Widening the net - spatio-temporal variability in the krill population structure across the Scotia Sea

Running Header - Spatial and temporal variability in krill population structure during the CCAMLR 2000 survey.

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Abstract

Resolving the spatial variability in the population structure of Antarctic krill *Euphausia superba* requires a synoptic sample, as in the design of the CCAMLR 2000 survey, however, this approach is not appropriate to assess the temporal variability. Measurement of the size of krill in the diet of Antarctic fur seals *Arctocephalus gazella* has been shown to provide a good representation of the temporal changes in the krill population structure from within their foraging area. At Cape Shirreff, South Shetland Islands krill in nets had modes at 46-48 mm and 52-54 mm and appeared to reflect the presence of larger krill offshore and smaller krill inshore, krill in the diet of fur seal contained both of these modes, indicating that the foraging area of fur seals integrated the spatial variability in the krill population. At Signy Island, South Orkney Islands, krill in both nets and fur seal diets had a mode at 52 mm when sampled simultaneously, however, the krill in the diet of seals showed a decline in size later in the season with an overall mode at 48 mm. At Bird Island, South Georgia there was little overlap between net samples, with a mode between 30 - 40 mm, and fur seals, with distinct modes at 44 mm and 54 mm and there was also much greater spatial variability in the size of krill in net samples than in the other two locations. Extension of the comparison of the size of krill in the diet of seals, to include spatially congruent net samples collected immediately prior to the CCAMLR 200 survey, showed almost complete overlap and indicated an even greater spatial variability in the krill population structure at South Georgia. Interactions of oceanographic transport and enhanced growth rates of krill at South Georgia may combine to produce a higher degree of spatial variability in the krill population compared to other locations and this may limit the utility of using differences in the length of krill as indicators of their provenance. This study has underlined the importance of using data from multiple sources to consider large-scale population dynamics of

krill, information that is crucial to the effective management of commercial exploitation of krill.

Keywords

Antarctic krill *Euphausia superba*, population structure, variability, CCAMLR 2000 survey, Antarctic fur seal *Arctocephalus gazella*.

Introduction

The size structure of the population of Antarctic krill *Euphausia superba* in the Scotia Sea is the product of a complex set of interactions between physical and biological processes that combine to produce a high level of both spatial and temporal variability (Murphy et al. 1998). In order to investigate the causes and consequences of variability in the krill population it is essential to consider the relative contributions from different sources of variability. Resolution of the variability into its spatial and temporal components requires a combination of analyses at appropriate scales of measurement. Thus, in order to assess the spatial variability, a simultaneous set of samples of the krill population across the entire area is required. In contrast, however, an assessment of the temporal variation might best be addressed through repeated sampling, at a single site, over a longer time scale. The design of the CCAMLR 2000 krill survey provides a detailed 'snapshot' of the biomass, distribution and size structure of the krill population across the whole of the Scotia Sea (Trathan *et al.* 2001), however, logistic and financial constraints mean that conducting replicate ship-based surveys to assess the temporal variability may not be practicable. Therefore, an alternative to ship-based sampling may be required to address the issue of temporal variability.

Long term monitoring of the size of krill in the diet of krill-dependent predators, such as Antarctic fur seal *Arctocephalus gazella,* has proved very effective in revealing temporal changes in the population structure of krill at South Georgia both within and between years (Reid et al. 1999, Murphy and Reid 2001, Reid 2001). Since Antarctic fur seals are found on all island groups within the Scotia Sea (Boyd 1993) extending the diet sampling protocols developed at South Georgia to other sites in the Scotia Sea may provide a sampling mechanism suitable to examine temporal variation in krill population size structure at different geographical locations.

During the design phase of the CCAMLR 2000 survey intensive net sampling was planned in the regions of South Georgia, the South Orkney Islands and the South Shetland Islands (Trathan et al. 2001). Located within each of these regions are land-based CCAMLR Ecosystem Monitoring Programme (CEMP) sites, where Antarctic fur seals are present during the summer and this presented an opportunity to collect samples of krill from the diets of seals from before, during and after the periods of ship-based net sampling. Integrating these time-series of samples from different locations with data from the synoptic survey should provide a suitable combination of sampling approaches in order to examine both the spatial and temporal variation in the krill population in the Scotia Sea.

The aim of this paper is to use the data on the length-frequency distribution of krill in the diet of Antarctic fur seals collected in the three different areas over the time period spanning the CCAMLR 2000 survey to: 1. establish the level of concordance between the length-frequency distribution of krill in the diet of Antarctic fur seals and simultaneous net samples at the different locations, 2. investigate temporal changes in the krill population structure during the course of the summer, and 3. to consider the potential contributions of temporal and spatial variation in the overall variability in the size structure of the krill population in the Scotia Sea.

Methods

Faeces (scats) of Antarctic fur seals were collected at regular intervals between mid-December 1999 and late March 2000 (or for as long as possible between these dates depending upon logistic constraints) at Cape Shirreff (Livingston Island, South Shetland Islands, 62^0 28'S 60^0 46'W) , Signy Island (South Orkney Islands, 60^0 42' S 45^0 38' W) and Bird Island (South Georgia,

54^0 00' S 38^0 03' W) (see Fig. 1). At Cape Shirreff and Bird Island there are colonies of breeding fur seals (Boyd 1993) while at Signy the population of fur seals consists almost entirely of non-breeding sub-adult and adult male seals (Hodgson and Johnston 1997) Only whole, fresh scats were collected and all sorting and measurement of krill followed the methods of Reid and Arnould (1996). The length of krill in net samples was measured following the protocol outlined in Siegel et al (this volume). Krill from scats collected within the same seven day period were considered as a single samples as were those krill from individual net hauls. All composite length-frequency distributions use the mean proportions in each 2 mm size classes in order to standardise with respect to sample size.

Results

Samples size of krill measured from Antarctic fur seals and nets

A total of 2521 krill were measured from 96 scats collected in the South Shetland Islands between 5 January and 8 March with 1011 krill measured from the 9 net samples. At the South Orkney Islands 2366 krill from128 scats were measured between 12 January and 22 March and 546 from the 4 net samples. Between 22 December and 5 April 1046 krill were measured from 181 scats and 448 krill were measured from the 5 net samples at South Georgia. For details of the location, timing and sample size of krill measured for each net see Table 1.

Population size structure

i. South Shetland Islands

The modal size class in the composite length-frequency distribution of krill in the diet of

Antarctic fur seals was 52 mm as was the modal size class in the composite length-frequency distribution from nets; in both cases 86 % of krill were between 46 - 56 mm in length (Fig. 2). In the weekly samples there was evidence of two distinct modes, at 46-48 mm and 52-54 mm, both of which were present throughout the sampling period (Fig 3) while a mode at 56 mm was present only during the weeks prior to the collection of the net samples. There was a decrease in the mean size of krill between January and March ($F_{(1,9)}$ = 18.19 P=0.003) which was reflected in a significant decline the proportion of krill >= to 52 mm over the same period March ($F_{(1,9)}$ = 22.43 P=0.001). The individual net samples suggest that the modal size class of 52-54 mm was prevalent offshore (nets 2, 3, and 5) while smaller krill, with a modal size class of 48 mm dominated inshore catches (nets 1,4, 6, 7 and 9) (Fig 4).

ii. South Orkney Islands.

The composite length-frequency distribution of krill in the diet of Antarctic fur seals had a modal size class of 48 mm with 95 % of krill between 44 - 54 mm in length while the composite length-frequency distribution from net samples had a modal size of 52 mm with 79 % of krill between 44 - 54 mm in length (Fig 5). In the weekly samples there was evidence of a distinct mode at 52 mm at the beginning of the series with a distinct mode at 48 mm at the end (Fig. 6) There was a gradual transition from the larger to the smaller mode during the sampling period which was reflected in a decline in the mean size of krill ($F_{(1,11)}$ = 29.98 P=0.000). There was a very similar size structure of krill in the individual net samples, each of which had a mode of 52 mm and with relatively few krill smaller than 44 mm (Fig 7).

iii. South Georgia .

