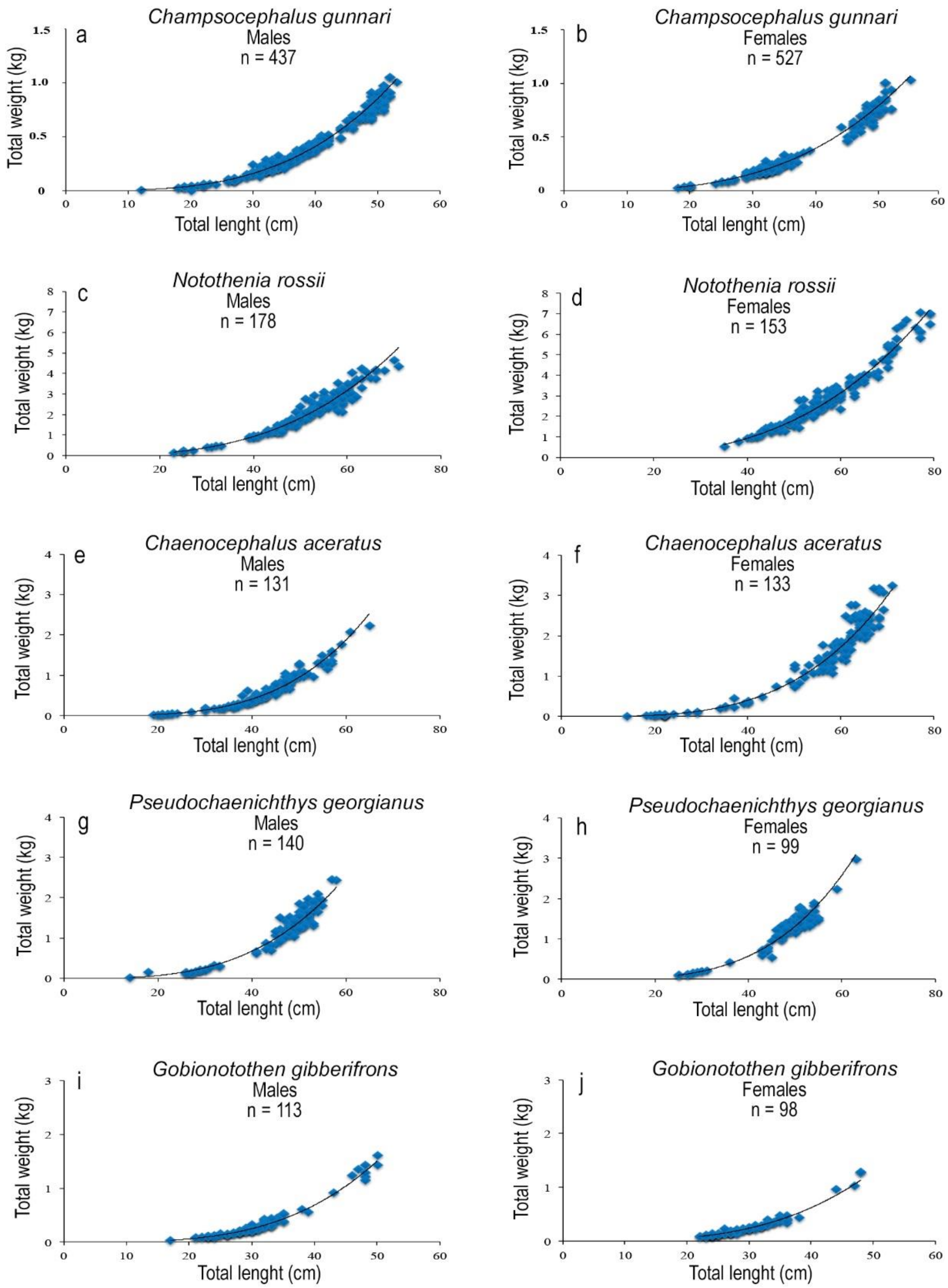

Figure 11. Total length-total weight relationship for the principal species during the cruise. a-b) *Champsocephalus gunnari*, c-d) *Notothenia rossii*, e-f) *Chaenocephalus aceratus*, g-h) *Pseudochaenichthys georgianus*, i-j) *Gobionotothen gibberifrons.*

The captured specimens showed total lengths (mean = 52.16 cm), exceeding the maximum sizes previously recorded in the same area by Kock *et al*. (2007) and Kock & Jones (2012a).

Catches of *C. gunnari* made with bottom trawls were extremely low around Elephant Island and almost zero around the South Orkney Islands. The lengths of the captured specimens were centered in sizes between

Table 6. The individual average weight (kg) of fish caught with bottom trawling.

