APPENDIX D

REPORT OF THE WORKSHOP ON SMALL-SCALE MANAGEMENT UNITS, SUCH AS PREDATOR UNITS

(Big Sky, Montana, USA, 7 to 15 August 2002)

CONTENTS

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INTRODUCTION

1.1 Last year, the Scientific Committee endorsed the proposal by WG-EMM to hold a Workshop on Small-scale Management Units, such as Predator Units, during its meeting this year (SC-CAMLR-XX, paragraphs 6.11, 6.12 and 6.15 to 6.19; SC-CAMLR-XX, Annex 4, paragraphs 4.1 to 4.11 and 5.9 to 5.13). The aim of the workshop was to define these units in order to facilitate the subdivision of the precautionary yield in Area 48, but that the manner in which the overall catch limit would be subdivided would be determined at a future meeting (SC-CAMLR-XX, paragraph 6.18).

1.2 The delineation of small-scale management units would be achieved primarily by collating and comparing information on: (i) local predator foraging ranges and population distributions (especially of land-based predators); (ii) krill abundance, dispersion and movement; and (iii) fishing fleet behaviour and patterns of fishing (SC-CAMLR-XX, paragraph 6.16).

1.3 The workshop was convened by Dr W. Trivelpiece (USA), from 7 to 15 August 2002.

1.4 A Steering Committee convened by Dr Trivelpiece, comprised Drs A. Constable (Australia), R. Hewitt (USA), S. Kawaguchi (Japan), V. Sushin (Russia), P. Trathan (UK) and D. Ramm (Secretariat). This committee helped prepare for the workshop, including the preparation of the draft agenda, coordination and standardisation of data and the development of direction for the analyses.

1.5 It was noted that a meeting was held between Drs Kawaguchi, Constable, Ramm and I. Ball (Australia) at the CCAMLR Secretariat from 3 to 7 June 2002 to help develop analyses appropriate for fisheries data as requested by the Scientific Committee (SC-CAMLR-XX, paragraph 6.17). The results of this work were submitted to the meeting in WG-EMM-02/28 and 02/40.

1.6 The Agenda is given as Attachment 1 to guide the discussion and work of the workshop.

1.7 The work was divided into the major sections of the agenda and coordinated by Drs Trivelpiece (predator distribution and abundance), Trathan (predator foraging areas), Hewitt (krill distribution and abundance) and Kawaguchi (krill fishery). Dr Constable prepared the report with the assistance of these coordinators and Dr Ball, Ms J. Emery (USA), Dr P. Gasiukov (Russia), Mr M. Goebel (USA), Mr C. Jones (USA) and Drs K. Reid (UK) and G. Watters (USA).

PRINCIPLES FOR THE DEVELOPMENT OF SMALL-SCALE MANAGEMENT UNITS

1.8 Last year, WG-EMM endorsed the use of the principles for developing small-scale management units described in WG-EMM-01/52 as a guide for its work this year in developing these units (SC-CAMLR-XX, Annex 4, paragraph 4.10). Dr Constable provided an overview of these principles and other elements of this paper. He described how the paper proposed the integration of data from the local krill populations, foraging areas of related predators, fishing ground information and potential influences of the environment (SC-CAMLR-XX, Annex 4, paragraph 5.10). He noted that these units could not only be used to subdivide the catch in Area 48 but would help: (i) to reduce the potential for undesirable local effects on predators by spreading catch and effort; and (ii) to ensure undesirable effects do not arise by providing the opportunity for a spatially-structured monitoring program (SC-CAMLR-XX, Annex 4, paragraph 4.4). With regard to the second point, these units could be used to provide strategic advice on the potential effects of fishing as intended through CEMP (SC-CAMLR-XX, Annex 4, paragraph 4.5). He noted that these units do not have to be ecosystem units but are simply units to help management (SC-CAMLR-XX, Annex 4, paragraph 4.8).

1.9 In his presentation, Dr Constable also summarised the results of discussions by the Steering Committee as well as methods proposed to be used in the development of small-scale management units. These points and the subsequent discussion are summarised in the following paragraphs.

1.10 The Workshop thanked Dr Constable for his detailed presentation of the principles, methods for characterising the spatial subdivision of krill, the krill fishery and predator foraging areas, and issues to be considered in the further development of small-scale management units. The presentation was archived with the CCAMLR Secretariat.

1.11 Papers specifically relevant to the workshop included:

(i) fisheries – WG-EMM-02/06, 02/18, 02/28, 02/40 and 02/63 Rev. 1; and
(ii) predators – WG-EMM-02/05, 02/14, 02/33, 02/41, 02/51, 02/53 and 02/55.

1.12 Data provided to the workshop are described under each section of the analyses below.

1.13 The workshop agreed that the primary part of its work was to determine:

(i) krill aggregations, which are predictable locations where krill are found at relatively high densities from one year to the next over a number of years;

(ii) predator foraging areas, which are predictable locations where a predator obtains food from one year to the next over a number of years; and

(iii) fishing grounds, which are predictable locations where the fishery obtains relatively reliable catches from one year to the next over a number of years.

1.14 The workshop agreed to use the method in WG-EMM-02/40 to determine these predictable locations. Such locations are identified by their relative within-year importance averaged over a number of years rather than being determined as an average density, consumption or catch over time. Thus, the method is designed to account for interannual variation in the importance of locations, where a location is a fine-scale area, say 10 x 10 n miles. The key features of the method are:

(i) bin the data at an appropriate spatial scale, e.g. 10 x 10 n mile areas;

(ii) normalise data within each year to provide a measure of the relative importance of different locations in each year;

(iii) smooth the data within each year using a bivariate normal kernel smoothing algorithm to take account of uncertainty in the location of the observations as well as uncertainty in the values in the spaces between observations;

(iv) average these values over the time series to give an average importance of those locations; and

(v) identify grounds or areas of importance by determining a threshold such that the area covers, say 95%, of the accumulated importance of the region.

1.15 For predators, the workshop agreed to circumscribe the foraging areas, in the first instance, using an average maximum foraging distance as described in WG-EMM-02/33. Within those ranges, the workshop agreed to subdivide them further by delineating the foraging grounds using the method described above combined with the approach in WG-EMM-02/41, which was based on methods previously described (Barlow and Croxall, 2001; Trathan et al., 1998; Wood et al., 2001; Worton, 1989). The additional step that preceded the above method was to convert tracking data to foraging densities at an appropriate scale, say 0.1° latitude x 0.2° longitude.

1.16 Areas of greatest importance to land-based predators would be identified by:

(i) estimating a characteristic foraging pattern (distance by foraging density) for each species using the methods above;

(ii) determining the location and distribution of colonies of each species of the most abundant land-based predators (i.e. centres of abundance/biomass);

(iii) use the relevant characteristic foraging pattern of each species to circumscribe a potential foraging ‘footprint’ associated with each population centre for the respective species;

(iv) weight the foraging area for each population centre by the biomass of predators in that centre; and

(v) sum all the weighted values from (iv) for each grid square in the area.

1.17 The partitioning of the foraging areas into predator units would be undertaken based on these overall estimates of biomass-weighted foraging density as well as by considering variation in the foraging locations of individual species. The latter consideration is important to ensure that individual species requirements will be met within the overall subdivision, particularly those of much lower abundance. Prof. J. Croxall (UK) indicated that there were no rare or endangered species that needed to be given special status in this analysis.

1.18 The workshop agreed that a nested approach to the subdivision of the region was necessary in order to account for the features described above as well as accounting for the potentially different summer (breeding) and winter (non-breeding) foraging activities by predators. It was considered that a subdivision based on summer breeding activities would result in a number of smaller areas. Winter foraging distributions would likely be comprised of several of these smaller predator units.

1.19 Dr Constable noted that issues surrounding the movement of krill from one small-scale management unit to another would need to be considered when the manner in which these units would be used by the Commission was to be discussed. He also noted that the small-scale management units would mostly be determined by species that have specific foraging areas rather than species that have widely distributed foraging activities.