The composite length-frequency distribution of krill in the diet of Antarctic fur seals contained two distinct modes at 44 mm and 54mm whereas the composite length-frequency distribution from net samples had an indistinct mode between 30 - 40 mm (Figure 8). In the weekly samples from Antarctic fur seals krill representing the smaller mode (44 mm) were present throughout the sampling period, however, the larger mode (54 mm) was only present during the period up to late January (Fig 9). The analysis of the individual net hauls indicated considerable variability in the sizes of krill with each of the five net samples having different modal size classes which ranged from 28 mm to 40 mm (Fig 10).

Discussion

Comparison of length-frequency distributions from Antarctic fur seals and net samples.

In the South Shetland Islands the length-frequency distribution of krill from both Antarctic fur seals and nets showed extensive overlap indicating that the variability reflected in the spatially explicit net samples was also reflected within the foraging areas of the fur seals. At the South Orkney Islands the dominance of the 48 mm size class in the diet of Antarctic fur seals compared to the net samples was a consequence of the shift in the modes from 52 mm to 48 mm over the course of the season. Thus for the majority of the period after the net samples were collected there were relatively fewer krill in the 52 mm size class compared to the 48 mm size class, however, comparison of the length-frequency distributions of krill from Antarctic fur seals and nets from the same time period showed extensive overlap with modal size of 50-52 mm, although there were relatively more krill in the lower tail of the distribution (i.e < 40 mm) in the net samples. At South

Georgia there was little overlap in the length-frequency distributions of krill from nets and Antarctic fur seals even when comparisons were restricted to samples collected at the same time. Whilst 80 % of krill from nets were of 40 mm or less only 10 % of those from Antarctic fur seals were of this size, in addition, there was a distinct mode at 54 mm in the diet of Antarctic fur seal which was not represented in any of the net samples.

The interpretation of these results are constrained by the limitation of the sampling regimes, in particular the small number of net samples in the South Orkney Islands and at South Georgia; the different part of the fur seal population present in the South Orkney Islands and the single land-based sampling site in each of the regions. Nevertheless, at both the South Shetland Islands and South Orkney Islands there was a relatively high level of overlap in the sizes of krill taken by Antarctic fur seals and nets which probably reflects the dominance of large krill in the population since these are effectively fully sampled by Antarctic fur seals (Murphy and Reid 2001). At the South Shetland Islands there was a relatively well defined spatial variability and evidence of a relatively small temporal change. This temporal change may reflect changes in the foraging distribution of seals leading to sampling different components of the krill population, however, in previous studies of the krill in this region there has been evidence for distinct changes in the age-composition and distribution of krill (Lascara et al. 1999). At the South Orkney Islands whilst there was also a temporal change in the size structure, although there was no evidence of spatial heterogeneity, at least during the period of net sampling. This is in contrast, to the situation at South Georgia where there was far less overlap in the sizes of krill taken by nets and seals. There was also evidence of a distinct temporal change in the size of krill taken by Antarctic fur seals and considerable evidence of a high degree of spatial variability in the regional net samples. This spatial variability at South Georgia had a less well defined pattern, especially with respect to bathymetry, compared to the South Shetland Islands. Thus it appears that at the South Shetland Islands and the South Orkney Islands there was a relatively similar pattern of change in krill population structure, however, in both cases the krill population was dominated by large krill throughout the sampling period. In contrast at South Georgia there were extensive spatial and temporal differences which combined to produce the greatest amount of variability in the population structure and the lowest level of overlap with the diet of Antarctic fur seals.

The extent of overlap between the krill taken by Antarctic fur seals and nets will depend to some extent on the nature of the krill population structure; when the population in dominated by large krill there will be a high level of overlap, whereas this overlap might well decrease when small krill dominate in the population (Reid et al. 1999). In 2000 the dominance of large krill in the population at both the South Shetland Islands and the South Orkney Islands resulted in a high degree of overlap. Initially it would appear that the lack of overlap at South Georgia might well reflect the dominance of small size of krill in the population in that region. Previous comparisons of the krill in the diet of Antarctic fur seals and nets have demonstrated the importance of making comparison at appropriate scales, in both a temporal and spatial dimension (Reid et al. 1999). While the current data can be compared at a simultaneous temporal scale (i.e collected at the same time), all of the locations of net samples from South Georgia (Fig 1) were to the east of the foraging area used by lactating female Antarctic fur seal from Bird Island (Boyd et al. 1988, Boyd et al. submitted). However, the length-frequency distribution of krill from within the foraging area of female Antarctic fur seals, collected immediately prior to the CCAMLR 2000 survey (data from Sushin et al. 2001), overlaps almost completely with the length-frequency distribution in the diet of

Antarctic fur seals collected during the same time period (Fig. 11). Thus, as in previous comparisons, when comparisons are made at appropriate scales the sizes of krill in the diet of Antarctic fur seals shows good agreement with the sizes of krill taken in nets. Taken together these additional net samples indicate an even greater level of spatial heterogeneity in the krill population at South Georgia compared to that shown by the CCAMLR 2000 survey net samples.

The spatial variability in the size structure of the krill population at South Georgia is consistent with previous analyses in which larger krill have predominated in samples taken to the west of the island and smaller krill in the east (Watkins et al. 1999). It has been suggested that this geographical variation in the size of krill may be due to differing source regions of the krill; the larger krill at the western end of the island are considered to be associated with the Antarctic Circumpolar Current water and originate in the southern Scotia Sea and the Antarctic Peninsula region while the smaller krill at the eastern end of the island have been described as originating the Weddell Sea (Watkins et al. 1999). An alternative scenario is emerging as a results of increasing interest in the role of the Southern Antarctic Circumpolar Current Front (SACCF) in the transport of krill into the South Georgia region (e.g Murphy et al 1998, Thorpe et al. in press). This transport mechanism has the potential to introduce krill into the eastern end of the system from where they are transported westwards. It may be that the interactions of relatively high growth rate of krill at South Georgia (Reid 2001) and oceanographic transport around the island combine to produce a high level of spatial variability in size structure in a single population. The differences in the modal sizes in the net samples from South Georgia, ranging from 28-40 mm with the smallest in the east and modal size generally increasing further west, is consistent with krill of the same size class entering the system and being transported through a region in which they experience enhanced growth rates. In a complex oceanographic system, such as associated with oceanic islands, a 'synoptic' sample across the region would likely reveal a high degree of spatial variability in size of krill. Nevertheless those krill that have been exposed to the enhanced growth conditions for longer and by analogy have been transported further through the region would be expected to be more abundant further west. Conversely those krill in the eastern region would be smaller having been in the 'system' for a shorter period of time.

The greater temporal variation in the krill taken by Antarctic fur seals at South Georgia may to some extent also reflect the locally high rate of mortality of krill (Murphy and Reid 2001) which is manifested in the reduction in the abundance of the krill in the larger mode during the course of the summer. The potential interaction between demographic parameters (i.e growth and mortality) and transport within the South Georgia region has the potential to produce a very high degree of spatial and temporal variability in population structure of krill around the island. Therefore, it may be inappropriate to use differences in the size of krill at different locations around the island as an indicator of different source regions for those krill. This does not mean that the multiple source region hypothesis should be rejected simply that it is not should not be based on the size of krill alone and some other indicator of the provenance of these krill is required.

Given the interactions of spatial and temporal variability in the krill population over the whole of the Scotia Sea it is important to consider the potential limitations of different sampling protocols. Watkins et al. (1990) showed that small-scale heterogeneity can have a marked effect the sample sizes required to characterise the krill population and suggested that a minimum of 20 net samples would be required to remove the effects of this heterogeneity at a regional scale.