Species	Code	Average weight (kg)
Notothenia rossii	NOR	2,442
Champsocephalus gunnari	ANI	0.344
Pseudochaenichthys georgianus	SGI	1,241
Gobionotothen gibberifrons	NOG	0.298
Chaenocephalus aceratus	SSI	1,093
Lepidonotothen squamifrons	NOK	0.382
Chionodraco rastrospinosus	KIF	0.491
Gymnoscopelus nicholsi	GYN	0.035
Notothenia coriiceps	NOC	1,440
Dissostichus mawsoni	TOA	13,141
Lepidonotothen larseni	NOL	0.054
Bathyraja maccaini	BAM	0.455
Trematomus eulepidotus	TRL	0.174
Muraenolepis microps	MOY	0.358
Bathyraja eatonii	BEA	0.478
Trematomus hansoni	TRH	0.655
Cryodraco antarcticus	FIC	0.066
Ophthalmolycus amberensis	LYA	0.410
Notothenia squamifrons	NOS	0.142
Parachaenichthys charcoti	PCH	0.109
Nototheniops nudifrons	NOD	0.068
Anotopterus pharao	ANH	0.600
Pogonophryne marmorata	PGM	0.350
Pogonophryne spp.	POG	0.405
Neopagetopsis ionah	JIC	0.213
Pogonophryne scotti	SZT	0.295
Racovitzia glacialis	RGG	0.118
Bathydraco antarcticus	BDN	0.180
Notothenia acuta	NOA	0.155
Trematomus newnesi	TRW	0.110
Paraliparis spp.	PVZ	0.020

28 and 40 cm, similar to Kock *et al*. (2002, 2007) and Kock & Jones (2012a), with a sex ratio in which females predominated slightly over males.

A remarkable aspect was the finding of a large number of small mackerel icefish juveniles, on the west side of the Elephant Island continental shelf (92-135 m), which would indicate the presence of a nursery area for this species. Meanwhile, *C. gunnari* adults concentrated in deeper waters (Alegría & Arana, 2016; Alegría *et al*., 2017). The specimens found in great abundance in this place, with a size of 5-13 cm TL, possibly correspond to the young of the one-year class (Frolkina, 1989).

All the cruises carried out in these areas have found the highest concentration of fishes north and northwestern of Elephant Island (*e.g*., Jones *et al*., 2001; Kock & Jones, 2002, 2012a) and north, northwestern and northeastern of the South Orkney Islands (*e.g*., Arana *et al*., 2016). It should be noted that the Antarctic krill *Euphausia superba* constitutes the main food of *C. gunnari* and *N. rossii (e.g.,* Kock, 1991; Jones *et al*., 1999a, 2003) and that concentrations of krill can also found in these geographic regions.

The parameters obtained from the length-weight relationship were similar to those indicated by Kock & Jones (2005, 2012a).

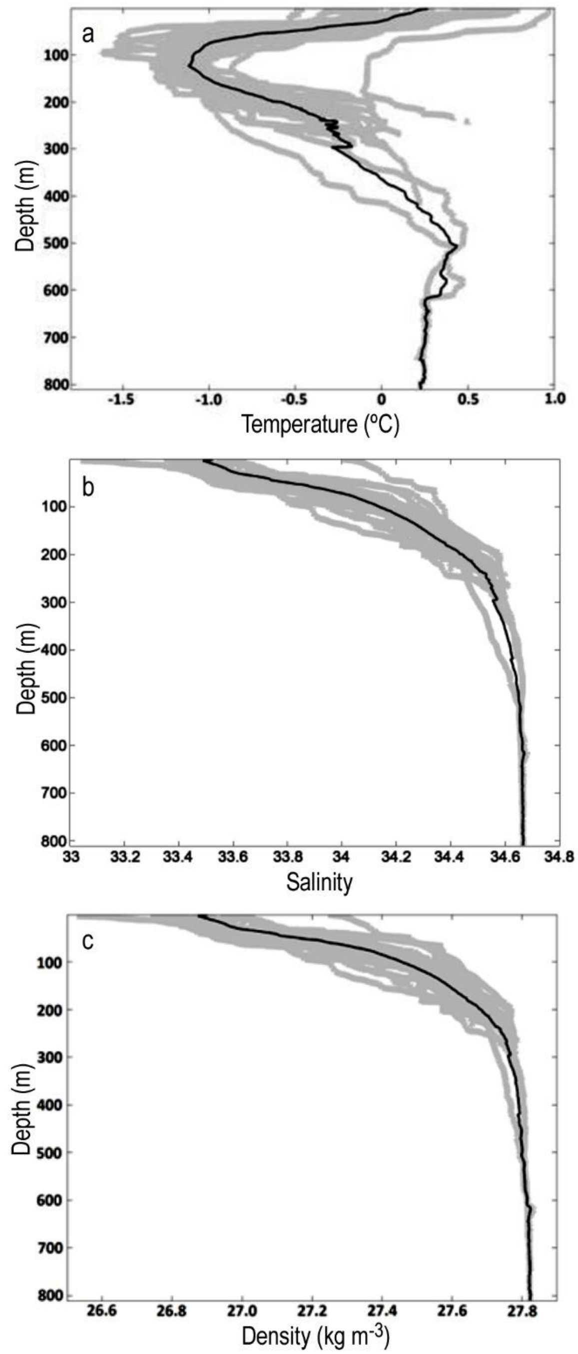

Figure 12. Temperature profiles a) temperature, b) salinity, c) density around the South Orkney Islands. The black line represents the average temperature of all the profiles.