1.20 Dr W. Fraser (USA) noted that oceanographic and bathymetric features may be primary determinants of foraging locations by predators. The workshop noted that these and other environmental influences may be important but these would be considered following the initial work on krill, predators and the fishery.

1.21 The workshop agreed that there were some natural locations for delineating small-scale management units, such as between the island groups. Other areas that may be easily separated could be between Bransfield Strait and Drake Passage.

1.22 The workshop agreed to begin its work by reviewing the spatial patterns in the available data for krill, predators and the fishery on a smaller scale than subareas, including consideration of how to account for seasonal and interannual variation in the behaviour of predators and the fishery. In part, the methods for analysing the data would account for this but the workshop noted that some consideration may be given to these issues in the final synthesis.

1.23 Although there is potential for future changes in krill, predator foraging and the fishery, as well as having more data in the future on existing patterns, the workshop noted the view of the Scientific Committee that the information available to the workshop is the best information available for delineating small-scale management units (SC-CAMLR-XX, Annex 4, paragraph 5.13).

1.24 Dr G. Kirkwood (UK) noted that consideration will need to be given to separating the areas foraged by land-based predators, which primarily include the shelf areas, from the areas foraged by sea-based predators. Also, Dr I. Everson (UK) noted that the fishery was mostly concentrated in the foraging range of land-based predators. He noted that the CCAMLR-2000 Survey could be used to identify whether fishable concentrations of krill are likely to occur in the offshore areas.

1.25 The workshop welcomed the participation of members from the USA Palmer LTER Program who could provide an overview of the region to the southwest of the primary fishing areas in the South Shetland Islands. It was noted that this area could provide a location for monitoring the behaviour of the Antarctic marine ecosystem in the absence of fishing. The workshop encouraged further participation of this group in future meetings of WG-EMM.

1.26 The workshop agreed that the use of diet data was outside the scope or time available for delineating small-scale management units, although such information would be useful in determining how to subdivide catch limits in the future, if necessary.

1.27 Presentations were provided to the workshop outlining the data available for analyses and the patterns currently observed:

(i) predators at South Georgia and South Orkney Islands – Dr Trathan;
(ii) fur seals at Livingston Island – Mr Goebel;
(iii) penguins at South Shetland Islands – Dr Trivelpiece;
(iv) demersal fish species around South Shetland and South Orkney Islands – Mr Jones;
(v) krill distribution and abundance – Dr Hewitt;
(vi) Japanese krill fishery – Dr Kawaguchi; and
(vii) Soviet krill fishery – Dr Sushin.

1.28 Dr Ball had developed software ('Tracks and Fields') to support the methods described above for predators, fisheries and krill. He gave a brief presentation on how the software worked as well as a brief tutorial on how to use it as part of the method for determining areas of importance, which also required the use of standard spreadsheet and statistical packages. The workshop thanked Dr Ball for his presentation and for providing this software, which was used by all participants for analysing their datasets. The software with its manual was archived with the CCAMLR Secretariat.

1.29 Dr J. Watkins (UK) presented results from a simulation study undertaken by Drs E. Murphy and S. Thorpe (UK) on the potential movement of krill through the Scotia Sea based on the distribution of krill determined from the CCAMLR-2000 Survey and the use of the oceanographic model from the Ocean Circulation and Climate Advanced Modelling project. The advantage of this model over other models previously used is its use of known wind vectors to drive the model. It was noted that krill from the Scotia Sea were likely to be split to the southeast of South Georgia so that not all would pass directly by South Georgia, but that some would be advected directly past the South Sandwich Islands. The model also indicated the potential for retention of krill in the island areas, particularly around the Antarctic Peninsula and the South Orkney Islands. Dr Watkins noted the potentially important role of the ice-edge extent in driving the distribution of krill. The workshop thanked Dr Watkins for his presentation and encouraged further work using this model.

KRILL FISHERY

2.1 The patterns of the krill fishery were analysed according to the method outlined in paragraph 1.14. This analysis considered the relative importance of 10 x 10 n mile areas to the fishery when subdivided in the following ways:

(i) historical fishing period (five-year periods); and
(ii) country.

2.2 These analyses were then integrated to provide advice on the nature of fishing grounds in the region.

2.3 The data used in these analyses were catch data taken from the CCAMLR database reported for 10-day periods from 1986 to 2000. Data were extracted from the database for 10 x 10 n mile areas. Records for which only fine-scale data were available (30 x 30 n mile areas) had the catches evenly divided into nine areas in order to match the appropriate scale.

2.4 Data were also available for the USSR krill fishery around South Georgia between 1986 and 1990, as presented in WG-EMM-02/63 Rev. 1. These data were analysed in a similar way but were based on haul by haul data and summarised by 3 x 1.5 n mile areas.

Historical Fishing Period

Average Annual Importance of Fishing Locations

2.5 The average normalised catches for two periods, 1986–1990 and 1996–2000, are shown in Figures 1 and 2 respectively. These show how the major fishing areas included South Georgia, South Orkney Islands and Elephant Island. In recent years, the fishery has concentrated more on the South Shetland Islands and South Georgia with less emphasis on the South Orkney Islands and Elephant Island.

Seasonal Importance of Fishing Locations

2.6 The average importance of different locations within each season is shown in Figure 3. The figure shows the progression of the fishery during the year from October through to September (quarter 2 – October to December, quarter 3 – January to March, quarter 4 – April to June, quarter 1 – July to September). This shows the general trend of the fishery concentrating in Subareas 48.1 and 48.2 at the beginning of the fishing year, moving further south in summer and then moving north in winter. South Georgia is not important from October to March.

2.7 In terms of differences between the 1986–1990 and 1996–2000 periods, the South Orkney and South Shetland Islands have increased in importance during July to September in recent years. The South Orkney Islands have become much less important for the two quarters between October and March. King George and Livingston Islands have become more important for the three quarters between October and June.

USSR Krill Fishery around South Georgia from 1986 to 1990

2.8 The analysis of the USSR krill fisheries in Subarea 48.3 has been based on haul-by-haul data for 1986 to 1990. It covers the main fishing season for this area, which was from April to September (quarters 4 and 1 according to CCAMLR split-years). This period comprises 10 quarters in all – 5 years x 2 quarters per year. The results are shown in Figure 4.

2.9 The workshop agreed that there are three clearly identifiable areas to the north of South Georgia:

(i) a main eastern fishing ground, which is well pronounced during all fishing seasons and present in nine out of 10 quarters in this fishing period;

(ii) a small eastern fishing ground, which can be observed only in the April–June quarter and was observed in only two of those quarters in the fishing period; and

(iii) a western fishing ground, which exists only during the July–September quarter but was present in all years.

Country

2.10 The fishing patterns of five main countries were examined for each of the two periods (Figure 5). Japan, Republic of Korea and Poland were fishing in both periods, while the USSR fleet fished in the 1986–1990 period and the Ukrainian fleet fished in the 1996–2000 period.

2.11 Japan changed its predominant fishing locations from primarily Elephant Island followed by the South Orkney and South Shetland Islands in the earlier period to the South Shetland Islands and South Georgia in the later period, with the South Shetland Islands being of primary importance to the fishery in recent years.

2.12 The Republic of Korea has expanded from the Elephant Island region to include all the island groups.

2.13 The USSR and Ukrainian fleets have concentrated on the South Orkney Islands and South Georgia.

2.14 Poland has moved its fishery from being primarily around South Georgia to being primarily around the South Shetland Islands and Elephant Island.

Fishing Grounds

2.15 The workshop agreed that the following fishing grounds could be identified from these analyses:

(i) eastern South Georgia – east of 37.5°E;
(ii) western South Georgia – west of 37.5°E;
(iii) northwest of South Orkney Islands;
(iv) Elephant Island; and
(v) Drake Passage – north of King George and Livingston Islands.