However, the requirement for a near-synoptic acoustic determination of krill biomass precluded the possibility of net sampling at that intensity during the CCAMLR 2000 survey. It is therefore important to consider what collateral information may be available on the composition of the krill population either from predators, or alternative net samples such as commercial fisheries, when considering the regional population dynamics of krill. For example whilst there was little evidence of krill smaller than 42 mm in the netting conducted as part of the CCAMLR 2000 survey in the Antarctic Peninsula region smaller size classes of krill were present in samples from a research cruise in December and in commercial catches taken during January and February (Jones et al this volume, Hewitt (ICW) this volume)). Similarly, net samples collected during the CCAMLR 2000 survey at South Georgia did not contain krill with a modal size of 52-54 mm yet this portion of the krill population was present in the diet of Antarctic fur seals and in net samples from an associated krill survey. Therefore consideration of the regional population dynamics should include information from all appropriate sampling, particularly where the latter indicate the presence of components of the krill population not present in the CCAMLR 2000 net samples.

Conclusion

The analysis of the krill taken by scientific nets and Antarctic fur seals in all three locations in the Scotia Sea suggests that when comparisons are made at appropriate temporal and spatial scales Antarctic fur seals provide a view of the krill population structure that is congruent with net samples. There are, inevitably, constraints on both sampling methods, with net samples providing high spatial resolution but generally being available for a relatively limited time period, compared to the lower spatial resolution and greater temporal coverage available from predator samples. Since the variability in the regional krill population size structure reflects a combination of the spatial and temporal components of that variability, it is essential to consider different sampling approaches that more appropriately address different components of this variability. Understanding the regional population dynamics requires information on the size structure of the krill population at a range of scales collected using a range of sampling approaches relevant to those scales. Such information, including the transport from source regions and inter-annual fluctuations in recruitment, is essential to the effective management of the commercial exploitation of krill resources.

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References

Boyd, I. 1993. Pup production and distribution of breeding Antarctic fur seals *(Arctocephalus gazella*) at South Georgia. Antarctic Science 5:17-24.

Boyd, I. L., D. J. McCafferty, K. Reid, R. Taylor, and T. R. Walker. 1998. Dispersal of male and female Antarctic fur seals *Arctocephalus gazella*. Canadian Journal of Fisheries and Aquatic Sciences 55.

Hewitt in prep Paper based on 'Report of the workshop for the International Coordinated Survey in conjunction with CCAMLR 2000 survey' (This volume)

Hodgson, D. A., and N. M. Johnston. 1997. Inferring seal populations from lake sediments. Nature 387:30-31.

Jones, in prep The commercial harvest of krill in the Southwest Atlantic before and during the CCAMLR-2000 survey (This Volume)

Lascara, C. M., E. E. Hofmann, R. M. Ross, and L. B. Quetin. 1999. Seasonal variability in the distribution of Antarctic krill *Euphausia superba*, west of the Antarctic Peninsula. Deep Sea Research 46:925-949.

Murphy, E. J., and K. Reid. 2001. Modelling Southern Ocean krill population dynamics: biological processes generating fluctuations in the South Georgia ecosystem. Marine Ecology Progress Series.

Murphy, E. J., J. L. Watkins, K. Reid, P. N. Trathan, I. Everson, J. P. Croxall, J. Priddle, M. A. Brandon, A. S. Brierley, and E. Hofmann. 1998. Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill. Fisheries Oceanography 7:381-390.

Reid, K. 2001. Growth of Antarctic krill *Euphausia superba* at South Georgia. Marine Biology 138:57:62.

Reid, K., and J. P. Y. Arnould. 1996. The diet of Antarctic fur seals *Arctocephalus gazella* during the breeding season at South Georgia. Polar Biology 16:105-114.

Reid, K., J. Watkins, J. Croxall, and E.J. Murphy. 1999. Krill population dynamics at South Georgia 1991 - 1997, based on data from predators and nets. Marine Ecology Progress Series 117:103-114.

Siegel, V, et al. submitted Krill demography in the Atlantic sector of the Antarctic during the CCAMLR 2000 Survey (This Volume)

Sushin, V. A., Chernyshkov, P. P., Litvinov, F. F., Watkins, J. L., Brierley, A. S. (2000) Krill distribution related to water structure and dynamics on the South Georgia shelf in January 2000 (AtlantNIRO-BAS Core Program 1999/2000). WG-EMM-00/51, CCAMLR, Hobart.

Trathan, P. N., J. L. Watkins, A. W. A. Murray, A. S. Brierley, I. Everson, C. Goss, J. Priddle, K. Reid, and P. Ward., Hewitt, R., Demer, D., Nagonobu, M., Kawaguchi, S., Sushin, V, Kasatkina, S. M., Hedley, S., Kim, S., Pauly, T. 2001. The CCAMLR-2000 Krill Synoptic Survey: A description of the rationale and design. CCAMLR Science 8:1-23.

Watkins, J. L., A. W. A. Murray, and H. I. Daly. 1999. Variation in the distribution of Antarctic krill *Euphausia superba* around South Georgia. Marine Ecology Progress Series 188:149-160.

Figure Legends

Figure 1 - The location of land-based sampling sites and net samples (indicated by the Net number in Table 1) used in the comparison of the length-frequency distribution of krill. The numbers.

Figure 2. The composite length-frequency distribution of krill in the diet of Antarctic fur seals at Cape Shirreff from January - March 2000 and in nets from the South Shetland Islands region during the CCAMLR 2000 survey.

Figure 3. The length-frequency distribution of krill in the diet of Antarctic fur seal at Cape Shirreff for each seven day period from 5 January to 23 Feb with the length-frequency distribution from net samples aligned to the period of simultaneous sampling.

Figure 4. The length-frequency distribution of krill in net samples from the South Shetland Islands during the CCAMLR 2000 survey. The numbers refer to the Net number in Table 1).

Figure 5. The composite length-frequency distribution of krill in the diet of Antarctic fur seals at Signy Island from January - March 2000 and in nets from the South Orkney Islands region during the CCAMLR 2000 survey.

Figure 6. The length-frequency distribution of krill in the diet of Antarctic fur seal at Signy Island for each seven day period from 12 January to 1 Mar with the length-frequency distribution from net samples aligned to the period of simultaneous sampling.

Figure 7. The length-frequency distribution of krill in net samples from the South Orkney Islands during the CCAMLR 2000 survey. The numbers refer to the Net number in Table 1).

Figure 8. The composite length-frequency distribution of krill in the diet of Antarctic fur seals at Bird Island from January - March 2000 and in nets from the South Georgia region during the CCAMLR 2000 survey.

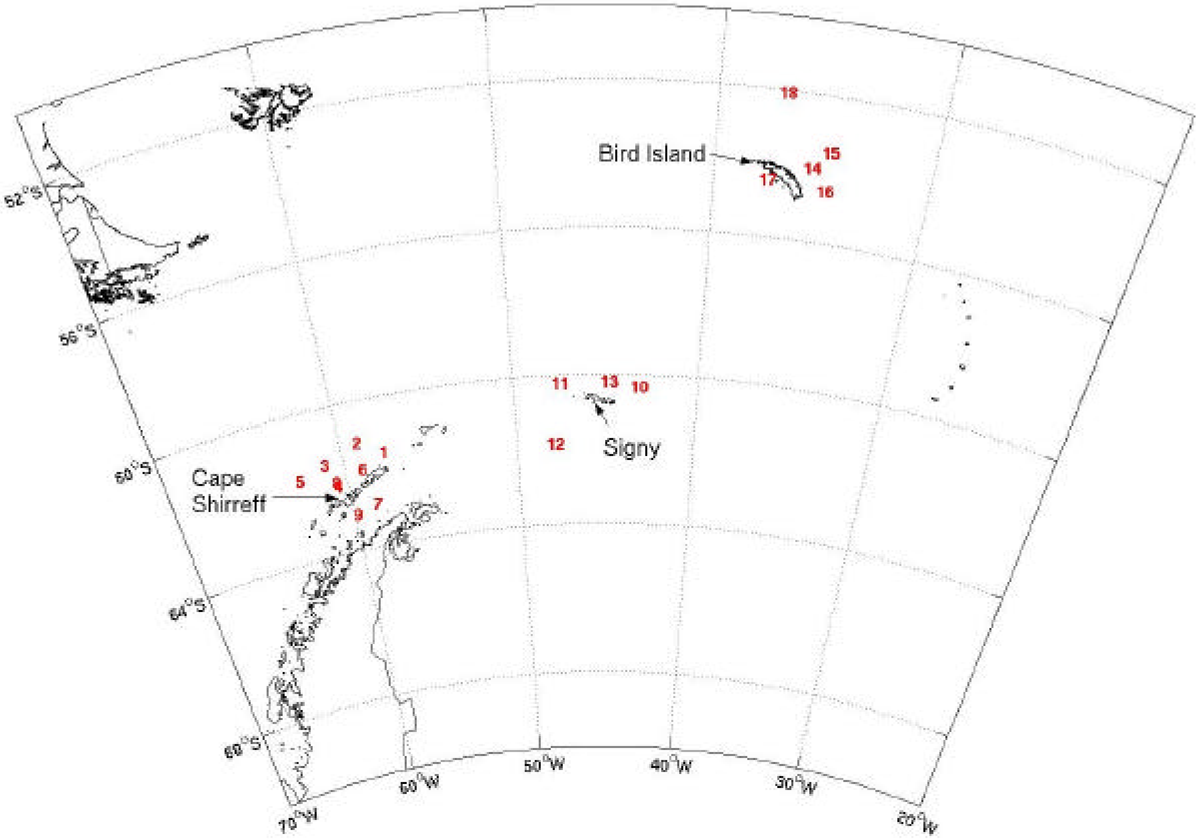
Figure 9. The length-frequency distribution of krill in the diet of Antarctic fur seal at Bird Island for each seven day period from 5 January to 23 Feb with the length-frequency distribution from net samples aligned to the period of simultaneous sampling.