This time, most individuals sampled were in the gonad stage of developing, or developed, with practically none in the mature or post-spawning state. *N. rossii* was the species that presented the most development in its gonads, which would be explained by the fact that the spawning period of this species is estimated to take place between May and June around Elephant Island, according to those same authors. On the other hand, *Pseudochaenichthys georgianus* would spawn in March, according to Gubsch (1982) or May-June, according to Kock & Jones (2012a). This situation was not reflected in the information collected during this survey. However, when comparing these results, with those obtained in the same 2016 period, a different result is achieved. According to Plaza *et al.* (2016), finding hydrated ovaries in species like these, which commonly spawn in autumn or winter, would be because they have a more extended period of reproduction or that interannual variations are produced associated with environmental factors that activate the spawning season.

Acoustic records provided potentially new information on the distribution of pelagic resources, such as krill and semi-pelagic finfish species such as mackerel icefish, as well as other finfish species. Strong evidence of *C. gunnari* aggregations were detected in the north and northwest sectors of both islands, similar to findings of Jones *et al*. (1999a, 2001), Jones & Kock (2009), Kock & Jones (2012a), Alegría & Arana (2016), and Arana *et al*. (2016). In *C. gunnari*, shoals were detected acoustically around Elephant Island corresponding to areas with steep slopes, while in flat bottom areas, their presence was low or null. According to Alegría *et al*. (2017), these concentrations showed different forms of aggregation: some near the bottom, forming dense shoals above 10 m from the seafloor, while in other cases, shoals were raised at significant heights, with individuals dispersed in the water column. Similar to a previous study (Kasatkina & Frolkina, 2003), the results obtained during this survey indicated a high correlation between mackerel icefish and krill concentrations, which can be expected given that krill represents the main prey-food of this species (*e.g*., Kock, 1991; Jones, 2000; Jones *et al*. 2003). On the other hand, the apparent low abundance of *G. gibberifrons* around Elephant Island confirmed a continuing declining trend for this species (Kock & Jones, 2012b).

During this survey, a single large concentration of mackerel icefish was identified northwest of Elephant Island, coinciding with the region where dense concentrations had been reported in previous surveys (Jones *et al*., 2003; Arana *et al*., 2018). Across the rest of the study area, as well as the South Orkney Islands, this species was present in very low quantities, differing from previous investigations, where significant concentrations were found in several places around both islands. The reason for this difference cannot be explained with the available information. However, it could be related to the prevailing lunar phase when the survey was carried out (waning and new moon) when according to anecdotal reports from fishers, this species only concentrates during crescent and full moon phases.

It's worthwhile noting that this species is mainly demersal during daylight hours, and thus are difficult to detect by hydroacoustic means (Ona & Mitson, 1996; SIMRAD, 2000; Simmonds & MacLennan, 2006). Additionally, when using bottom trawl nets with a narrow vertical opening at the mouth, it is difficult or impossible to correlate the catches obtained from resources that are immediately above the height of the influence of the net.

In most cases, *C. gunnari* remains very close to the seafloor and is much better sampled by bottom trawls than semi-pelagic gear (Kock & Jones, 2005; CCAMLR, 2006, 2011b). For this reason, mackerel icefish is currently surveyed using bottom trawling. Still, the resulting abundance estimates may be biased due to the semi-pelagic distribution, as has been described by Gherasimchook (1987), Shust (1998), Kasatkina & Frolkina (2003), among others; or described as benthopelagic by Jones *et al*. (2003) and other authors. An acoustic estimate of the pelagic component of the population could indicate the magnitude of this bias (Fallon *et al*., 2016). For this reason, the identification of the correct concentration, their geographical and bathymetric distribution, and the simultaneous use of midwater trawling with bottom trawling combined with an acoustic survey, would contribute to better estimating the *C. gunnari* biomass in the Southern Ocean, especially when this species is dispersed in the water column.

On the other hand, it is well known that *C. gunnari* concentrates in certain places within its bathymetric range. In contrast, in others, its presence is almost null, a characteristic that has been observed in various investigations carried out in the Southern Ocean. This feature indicates the need to rethink methodologies required to estimate biomass for this species, particularly concerning patchy concentrations in relatively small geographic areas, and their absence in others.

Finally, it is important to determine the status of the population of *C. gunnari* and other demersal fish species in an area that has remained closed to fishing for almost three decades. To this end, efforts aimed at expanding both biological and sampling strategies for this species must be continued to determine the degree of its recovery reliably.

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