2.16 The workshop agreed that the fishery was currently concentrated in the vicinity of the shelf break in these areas.

2.17 The workshop noted that the importance of Bransfield Strait is very small at present and that the fishery does not extend to the west of Livingston Island because of hazardous bathymetry and difficult conditions.

2.18 Drs Gasiukov and Sushin indicated that the fishing grounds at South Georgia may come from different sources of krill and are influenced by the oceanography of the region (WG-EMM-02/63 Rev. 1), such that:

(i) catches in the eastern fishing ground comprise krill associated with the eastern route of krill drift to South Georgia; and

(ii) catches in the western ground comprise krill associated with the western route of krill drift to South Georgia.

2.19 Drs Trathan and Everson indicated that these grounds may not be differentiated in such a way but may be connected through the seasonal transport of krill across the northern area of South Georgia.

2.20 The workshop noted that oceanography is likely to influence the availability of krill in these grounds and that further consideration would be needed to understand the connections between these areas and the potential for interannual fluctuation in krill availability. However, it was agreed that the analyses presented to the workshop are sufficient for circumscribing fishing grounds and to facilitate the delineation of small-scale management units. Those other issues will need to be considered when identifying how those units will be used in the future.

KRILL

3.1 Analyses of krill distributions were undertaken for the CCAMLR-2000 Survey as well as for eight small-scale surveys undertaken by the US AMLR Program around the Antarctic Peninsula (1998–2002).

CCAMLR-2000 Survey

3.2 Sample-weighted krill densities for the CCAMLR-2000 Survey were obtained using the smoothing algorithm in 'Tracks and Fields' (Figure 6). These results show aggregations of krill to the northwest and southeast of South Georgia, aggregations near Maurice Ewing Bank, high density of krill around the South Orkney Islands and aggregations of krill around the South Shetland Islands, particularly Livingston Island and in Bransfield Strait, and Elephant Island. Also, there were large aggregations in areas away from the island shelf areas to the east of the South Orkney Islands.

Predictable Krill Locations in Subarea 48.1

3.3 Areas where predictable concentrations of krill were found from 1998 to 2002 were estimated using the eight small-scale acoustic surveys undertaken by the US AMLR Program.

3.4 Data were analysed using the methods described in paragraph 1.14. The raw data were Nautical Area Scattering Coefficients (NASCs) for each 1 n mile interval, which was used as a measure of krill density for those intervals (MacLennan and Fernandez, 2000). The method was modified to obtain relative densities (importance) of krill for each 1 n mile grid square for each survey. The normalised, smoothed densities arising from 'Tracks and Fields' were accumulated densities at each point according to the contributions of other points dictated by the smoothing algorithm. Thus, the relative density at each point needed to be restored to a relative density per unit effort. This was achieved by dividing the relative density at that point by the relative effort for that point. The relative effort was obtained by using 'Tracks and Fields', but using the sampling effort at each point (=1) in place of the values for krill density and smoothing as for density. The resulting density values were then normalised to restore the relative densities for comparison across years.

3.5 The parameters used in 'Tracks and Fields' are given in each figure.

3.6 The results for the eight acoustic surveys in Subarea 48.1 are shown in Figure 7. The average relative densities of krill in January and in February–March are shown in Figure 8.

3.7 For January, these results indicate that the average location of aggregations occurs to the northwest of Elephant Island with lesser aggregations to the northeast and south of Elephant Island, to the north of Livingston Island, and to the northwest and immediately to the south of King George Island. Some smaller aggregations are present further to the west and east of the South Shetland Islands.

3.8 For February–March, these results indicate that the average location of aggregations occurs predominantly to the north of Livingston Island with lesser aggregations to the north of King George Island and even smaller aggregations further east, including around Elephant Island. There is also an aggregation in Bransfield Strait around the shelf break off the Antarctic Peninsula to the southeast of King George Island.

3.9 Overall, the aggregations in this area are concentrated over the shelf and at the shelf break.

3.10 The workshop agreed that Subarea 48.1 could be separated into the following areas based on the persistent locations of high densities of krill:

(i) Elephant Island;
(ii) Bransfield Strait to the south of Livingston and King George Islands;
(iii) Drake Passage to the north of Livingston and King George Islands; and
(iv) west of Livingston Island.

3.11 The workshop noted that there were higher aggregations of krill to the north of Livingston Island compared to the north of King George Island but it was difficult to separate the two.

KRILL PREDATORS

Patterns of Distribution and Abundance

4.1 The distribution and indices of abundance of predators were used to help determine centres of foraging activity in the South Atlantic. This was to be achieved by combining the information on predator distribution and abundance with the known information on foraging ranges from the main areas currently being regularly monitored.

4.2 The workshop agreed to concentrate on the distribution and abundance of four main groups of krill predators: land-based predators, including Antarctic fur seals, macaroni, gentoo, chinstrap and Adélie penguins and black-browed albatrosses, and krill-eating fish species.

Land-based Predator Breeding Colonies

4.3 For the land-based predators, data on the distribution and abundance of breeding colonies were compiled from the following sources: Woehler (1993), Trathan et al. (1996) and WG-EMM-02/51.

4.4 For the purposes of the workshop the colony information for each species was pooled into centres of biomass. The pooling of colonies was based on an assessment of whether the colonies were likely to have overlapping foraging ranges. Colonies were considered to have a functional overlap where the distance between colonies was less than the critical foraging distance (CFD) where

$$\text{CFD} = \text{maximum foraging distance}/\sqrt{2}.$$

4.5 Colonies were initially grouped together with those colonies with which they directly overlapped. These groups were aggregated where individual colonies occurred in more than one group, this procedure was carried out until no single colony occurred in more than one colony group (see Figure 9). The numbers of predators in the colonies included in each group were summed and the colony group was centred on the colony with the largest breeding population size.

4.6 Distributions of colonies and the resulting centres of biomass in Subareas 48.1, 48.2 and 48.3 are shown in Figures 10 to 19 and listed in Attachment 2.

Fish

4.7 The spatial distribution and abundance of krill-eating finfish biomass on shelf regions in Area 48 was assessed using data obtained from recent research trawl surveys conducted by the US AMLR Program in the South Shetland Islands (1998, 2001), and the South Orkney Islands (2000), and from Russian and UK surveys around South Georgia (2000). These surveys were undertaken using bottom trawls made in depths ranging from 50 to 500 m, which encompasses the majority of the biomass of demersal finfish species.

4.8 Surveys conducted in the vicinity of the South Shetland Islands and Elephant Island included diet analysis for 20 of the most abundant species (Figure 20). Of these, 14 species were found to feed on krill (>25% average stomach contents). These species were pooled in the subsequent analysis of the spatial distribution and abundance of krill-feeding fish. Information for krill predators around South Georgia was restricted to *Champsocephalus gunnari*, which is the most abundant and primary krill-eating finfish species.

4.9 All research survey hauls were standardised to kg/n mile, and treated in an identical manner to that of other krill predators examined during the workshop. The abundance information was smoothed using 'Tracks and Fields' with kernel options set at a 0.1 smoothing level, a maximum distance of 3, and densities gridded to 0.1° latitude and 0.1° longitude resolution. Data were normalised and truncated at 95%.

4.10 The resulting spatial distributions are plotted in Figure 21.

4.11 Around the South Shetland Islands and Elephant Island (Figure 21a), the highest densities of krill-eating finfish biomass were west of Elephant Island and north of King George Island. This pattern is likely to be relatively consistent across years, as these areas also served as primary fishing grounds when the commercial fishery operated in this subarea.

4.12 Around the South Orkney Islands (Figure 21b), there were three modes in the spatial distribution and abundance of krill-eating finfish. The highest densities were on the western shelf of the islands, with another important area to the north, and a region of lesser importance on the eastern shelf.