Figure 10. The length-frequency distribution of krill in net samples from the South Georgia region during the CCAMLR 2000 survey. The numbers refer to the Net number in Table 1)

Figure 11. The composite length-frequency distribution of krill in the diet of Antarctic fur seals at Bird Island from January - March 2000 and in nets from the AtlantNIRO/BAS research cruise at South Georgia during January 2000.

Table 1. The station number, location, water depth, timing and number of krill measured in the net samples used in the comparison with the krill in the diet of Antarctic fur seals in the same region.

Net	Station	Longitude	Latitude	Depth (m)	Date	Time (utc)	n(krill)	Region
1	KM5032	-58.2007	-61.7510	287	30 Jan	1705	30	South Shetland Islands
2	KM5033	-59.6093	-61.3737	3465	31 Jan	0334	165	South Shetland Islands
3	KM5035	-61.6577	-61.7680	4792	01 Feb	0336	158	South Shetland Islands
4	KM5036	-61.1900	-62.4055	----	01 Feb	1425	164	South Shetland Islands
5	KM5037	-63.2400	-62.0263	4053	02 Feb	0334	45	South Shetland Islands
6	KM1523	-59.5888	-62.1078	98	25 Jan	0352	155	South Shetland Islands
7	KM1524	-59.0902	-63.0907	182	25 Jan	1619	154	South Shetland Islands
8	JR1634	-61.2177	-62.3020	225	07 Feb	0300	111	South Shetland Islands
9	JR1640	-60.3995	-63.2615	480	11 Feb	1511	29	South Shetland Islands
10	JR723	-43.5693	-60.6027	1870	30 Jan	1152	151	South Orkney Islands
11	KM918	-47.9097	-60.5028	1761	12 Jan	0331	89	South Orkney Islands
12	KM919	-48.3007	-62.1230	3295	12 Jan	1540	158	South Orkney Islands
13	YU4030	-45.1997	-60.4753	300	30 Jan	0328	148	South Orkney Islands
14	YU3003	-35.8182	-54.3353	225	14 Jan	1511	132	South Georgia
15	YU3004	-35.0600	-53.8518	3560	15 Jan	0359	88	South Georgia
16	KM303	-35.0760	-54.9063	143	12 Jan	0227	164	South Georgia
17	JR413	-37.7658	-54.7717	293	25 Jan	0149	41	South Georgia
18	JR415	-37.2818	-52.3862	2540	26 Jan	0153	23	South Georgia



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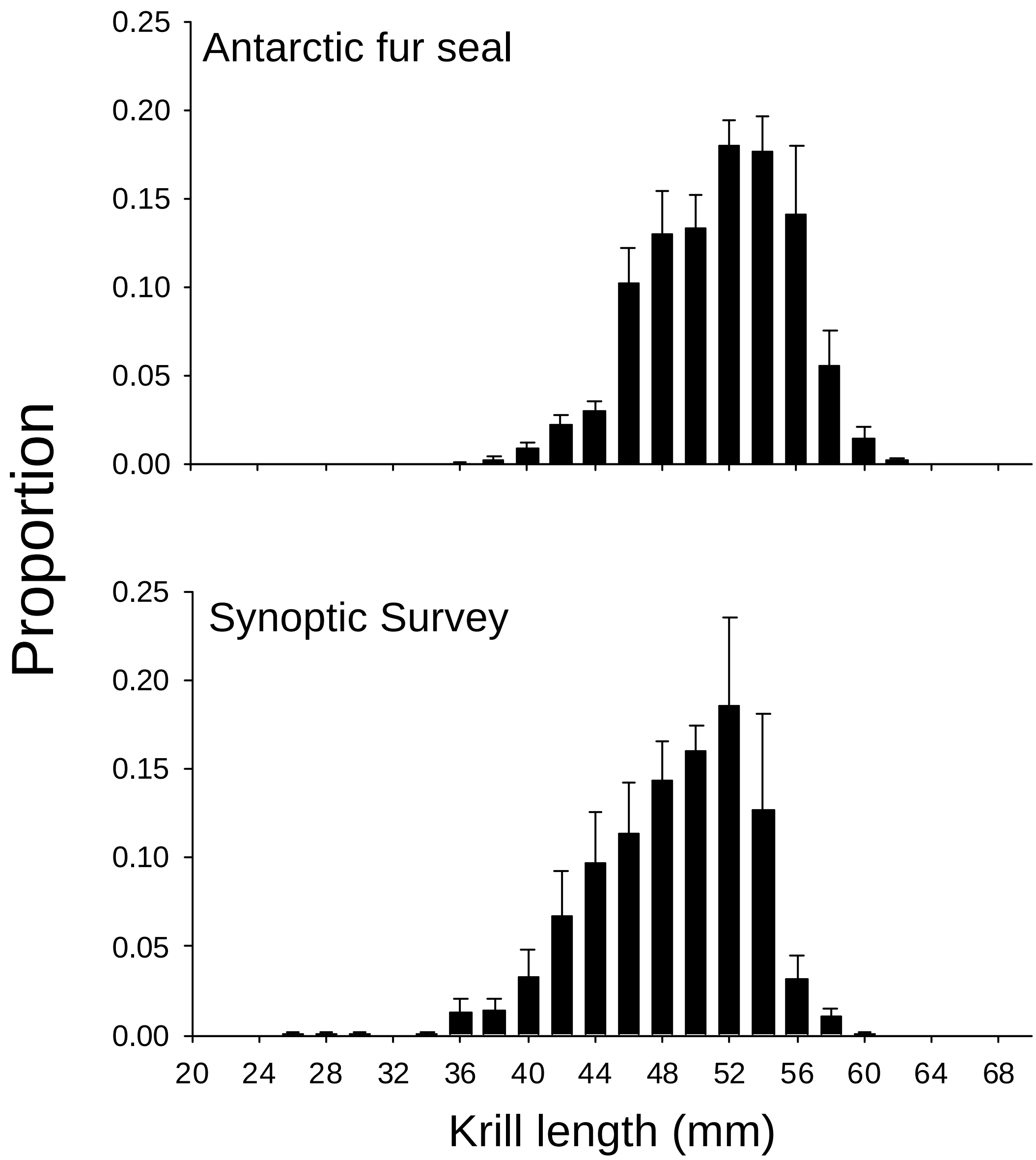
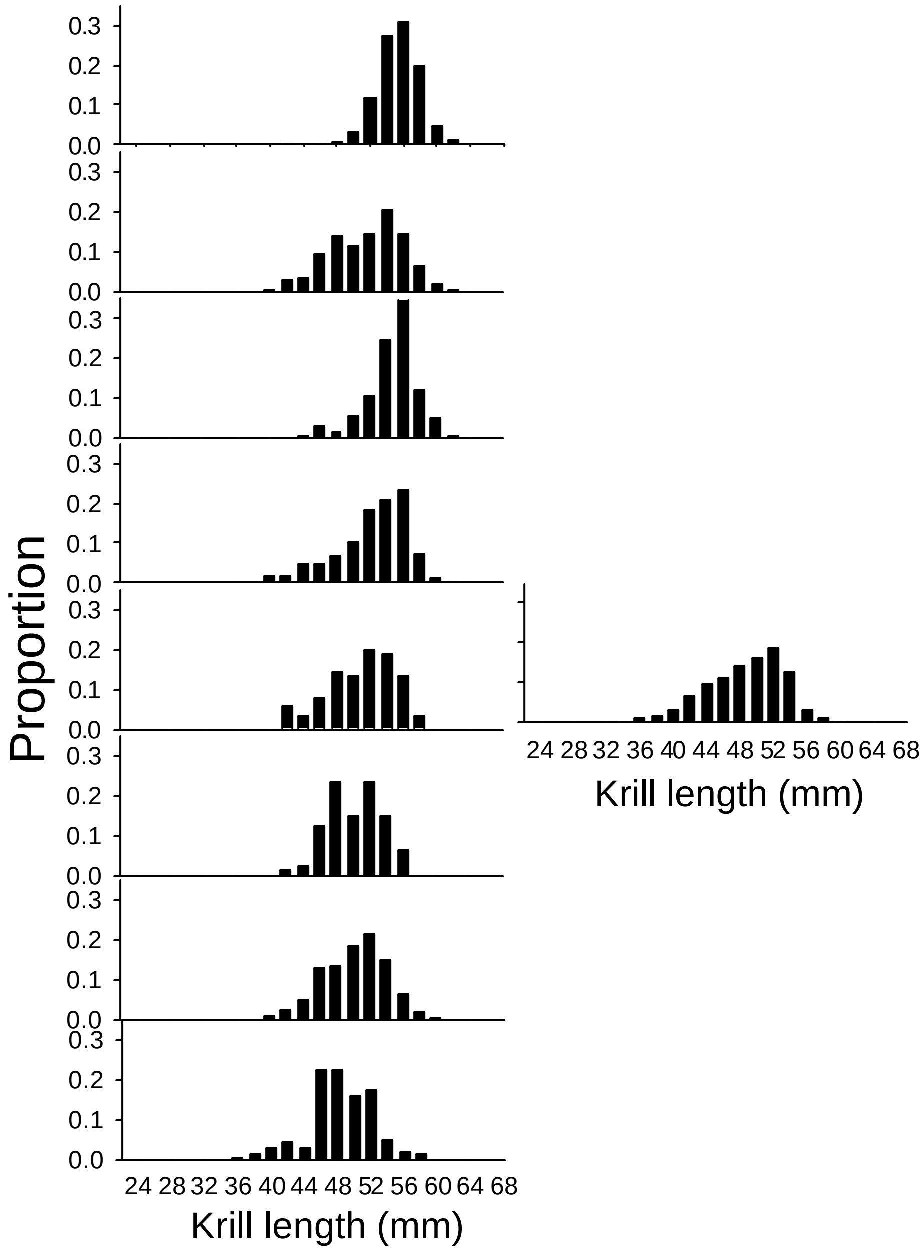