4.13 Around South Georgia (Figure 21c), the surveys indicated that the highest densities of *C. gunnari* were on the western shelf of South Georgia, near Shag Rocks, and other smaller areas of lesser importance. However, other surveys, from which the data were not available at the workshop, indicate that there may be areas of importance in the southeast shelf region of South Georgia as well (SC-CAMLR-XX, Annex 5, Appendix D, paragraph 5.24). Thus, it is likely that most shelf areas within the 500 m isobath of South Georgia are important krill feeding areas for *C. gunnari*, as well as other krill-eating finfish.

Spatial Patterns of Foraging

Subarea 48.1

4.14 Satellite-tracking data for penguins were made available to the workshop from studies in Subarea 48.1 undertaken through the US AMLR and NSF programs. These data were obtained using satellite tags (PTTs) deployed on Adélie, chinstrap and gentoo penguins, which were breeding at two colonies at the South Shetland Islands (Subarea 48.1), Cape Shirreff on the Drake Passage side of Livingston Island, and Copa in Admiralty Bay on the Bransfield Strait side of King George Island. The studies were undertaken from 1996 to 2002 (see Table 1 for details).

4.15 All PTTs were epoxied to the lower back feathers of the penguins to minimise the effects of drag and location data were obtained from the ARGOS satellite-tracking system.

4.16 ARGOS provides a Location Quality (LQ) code for each location fix, based on the number of uplinks received and the results of four plausibility checks ('NOPC', ARGOS 2000). LQs range from 0 to 3 with an ARGOS predicted accuracy of <150 m to 1 km+. Two other LQ codes, 'A' and 'B' are assigned lower assurance (due to fewer uplinks and/or lower NOPC).

4.17 All PTTs used on birds during the breeding season were set for continuous transmissions at 50 s intervals. PTTs deployed on chinstrap penguins from March to July 2000 and on Adélie penguins from February to April 2001 and February to March 2002 were set to transmit for 12 h on and 72 h off in order to save battery power during the winter period. Satellite data were sorted by site, individual, date and time. Only location data of classes 0 to 3 were used in these analyses.

4.18 The workshop noted that the number of replicates were small in many of the tracking periods. For that reason most conclusions by the workshop were drawn from the composite foraging area for each species, where all samples for a species were pooled together.

Chinstrap Penguins

4.19 The results are illustrated in Figure 22, which shows chinstrap penguins foraging over the shelf areas near the colonies being monitored at both Cape Shirreff and Copa. This pattern was consistent between breeding and winter seasons from 2000 to 2002.

4.20 In winter, two chinstrap penguins tagged at the Cape Shirreff colony were tracked from February to May 2000. Birds left the colony and travelled southwest, keeping well inshore until they reached the vicinity of Snow Island (area of concentration, Figure 22b). Here, they spent two to three weeks just off the western coast of Snow Island before moving well offshore. The birds remained in this offshore region for another two weeks, moving slowly to the northeast throughout the period. In mid-April, they returned to the inshore shelf area off Livingston Island and were proceeding to the northeast, on the shelf, when their signals were lost near Nelson Island from late April to early May.

4.21 From February to May 2000, three penguins were tracked from the Copa colony in Admiralty Bay, from where they proceeded to the northwestern end of King George Island where they spent the remainder of the March to May period foraging on the shelf in this vicinity (Figure 22c).

4.22 During the incubation period in November 2000, birds were at sea for 5- to 10-day intervals and their foraging distributions extended well beyond the shelf break (Figure 22d).

4.23 Foraging distributions of chinstrap penguins during the chick-rearing stage of the reproductive cycle were largely confined to the shelf, within approximately 10 km of the colony at Cape Shirreff, although some penguins were observed to make frequent trips out to the shelf break, approximately 30 km from the colony (Figures 22e and 22f).

Adélie Penguins

4.24 The results are illustrated in Figure 23, which shows the foraging areas for Adélie penguins from Copa colony in Admiralty Bay on King George Island. These penguins concentrate their foraging in Bransfield Strait (Figure 23a), particularly over the shelf and shelf break to the south off the western shore of the Antarctic Peninsula. Foraging trips are typically 10 to 14 days in length following clutch completion (Figure 23b). There were two distinct patterns followed by approximately half the birds tagged. One group moved to the southwest, the other proceeded to the northeast, entering the upper Weddell Sea in the 1996 season (not shown here).

4.25 Early winter distributions of Adélie penguins tagged at the Copa colony in 2001 and 2002 (Figures 23c and 23d) showed marked differences in behaviour of the three animals tagged each season. The behaviour in 2001 was similar to the incubation foraging behaviour described above while in 2002 the foraging tracks went deep into the Weddell Sea on the east side of the Antarctic Peninsula.

4.26 The workshop agreed to use the incubation foraging pattern for the purposes of its work.

Gentoo Penguins

4.27 The foraging distribution of gentoo penguins during the chick-rearing period in 2002 is shown in Figure 24. Gentoo penguins forage very close to the colony, where 90% of their locations were within the 100 m bathymetric contour line off Cape Shirreff.

Antarctic Fur Seals

4.28 Studies of foraging range and at-sea locations of Antarctic fur seals in the South Shetland Islands were conducted by the US AMLR Program at Cape Shirreff, an ice-free peninsula (ca. 2.5 km^2) on the north side of Livingston Island, South Shetland Islands (62°29'S, 60°47'W). Cape Shirreff has the largest breeding colony of Antarctic fur seals in the South Shetland Islands (SSI) and together with San Telmo Islands (<1 km northwest of Cape Shirreff) has an annual pup production of 8 500+ (85% of the total SSI pup production) (WG-EMM-02/51). The continental shelf (to 500 m) extends to approximately 30 km north at Cape Shirreff.

4.29 All individuals in the Cape Shirreff study were females from 23 to 76 days post-partum. Length, girth, and mass were recorded, and an ARGOS-linked PTT (Kiwisat 100, Sirtrack Ltd.), time-depth recorder (Wildlife Computers Mark 7) and a VHF radio transmitter were attached mid-back. Females were recaptured with their pups after one to three trips to remove all instruments; the mother and pup were released together after recording mass, length and girth.

4.30 Each PTT had a unique ID code and a transmission repetition rate of 34 s while the seal was at the surface. PTTs were equipped with a wet/dry conductivity switch.

Transmissions were continuous until the instrument logged 120 min ‘dry’, putting the PTT in a ‘sleep’ mode (saving battery life). The instruments were programmed to re-transmit after a two-minute ‘wet’ interval was detected.

4.31 For the data received from ARGOS, previous studies have determined that ‘A’ and ‘B’ assigned locations are frequently acceptable locations (Vincent et al., 2002; Boyd et al., 1998) and that often ‘A’ locations, in spite of their lower ARGOS rating, were considerably better than LQ-0 locations and of similar accuracy to LQ-1 locations (Vincent et al., 2002). Thus, for the Cape Shirreff study, all locations (LQ 1–3, A, B) were initially included regardless of their LQ rating. Starting with all ARGOS downloaded data (LQ 0–3, A, B), location fixes were filtered to eliminate positions that required an animal to travel at speeds greater than 4 m/s. Consecutive locations flagged for having travelling rates of >4 m/s were alternately deleted to determine which locations had the greatest error.

4.32 The sites of capture and release were recorded with a GPS unit accurate to 15 m. The accuracy of the onshore ARGOS location fixes was obtained by comparing positions with the more accurate GPS fixes.

4.33 Departure and arrival times were recorded using VHF transmitters and a continuously operating logging station. Trip durations were calculated using VHF data. Maximum distance travelled, considered a female’s maximum range, was calculated from the most distant ARGOS location received. The total distance travelled was recorded as the sum of the distances between locations.

4.34 The analyses comprised data obtained during January and February in each year from 1999 to 2002 (Table 2). Trip duration, foraging range and total distance travelled are shown in Table 3.

4.35 Data were analysed using ‘Tracks and Fields’ and the results are shown in Figures 25 to 27. Parameters used to smooth the data are shown in each figure.

4.36 Although the mean foraging range and trip duration varied from year to year, at-sea locations for fur seals in all years were centred over an area of the continental shelf and slope region approximately 40 km northwest of Cape Shirreff (Figure 26).

4.37 The distribution of foraging locations in February were more broadly distributed over the continental shelf slope region, were bimodal and were on average further west of Cape Shirreff (Figure 27).

Subarea 48.2

4.38 Foraging areas were determined for Adélie penguins and chinstrap penguins at Signy Island (Table 4). Methods of PTT attachment and deployment are described in WG-EMM-02/15. Tracks were obtained for both species during the summer chick-rearing period.

4.39 ‘Tracks and Fields’ was used to smooth the foraging tracks for these two species. The method followed that used for Subarea 48.3. The input to the program was ARGOS satellite-tracking data that had previously been screened to remove all low-quality positions; only positions of quality class 3, 2, 1 and 0 were used. Summaries of the ARGOS data are given in Tables 5 and 6. The parameters used in 'Tracks and Fields' were:

Trip duration maps	Yes
Smoothing parameter	0.1
Maximum distance	100
Latitude step size	0.1
Longitude step size	0.2
Truncation value	0.0005
Density isopleth	0.05
Minimum speed	0.0

4.40 The average annual footprints for chinstrap and Adélie penguins are shown in Figures 28 and 29 respectively.

Subarea 48.3

4.41 Foraging areas were determined for macaroni penguins, black-browed albatrosses and Antarctic fur seals at Bird Island (Table 4). Antarctic fur seals were also monitored at Husvik in 1998. Methods of PTT attachment and deployment are described in WG-EMM-02/21 and 02/22 and references therein.

4.42 The data analysis method used and parameter inputs to 'Tracks and Fields' were the same as that used for Subarea 48.2 with additions as described below. The ARGOS data available for analysis are described in Tables 7 to 9. Only summer data are used in this analysis.

4.43 An additional level of screening was carried out for black-browed albatrosses. This was to remove the effects of long-time intervals between positions that could distort the smoothing of foraging time allocation; these occasionally occurred where intervening low quality positions had been screened. Data were also screened to remove positions east of 0°E and north of 50°S.

4.44 All data were analysed according to breeding chronology. Thus, for Antarctic fur seals each of the breeding seasons were analysed separately. Similarly, for black-browed albatrosses, incubation was analysed separately from brood guard and chick rearing. For macaroni penguins, the breeding season was divided into incubation, brood guard, chick rearing and premoult. All foraging trips were analysed according to actual colony chronology, as this can vary slightly in some years.

4.45 In the 'Tracks and Fields' analysis a consistent set of parameters were chosen. This was selected after experimentation with the software to ensure results adequately reflected the input data. As smoothing is a non-parametric process, the assessment to compare different sets of parameters was made subjectively. A spatial analysis of the residuals from the smoothing was carried out by eye to ensure that smoothing was not extended too far beyond the input data.

4.46 The output of the 'Tracks and Fields' analysis was used to prepare average spatial foraging distributions for the various species for their various breeding periods during the summer breeding season. For this, the output data 'Isopleth Threshold' was used. Annual estimates of smoothed spatial foraging distribution for a given period were averaged and normalised using scripts written in S-Plus (Mathsoft Inc.) (archived with the secretariat). These average breeding chronology footprints were subsequently merged to provide an average footprint for the complete breeding season. The different chronological periods were weighted using the relative time duration that each period contributed to the total duration of the breeding season.

4.47 The average annual footprint for black-browed albatrosses, macaroni penguins, and Antarctic fur seals are shown in Figures 30 to 32 respectively.

Designation of Foraging Areas

4.48 The foraging areas for predators of krill were to be derived from aggregating the foraging locations of all colonies across all species.

4.49 The method proposed to achieve this involved extrapolating the characteristics of known foraging areas for each species described above to the centres of biomass for which no foraging data are available (paragraphs 4.3 to 4.6).

4.50 The foraging ranges were then pooled by weighting each grid square in the foraging range by the estimates of the colony or biomass centre along with the estimated foraging intensity for that square. These values are then summed across all biomass centres and species to give the distribution of foraging intensities expected across the region.

4.51 The workshop agreed to keep separate the foraging areas of the monitored colonies from the extrapolated foraging areas but would consider both when formulating its views on the different foraging areas in each subarea.

Extrapolated Foraging Areas

4.52 The general method for extrapolating to colonies without foraging information included the following steps for each species in each subarea:

(i) estimating the 'maximum foraging distance';

(ii) estimating the 'characteristic foraging density' by distance from the centre of foraging;

(iii) determining the centre of foraging for the colonies without foraging data; and

(iv) estimating a foraging area for those colonies based on the above information.

4.53 This method would produce estimated summer foraging areas for each species in each subarea. Data used for estimating these characteristic areas were derived where possible from the same subarea for which the data were needed. This was not always the case. Table 10(a) shows the origin of the data used for each species in each subarea.

4.54 Maximum foraging distance is the maximum distance, in nautical miles, from the centre of foraging in the areas encompassing 95% of the foraging activities of the species. The estimated distances are given in Table 10(b).

4.55 Characteristic foraging density was the density of foraging estimated as a function of distance from the centre of foraging to the maximum foraging distance. It is expressed as a proportion of the maximum intensity. The characteristic foraging densities are shown in Table 10(c). This table also shows the general spread of the distribution of characteristic summer foraging areas. In some cases, such as macaroni penguins in Subarea 48.3, almost all of the foraging effort occurs over a small area but a small amount of effort is spread over a large area.

4.56 The central point of most foraging areas was located at the position of the colonies and centres of biomass. The central points for chinstrap penguins in Subarea 48.1 were located half way between the colony and the shelf break. In addition, the central point for the Adélie penguin colony at Signy Island (Subarea 48.2) was moved south from the colony by the maximum foraging distance because it was believed that these penguins would primarily forage on the south side of the South Orkney Islands (WG-EMM-02/15). The coordinates of these foraging centres are given in Table 11.

4.57 Dr Ball provided the software 'Range Plotter', which placed a foraging distribution around a nominated foraging centre. In his earlier presentation of the use of 'Range Plotter', Dr Ball had indicated how the software could wrap the foraging area around the coast of land, including islands, and that the shape of the distribution could be altered.

4.58 The workshop thanked Dr Ball for providing such a useful piece of software to help complete its work. The software was archived with the CCAMLR Secretariat.

4.59 The workshop agreed that a circular foraging area placed around the nominated foraging centre was used in the absence of knowledge about the primary foraging directions of species at locations for which no foraging data were available (see paragraph 1.23). No limits were placed on the extrapolated foraging areas. The distribution of foraging density from the centre of foraging followed the characteristic foraging density for the appropriate species and region.

4.60 The workshop also agreed that this application of circular foraging areas could lead to having foraging extrapolated to areas where no foraging occurs.

4.61 Drs Sushin, Shust and Gasiukov stressed that this approximation of circular foraging areas gave a picture which is in contrast with the observed spatial foraging patterns described earlier in Subareas 48.2 and 48.3. This use of the method does not take into account observed direction of foraging trips or the effect of land on the foraging range. They requested that the method be evaluated at the next meeting of WG-EMM.

4.62 The workshop agreed to view the extrapolated foraging areas for each species within a subarea as well as the combined plots of all subject species. These would be plotted in two ways:

(i) overlap of foraging ranges, which would illustrate the total area likely to be used as well as overlap between foraging areas between colonies and between species; and

(ii) biomass-weighted foraging areas, which would have each foraging range weighted by the biomass of the colony (centre of biomass) and the characteristic foraging density, showing the areas of greatest use by predators.

4.63 The biomasses for each colony or centre of biomass were determined as the number in the colony multiplied by an estimate of the average weight of an adult of the respective species from the CCAMLR database (Attachment 2).