South Shetland Islands



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Krill length (mm)
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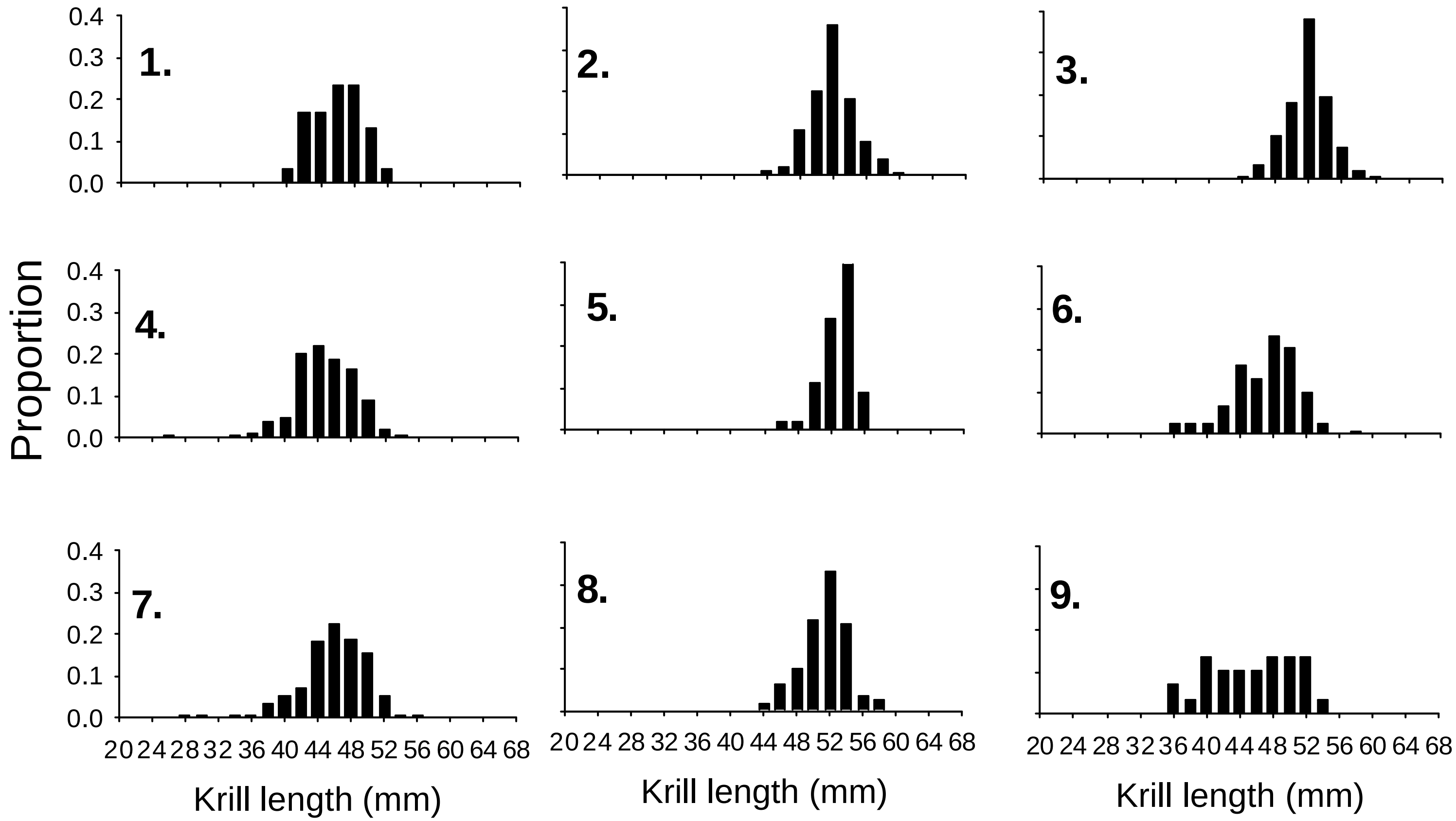
Krill length (mm)