4.64 Dr Watters developed a function 'plot blobs' within S-Plus to plot these figures for the workshop. This function is able to:

(i) overlay other plots, such as bathymetric or coastline maps;

(ii) restrict a presentation to a given subarea;

(iii) plot foraging densities within the foraging range or simply indicate the foraging range using uniform colour;

(iv) rescale the foraging densities to a common relative scale across figures, where the relative scale is from zero to the maximum foraging density; and

(v) weight the foraging densities from each colony or species by a selected set of statistical weights, say colony biomass or consumption.

4.65 The function requires input data as an S-Plus data frame, 'In.Data' with the following columns (labels are case sensitive):

(i) Longitude;
(ii) Latitude;
(iii) Isopleth.Threshold; and
(iv) colony.

4.66 The statistical weights need to be included in an S-Plus list with all unique colony names from the input data table.

4.67 The workshop thanked Dr Watters for developing this function for use by the workshop. The workshop greatly appreciated his efforts to develop this flexible and useful plotting routine. The function was archived with the Secretariat.

4.68 The results are illustrated for each subarea in Figures 33 to 35.

Delineation of Foraging Areas

Subarea 48.1

4.69 The workshop considered the results in Figure 33 as well as the known abundance and foraging ranges described for Antarctic fur seals (Figures 13 and 25 to 27), chinstrap penguins (Figures 11 and 22), Adélie penguins (Figures 10 and 23), gentoo penguins (Figures 12 and 24) and finfish (Figure 21).

4.70 The workshop agreed that the predator foraging areas could be broadly divided between Elephant Island, Drake Passage to the north of the South Shetland Islands and Bransfield Strait. In addition, the workshop noted that the foraging of Adélie penguins was likely to be concentrated in the eastern end of Bransfield Strait while chinstrap and gentoo penguins were likely to be concentrated in the western end. It was also noted that the primary location of foraging in Drake Passage was to the north of Livingston Island from Cape Shirreff.

4.71 The workshop agreed that an additional division based on these foraging areas could be made between Greenwich and Roberts Islands perpendicular to the axis of the South Shetland Islands and dividing both the shelf area in Drake Passage as well as Bransfield Strait.

Subarea 48.2

4.72 The workshop considered the results in Figure 34 as well as the known abundance and foraging ranges described for Adélie penguins (Figures 14 and 29), chinstrap penguins (Figures 15 and 28), gentoo penguins (Figure 16) and finfish (Figure 21b). It also noted the foraging area of black-browed albatrosses to the west of the South Orkney Islands (Figure 30).

4.73 The workshop noted that the biomass of land-based predators was concentrated towards the eastern end and south of the South Orkney Islands. It also noted the observed foraging areas were to the south and southwest of Signy Island for Adélie penguins and south for chinstrap penguins, and to the west of the South Orkney Islands for black-browed albatrosses. In addition, the density of krill-eating finfish was observed to be split to the west, north and east of Coronation Island.

4.74 The workshop agreed that the area to the west of the western end of Coronation Island could be separated from the remaining shelf area to the east of that point. This separation appeared best to be perpendicular to the shelf break to the north of Coronation Island.

4.75 The workshop noted the uncertainty as to whether penguins were likely to forage to the north of Coronation Island. It is conceivable that the large colonies of penguins on Laurie and Powell Islands would have access to the northern waters, unlike the penguins on Signy Island. However, it was noted that the northern side may be differentiated from the southern side.

4.76 Given the uncertainty as to whether penguins concentrated their foraging on the southern side of the island, the workshop agreed that the north and south of South Orkney Islands be separated in the interim pending more information on the foraging activities of penguins from Laurie Island.

Subarea 48.3

4.77 The workshop considered the results in Figure 35 as well as the known abundance and foraging ranges described for macaroni penguins (Figures 17 and 31), gentoo penguins (Figure 18), Antarctic fur seals (Figures 19 and 32) and finfish (Figure 21c). It also noted the foraging areas of black-browed albatrosses (Figure 30).

4.78 The workshop agreed that the primary area of foraging was centred to the northwest of South Georgia due to the concentration of land-based predators in the region as well as the known foraging locations of fur seals, macaroni penguins and black-browed albatrosses. It was also recognised that the area to the east and southeast of South Georgia was an important foraging location due to the foraging activities of the black-browed albatrosses and the presence of gentoo penguins at the southeast end of the island.

4.79 The workshop agreed that the distribution and feeding activity of krill-eating finfish provided some evidence to support the division of the shelf region into east and west, and to separate South Georgia from Shag Rocks. However, it was noted that this was only one year of data with no diet data to help explain the distribution.

4.80 Dr Everson indicated that there was a body of knowledge on diet and foraging activities of *C. gunnari* in the published literature, including work led by Dr K.-H. Kock (Germany), as well as well as in papers tabled at WG-FSA that could be used to further explore the spatial segregation of krill-eating finfish in the South Georgia region.

4.81 Dr Kirkwood proposed that the division between areas be indicated by north–south boundaries so that they are consistent with the work of WG-FSA. Such boundaries had been considered for *C. gunnari* by WG-FSA in 2000 (SC-CAMLR-XIX, Annex 4, Figure 24), although these boundaries were determined to facilitate a simple separation of Shag Rocks and South Georgia, and to provide a means of analysing survey data from the region.

4.82 The workshop noted that there is some uncertainty as to whether land-based predators forage on the south side of South Georgia during the breeding season.

4.83 Dr Trathan drew the attention of the workshop to the paper submitted by Prof. I. Boyd (UK) last year (WG-EMM-01/26) which estimated areas of highest consumption of krill by fur seals in the region. Using a different method, but the same data, the results of that analysis were similar to the results of the extrapolated foraging areas shown in Figure 35.

4.84 As for Subarea 48.2, the uncertainty as to whether predators forage on the southern side of the island meant that the workshop agreed that the shelf to the south of South Georgia be separated in the interim pending more information on the foraging activities in the region.

SYNTHESIS

5.1 The workshop reviewed the analyses described above for each statistical subarea to integrate the observed divisions in spatial distributions of krill, the krill fishery and krill predators into a spatial subdivision of each subarea.

5.2 The workshop recalled its decision to establish a nested hierarchy of areas such that the first division would be between the pelagic area and the area considered important to the summer breeding colonies of land-based predators. This division was to be based on the maximum foraging distance of the land-based predators. The second set of divisions was to be based on local units in which aggregations of krill, fishing grounds and predator foraging areas, as defined earlier in the report, could be separated from other areas. The workshop also agreed that separation of areas specific to individual predator species may be needed. This would form the third level of the hierarchy of areas.

Subarea 48.1

5.3 The integrated results for Subarea 48.1 are presented in Figure 36. This figure shows the divisions between Elephant Island, the South Shetland Islands and the Western Antarctic Peninsula, derived from the analysis of krill aggregations and the fishery. The workshop agreed to also maintain a division between Bransfield Strait and Drake Passage on the basis of this analysis.

5.4 The division between the pelagic area and the land-based predator area is shown in Figure 36(d).

5.5 The assessment of the predator divisions based primarily on the known foraging grounds of Antarctic fur seals at Cape Shirreff and the differences between Adélie and chinstrap/gentoo penguin foraging areas is overlaid on the extrapolated foraging areas in Figures 36(e) and 36(f). This pattern of division is supported by the analysis of krill-eating finfish (Figure 36g).

5.6 The workshop noted that the division between Greenwich and Roberts Islands overlaps with part of the observed krill aggregations (Figure 36h).

5.7 The workshop agreed that this subarea could be divided into pelagic and land-based predator areas and that the land-based predator area could be further subdivided into four main zones: Western Antarctic Peninsula, Drake Passage, Bransfield Strait and Elephant Island. These four zones were considered to provide a reasonable separation between the spatial structures of krill, the fishery and predator foraging grounds in that region.

5.8 The workshop also agreed to a further subdivision of Drake Passage and Bransfield Strait areas on the basis of the separation of the foraging areas of individual species. Both these areas were divided into east and west components with a boundary between Greenwich and Roberts Islands perpendicular to the axis of the South Shetland Islands.