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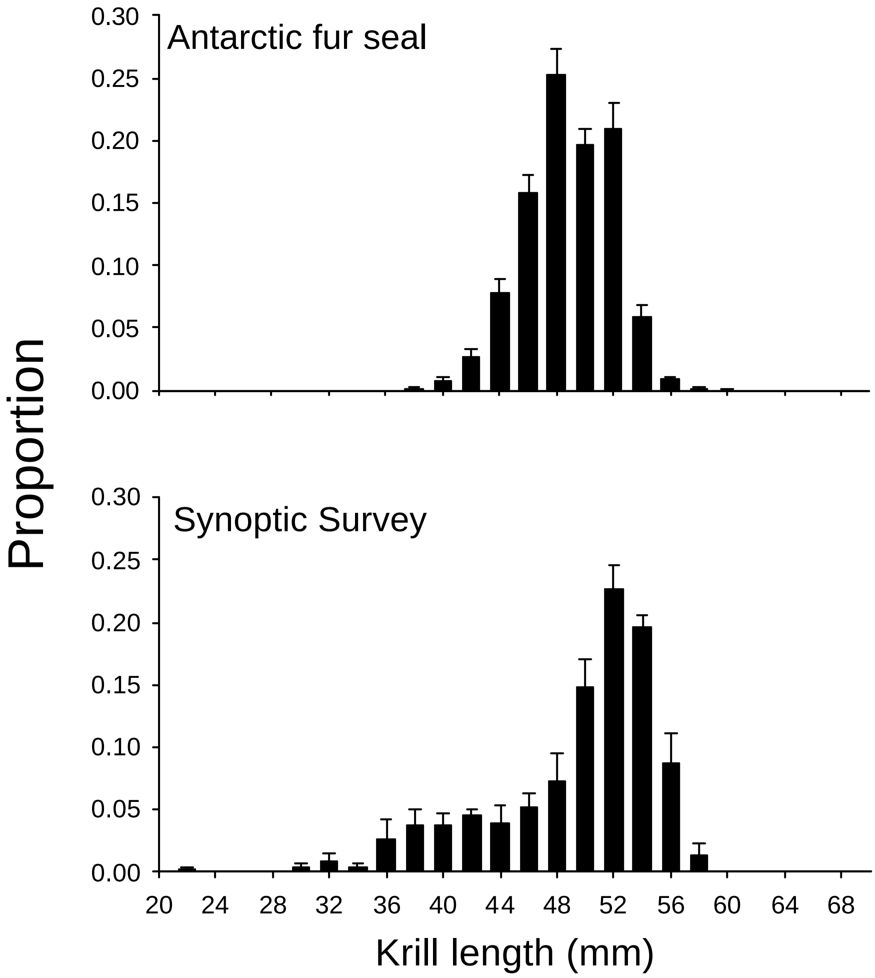
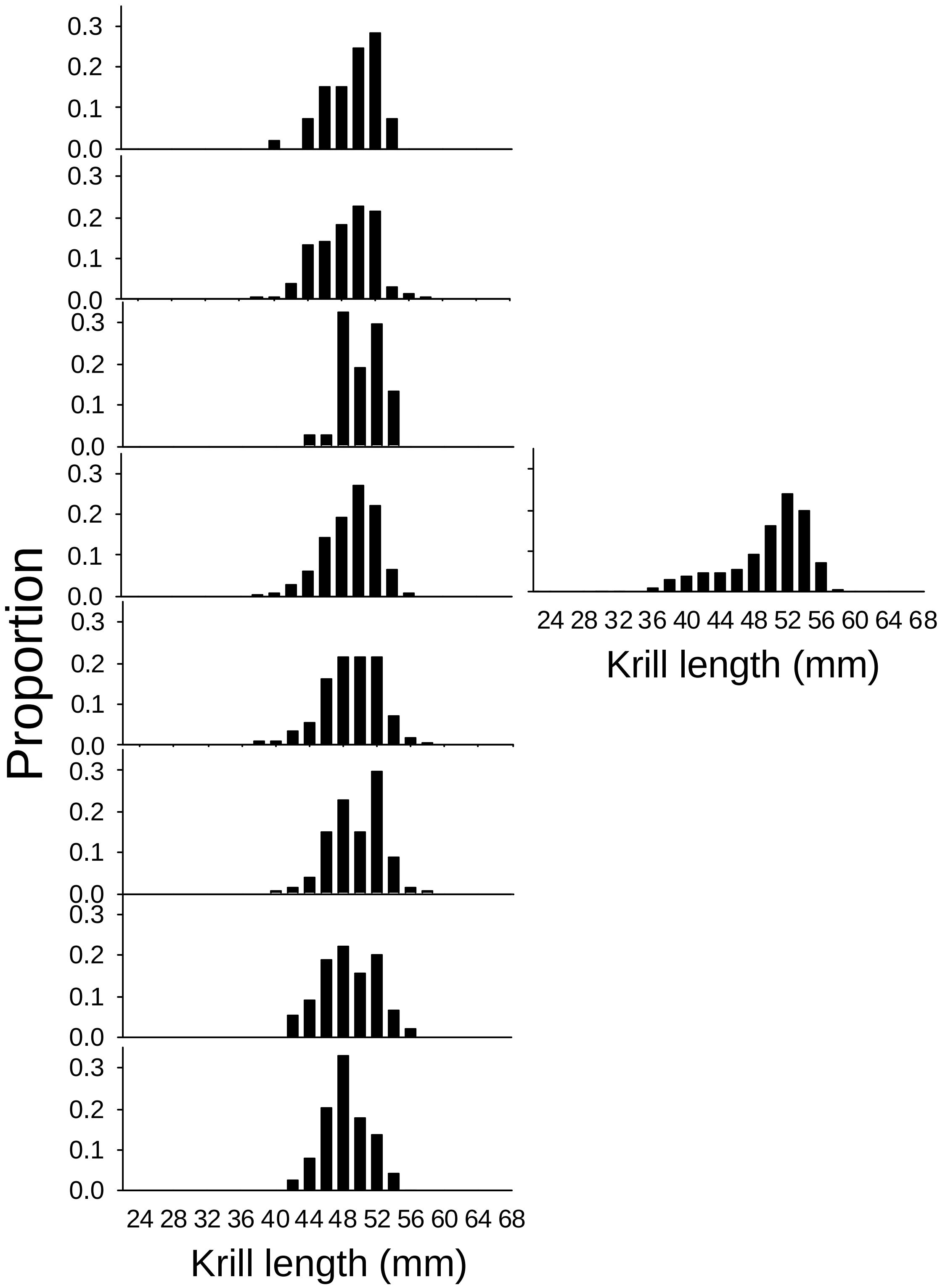
Krill length (mm)



South Orkney Islands



Proportion
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Krill length (mm)
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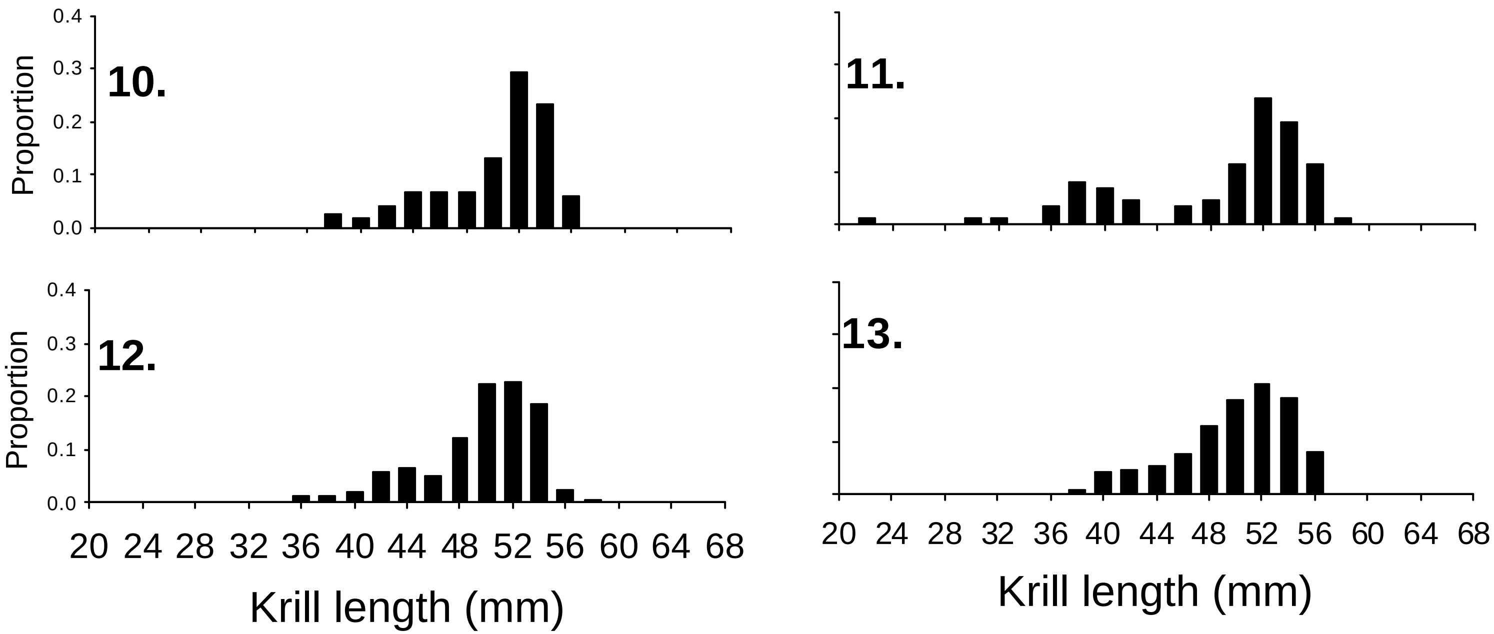
Krill length (mm)



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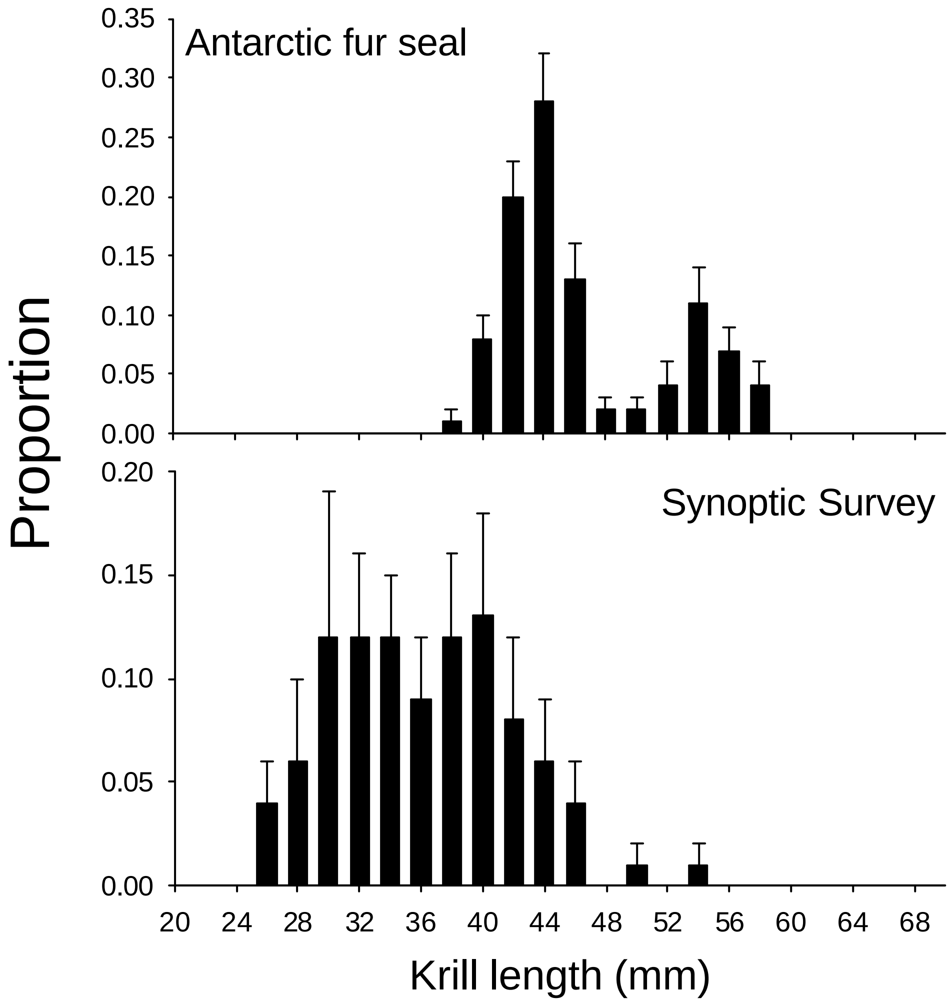
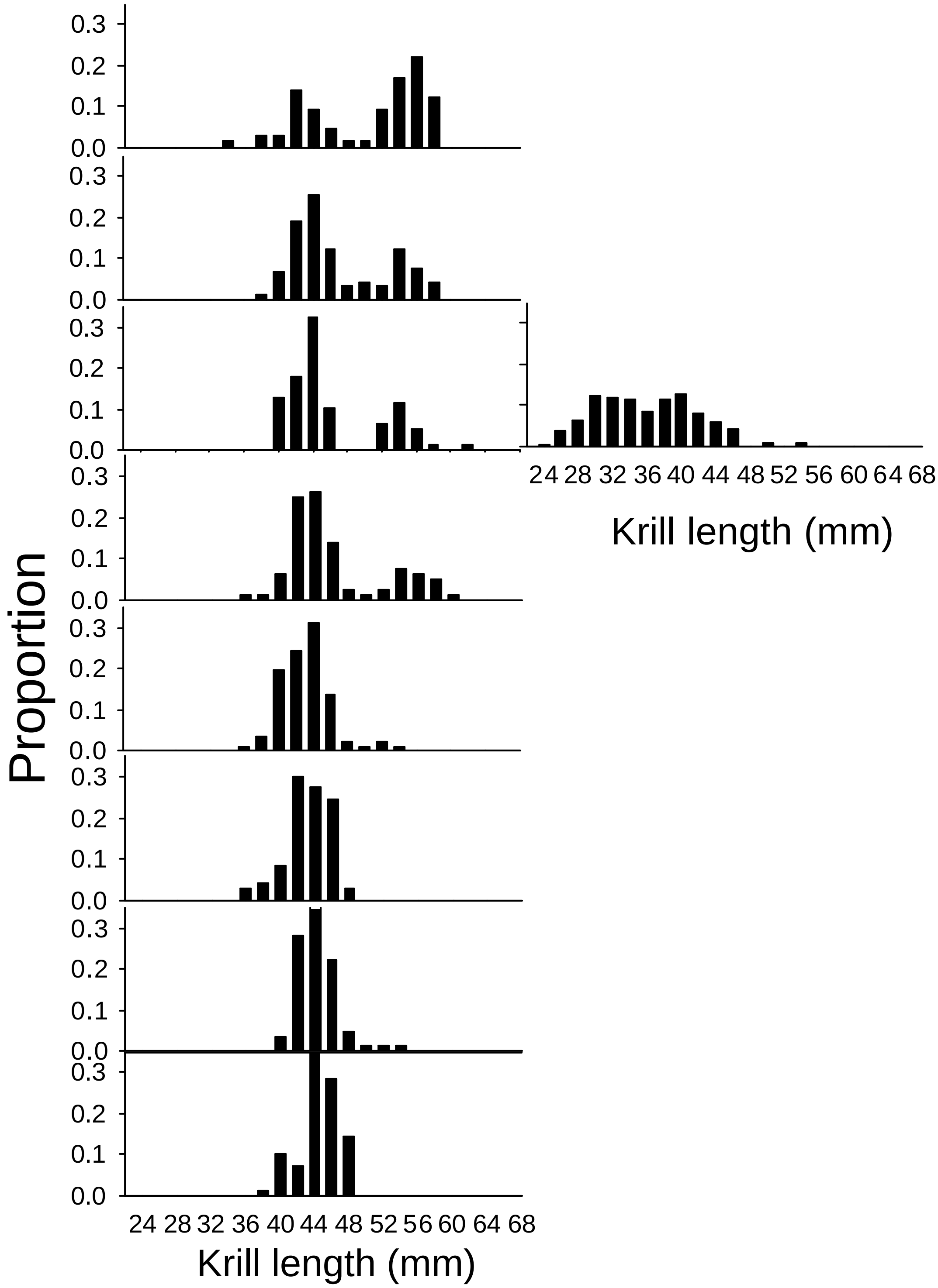
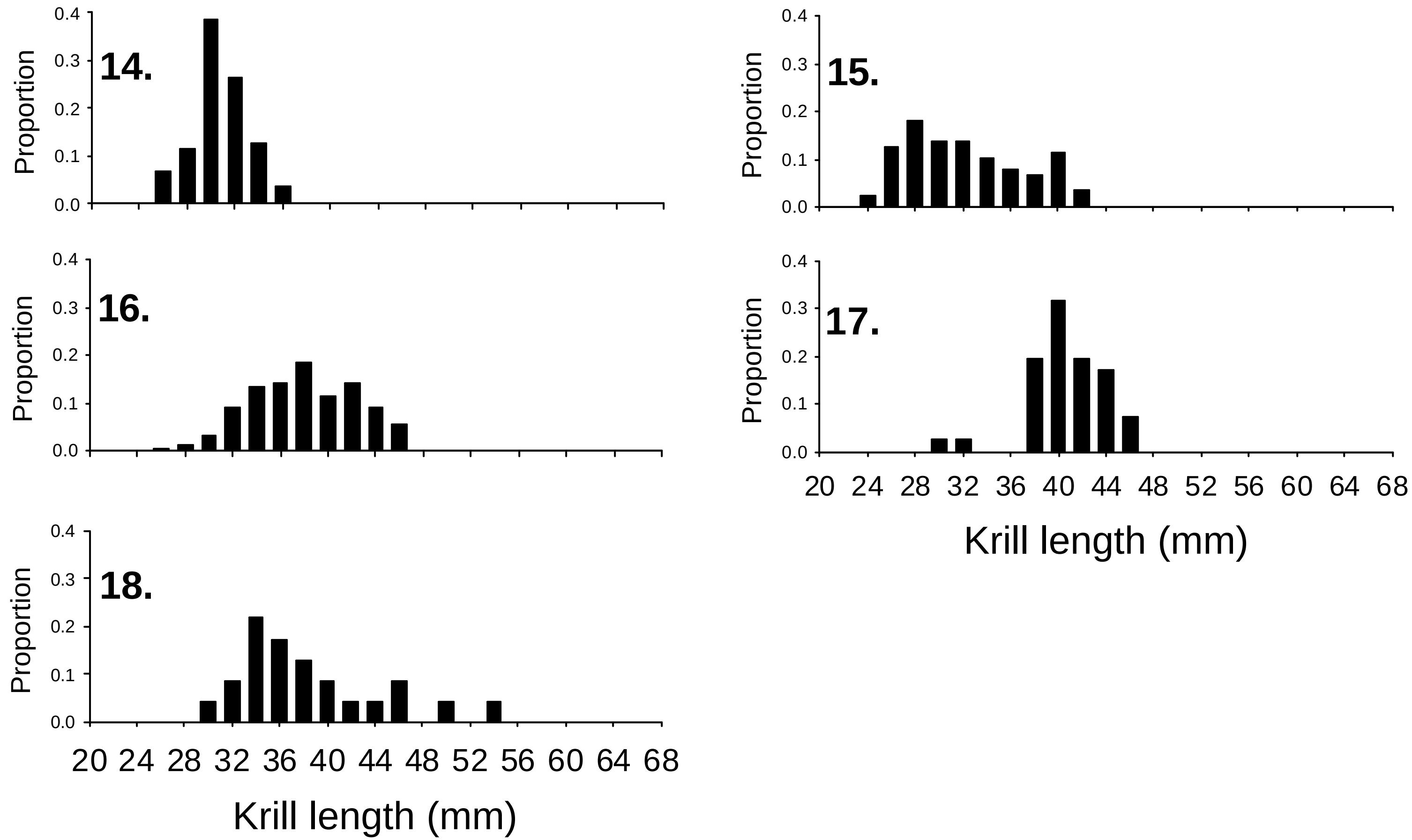
Krill length (mm)
Krill length (mm)