5.9 This agreed subdivision of Subarea 48.1 is shown in Figure 37.

5.10 Dr M. Naganobu (Japan) drew the attention of the workshop to the oceanography of the region and explained why he believed that the subdivision of Bransfield Strait and Drake Passage into eastern and western areas, as indicated by the dotted line, was likely not to be warranted because of the movement of krill through the region. He explained that part of the Antarctic Circumpolar Current divides near the western end of Livingston Island bringing a strong west–east flow of water into the northern side of Bransfield Strait. This water moves around the eastern end of King George Island to form an area of coastal upwelling to the north of Livingston and King George Island. This area has high productivity, supporting krill and its predators. This water movement also helps drive the difference between the South Shetland Islands and Elephant Island. An area of cold coastal water is retained on the south side of Bransfield Strait.

5.11 The workshop agreed that future work on how these proposed small-scale areas could be used for management will need to consider the oceanography of the region and the potential linkages between these areas, including the movement of krill.

Subarea 48.2

5.12 The integrated results for Subarea 48.2 are presented in Figure 38.

5.13 The aggregation of krill observed in the CCAMLR-2000 Survey was centred over the South Orkney Islands, including part of the northern shelf break and extending south over the larger area of shelf less than 500 m in depth (Figure 38a). The fishery is largely concentrated to the northwest of Coronation Island (Figure 38b).

5.14 The division between the pelagic area and the land-based predator area is shown in Figure 38(c).

5.15 The assessment of the predator divisions based primarily on the known foraging grounds of black-browed albatrosses and chinstrap and Adélie penguins shows a northeast to southwest division in foraging locations at the western tip of Coronation Island (Figure 38d).

5.16 This division is supported by the extrapolated foraging areas (Figure 38e) and the aggregations of krill-eating finfish (Figure 38f). The extrapolated foraging areas are very much influenced by the large number of penguins on Laurie and Powell Islands. The workshop noted that the fish distribution may vary over time but the evidence in the analysis presented here does support the division.

5.17 The workshop noted that it may be possible that penguins are restricted in their foraging to the south of the islands despite the extrapolated foraging grounds extending to the north of the islands (see paragraphs 4.59 to 4.61 for discussion of the method used for extrapolation). If this were the case, then it would be reasonable to separate the north side of the South Orkney Islands from the south side.

5.18 Dr Trivelpiece indicated to the workshop that such a division is likely, given that Adélie and chinstrap penguins forage over shelf areas and that the majority of the shelf area in the region is to the south of the islands.

5.19 Dr Everson indicated that it is conceivable that birds on Laurie or Powell Islands could forage to the north and south of Coronation Island. He suggested that satellite-tracking studies of these penguins would be very useful in identifying where the foraging locations are for these colonies.

5.20 The workshop agreed that an additional division along the axis of the South Orkney Islands to divide the southeastern foraging area identified above is warranted, pending further information on the foraging locations of birds in the east of the South Orkney Islands.

5.21 The agreed subdivision of Subarea 48.2 is shown in Figure 39.

Subarea 48.3

5.22 The integrated results for Subarea 48.3 are presented in Figure 40.

5.23 The workshop noted the two main areas of krill aggregations observed in the CCAMLR-2000 Survey and known from many UK surveys in the region (Figures 40a and 40b). The analysis of the USSR krill fishery from 1986 to 1990 showed a distinct pattern associated with the shelf break. There was a clear separation of these winter fishing grounds at 37.5°W. Although this separation was based on winter fishing patterns, the workshop agreed to use this as a basis for subdividing the region.

5.24 The division between the pelagic area and the land-based predator area is shown in Figure 40(c).

5.25 The assessment of predator divisions based primarily on the known foraging grounds of black-browed albatrosses, Antarctic fur seals and macaroni penguins shows that the division of the fishing grounds also divides the known foraging areas (Figure 40d).

5.26 A division of the South Georgia region at 37.5°W is supported by the extrapolated foraging areas (Figure 40e) and by the assessment of *C. gunnari* densities from surveys in 2000 (Figure 40f). The workshop noted that the fish distribution may vary over time but evidence in the analysis presented here does support the division.

5.27 The workshop also noted the separation of Shag Rocks and the South Georgia shelf by WG-FSA. However, it was noted that this separation was likely to be achieved by the boundary of the land-based predator foraging area and so did not warrant the addition of a new boundary as nearly all the Shag Rocks shelf region fell outside of the range of the South Georgia land-based predator foraging footprint.

5.28 The workshop noted that it may be possible that land-based predators are restricted in their foraging to the west and north of the island despite the extrapolated foraging grounds extending to the southwest of the island (see paragraphs 4.59 to 4.61 for discussion of the method used for extrapolation). If this were the case, then it would be reasonable to separate the southwestern side of South Georgia from the rest of the shelf areas. However, the workshop did not find sufficient reason to justify the separation of this part of the shelf.

5.29 The workshop agreed to a subdivision of the South Georgia area by a single north–south boundary at 37.5°W. This is shown in Figure 41.

5.30 The workshop noted that further work on the oceanography of the region and on the distribution of *C. gunnari* may provide insights into the relationship between these areas and how they may be used for management purposes.

ADVICE TO WG-EMM

5.31 The workshop recommended that the subdivisions of Subareas 48.1, 48.2 and 48.3 shown in Figures 37, 39 and 41 be considered as the best available advice on small-scale management units in the region.

5.32 The workshop noted the uncertainty surrounding the extrapolation of known foraging characteristics of land-based predators to colonies for which no foraging information was known. It was noted that the method for extrapolating predator foraging areas for colonies without foraging information might lead to the conclusion that foraging might occur in areas in which predators do not forage in reality. However, the proposals take account of the known information and are based, although not dependent, on the extrapolated results.

5.33 The workshop noted that these proposals provide a structure for considering how to subdivide the precautionary catch limit for krill in Area 48 as well as for developing management procedures for krill fisheries that can adequately take account of localised effects on predators.

5.34 The workshop noted that:

(i) this assessment is the first of its kind in CCAMLR;

(ii) this assessment used a variety of datasets that enabled the detailed analyses presented here, such that deficiencies in one dataset could be compensated by strengths in others;

(iii) fine-scale fisheries data were very important to the success of this assessment;

(iv) a number of uncertainties remain regarding the relationships between predators, krill and the fishery and further information on krill, krill movement, predator demand and predator foraging grounds may provide opportunities to refine these boundaries in the future;

(v) the next step is to develop an understanding of the linkages and dynamics between these areas in order to facilitate the subdivision of the precautionary catch limit for krill in Area 48, taking account of the oceanography and the environmental variability of the region;

(vi) this assessment has demonstrated the utility of satellite-tagging programs for an understanding of the relationships between predators, krill and the fishery, and, as a result, the workshop highly recommended further studies of this kind; and

(vii) the manner in which these proposed small-scale management units are used may have implications for monitoring that would need to be considered by the Commission.

CLOSE OF THE WORKSHOP

5.35 Dr Hewitt thanked all the participants for their diligence and hard work over the course of the meeting. In particular, he thanked Dr Trivelpiece and his steering committee for all their preparation and the thought they had put into ensuring the success of the workshop. He also thanked the providers of data, without which none of these assessments could have been undertaken.

5.36 Special thanks were given to the providers of software and statistical routines, Drs Ball and Watters.

5.37 The workshop also extended its special thanks to Dr Constable for his persistent vision, perseverance and hard work throughout all stages of the workshop.

5.38 The workshop closed on 15 August 2002.

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Table 1: Summary details of data for penguin species tracked in Subarea 48.1, including site of colonies, number of replicates, year of sampling and season of tracking. KGI = King George Island, LI = Livingston Island.