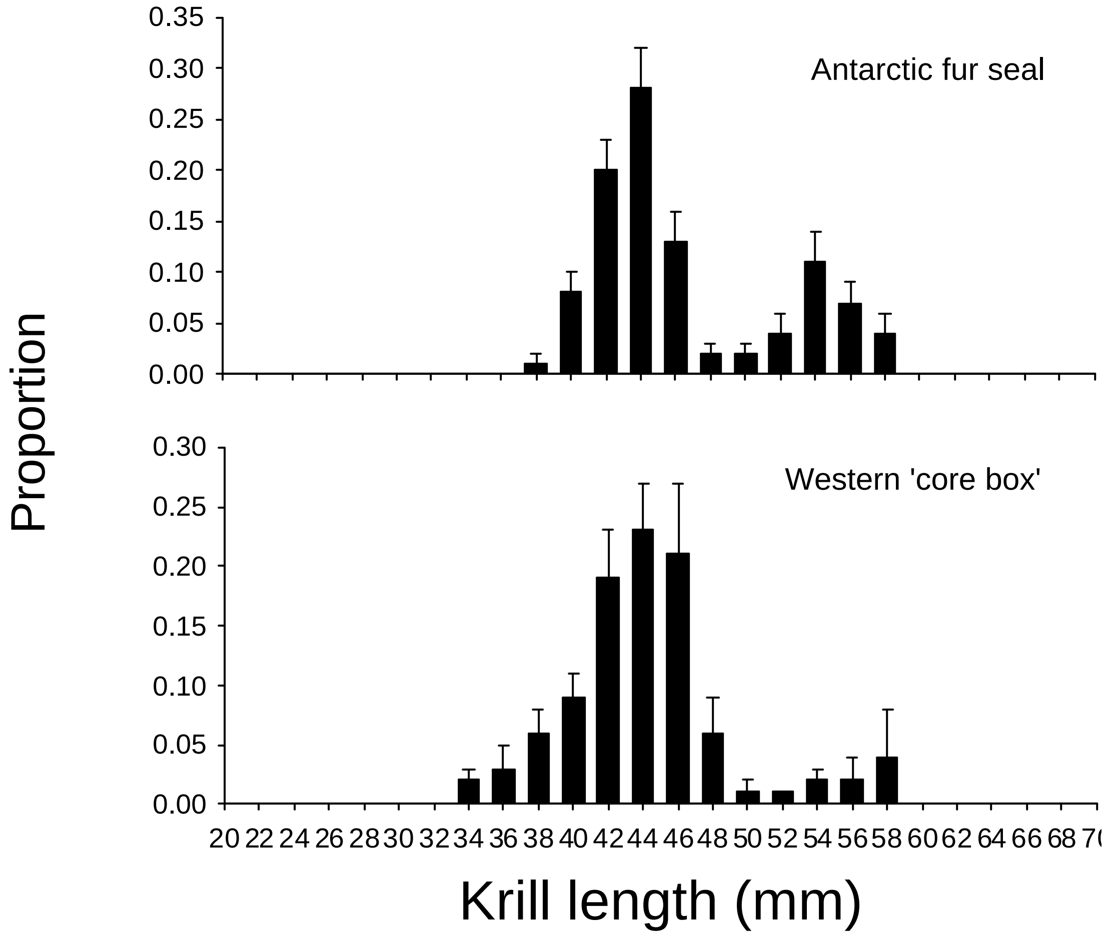


South Georgia


Proportion
0.0
0.1
0.2
0.3
24 28 32 36 40 44 48 52 56 60 64 68
Krill length (mm)
24 28 32 36 40 44 48 52 56 60 64 68
Krill length (mm)



14.
15.
16.
17.
18.
Proportion
0.0
0.1
0.2
0.3
0.4
20 24 28 32 36 40 44 48 52 56 60 64 68
Krill length (mm)



Proportion
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Antarctic fur seal
Western 'core box'
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
Krill length (mm)