Species	Site	N	Year	Period
Adélie penguin	Copa, KGI	8	1996	Oct–Nov
Adélie penguin	Copa, KGI	8	1997	Oct–Nov
Adélie penguin	Copa, KGI	3	2001	Feb–Apr
Adélie penguin	Copa, KGI	3	2002	Jan–Jul
Chinstrap penguin	Copa, KGI	3	2000	Mar–Jul
Chinstrap penguin	Cape Shirreff, LI	6	1999	Jan
Chinstrap penguin	Cape Shirreff, LI	2	2000	Feb–July
Chinstrap penguin	Cape Shirreff, LI	4	2000	Nov
Chinstrap penguin	Cape Shirreff, LI	3	2001	Jan–Feb
Chinstrap penguin	Cape Shirreff, LI	10	2002	Jan
Gentoo penguin	Cape Shirreff, LI	4	2002	Feb

Table 2: Number of ARGOS satellite uplinks by quality class code for Antarctic fur seals breeding at Cape Shirreff, South Shetland Islands.

Year	Season	Female	Total Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B
1999	Jan–Feb	35	3 122	13	62	463	1 325	511	748
2000	Jan–Feb	34	2 797	27	113	404	1 095	496	662
2001	Jan–Feb	25	5 237	149	321	852	1 567	836	1 512
2002	Jan–Feb	13	1 885	54	98	280	440	386	627

Table 3: Trip durations, foraging range, and total distance travelled by 95 female Antarctic fur seals foraging from Cape Shirreff, Livingston Island, from 1999 to 2002.

Parameter	1999	2000	2001	2002	All years
Female (N)	35	50	25	12	95
Trip (N)	39	42	55	34	170
Trip duration (days):					
Mean	4.5	4.4	3.8	3.3	4.0
SE	1.3	0.3	1.0	1.0	0.1
Min.	2.6	0.8	1.8	1.6	0.8
Max.	8.8	9.1	6.0	5.9	9.1
Foraging range (maximum distance travelled – km):					
Mean	106	83	78	67	83
SE	46	5	19	14	3
Min.	47	37	45	48	37
Max.	369	217	136	111	369
Total distance travelled (km):					
Mean	504	374	351	253	372
SE	197	25	95	86	14
Min.	154	99	164	109	99
Max.	1 258	814	561	448	1 258

Table 4: Deployment locations and PTT devices used for land-based predator species tracked in Subareas 48.2 and 48.3.

Species	Year	Period	Location	Device
Adélie penguin	1999	Summer	Signy Is	ST-10, ST-18
	2000	Summer	Signy Is	ST-10, ST-18
Chinstrap penguin	1999	Summer	Signy Is	ST-10, ST-18
	2000	Summer	Signy Is	ST-10, ST-18
Macaroni penguin	1999	Summer	Bird Is	ST-10, ST-18
	2000	Summer	Bird Is	ST-10, ST-18
	2001	Summer	Bird Is	ST-10, ST-18
Black-browed albatross	1992	Summer	Bird Is	Microwave, Toyocom
	1993	Summer	Bird Is	Microwave, Toyocom
	1994	Summer	Bird Is	Microwave, Toyocom
	1997	Summer	Bird Is	Microwave, Toyocom
Antarctic fur seal	1996	Summer	Bird Is	ST-10
	1997	Summer	Bird Is	ST-10
	1998	Summer	Bird Is	ST-10
	1998	Summer	Husvik	ST-10
	1999	Summer	Bird Is	ST-10
	2000	Summer	Bird Is	ST-10
	2001	Summer	Bird Is	ST-10

Table 5: Number of ARGOS satellite uplinks by quality class for Adélie penguins breeding at Signy Island, South Orkney Islands.

Year	Season	Male	Female	Male Uplinks	Female Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B	Quality Z
2000	Chick rearing*	3	6	349	498	18	70	260	175	155	166	3
2001	Chick rearing*	7	3	886	467	38	138	351	272	287	258	9

* Chick rearing is defined as 6 December to 20 February

Table 6: Number of ARGOS satellite uplinks by quality class for chinstrap penguins breeding at Signy Island, South Orkney Islands.

Year	Season	Male	Female	Male Uplinks	Female Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B	Quality Z
2000	Chick rearing*	3	7	179	487	15	44	174	109	172	149	3
2001	Chick rearing*	6	8	395	589	14	51	153	162	250	348	6

* Chick rearing is defined as 31 December to 20 February

Table 7: Number of ARGOS satellite uplinks by quality class for macaroni penguins breeding at Bird Island, South Georgia.

Year	Season	Male	Female	Male Uplinks	Female Uplinks	Sex not Known Trips	Sex not Known Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B	Quality Z
1999	Incubation[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chick rearing[2]	8	15	637	1 899	5	735	50	96	786	1 364	476	484	15
	Premoult[3]	1	-	433	-	-	-	4	4	84	208	70	59	2
2000	Incubation[1]	4	7	1 165	992	-	-	24	115	748	849	202	204	15
	Chick rearing[2]	6	18	585	1 238	-	-	17	75	443	759	243	274	12
	Premoult[3]	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	Incubation[1]	3	3	1 552	682	-	-	29	113	665	817	302	302	6
	Chick rearing[2]	4	13	212	973	-	-	13	45	208	407	230	271	11
	Premoult[3]	2	3	574	1 497	-	-	16	62	369	775	389	440	20

[1] Incubation is defined as 1 November to 31 December [2] Chick rearing is defined as 1 January to 17 February [3] Premoult is defined as 18 February to 21 March

Table 8: Number of ARGOS satellite uplinks by quality class for black-browed albatrosses breeding at Bird Island, South Georgia.

Year	Season	Number Trips	Number Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B	Quality Z
1992	Incubation[1]	-	-	-	-	-	-			
	Brood guard[2]	-	-	-	-	-	-			
	Chick rearing[3]	1	184	-	12	57	115			
1993	Incubation[1]	-	-	-	-	-	-			
	Brood guard[2]	3	17	-	-	5	12			
	Chick rearing[3]	66	2 098	11	191	392	1 504			
1994	Incubation[1]	-	-	-	-	-	-			
	Brood guard[2]	1	46	-	-	-	-			
	Chick rearing[3]	-	-	-	2	6	38			
1997	Incubation[1]	10	750	2	10	36	323	177	158	44
	Brood guard[2]	-	-	-	-	-	-	-	-	-
	Chick rearing[3]	-	-	-	-	-	-	-	-	-

[1] Incubation is defined as 1 November to 31 December
[2] Brood guard is defined as 1 January to 24 January
[3] Chick rearing is defined as 25 January to 15 April

Table 9: Number of ARGOS satellite uplinks by quality class for Antarctic fur seals breeding at Bird Island, South Georgia.

Year	Season	Female	Pup	Female Uplinks	Pup Uplinks	Quality 3	Quality 2	Quality 1	Quality 0	Quality A	Quality B	Quality Z
1996	Breeding season[1]	19	-	670	-	11	46	100	137	126	227	23
1997	Breeding season[1]	18	-	1 595	-	18	51	289	571	269	382	15
1998	Breeding season[1]	72	-	3 430	-	29	129	732	1 112	614	772	42
1999	Breeding season[1]	51	-	5 708	-	36	180	1 055	1 780	1 123	1 463	71
2000	Breeding season[1]	19	-	1 813	-	11	38	280	693	308	450	33
2001	Breeding season[1]	50	-	8 023	-	109	497	1 873	1 697	1 547	2 200	100

[1] Breeding season is defined as 1 December to 31 March

Table 10: Details of characteristic summer foraging areas for land-based predators in Subareas 48.1, 48.2 and 48.3.

(a) Subareas from which data originated to estimate the characteristic area for each species (rows) in each subarea (columns).

Species	Subarea		
	48.1	48.2	48.3
Adélie	48.2	48.2	
Chinstrap	48.1	48.2	
Gentoo	48.1	48.1	48.1
Macaroni			48.3
Antarctic fur seals	48.1		48.3

(b) Maximum foraging distance, in nautical miles, estimated for five predators in Area 48.

Species	Subarea		
	48.1	48.2	48.3
Adélie	96	96	
Chinstrap	20	46	
Gentoo	15	15	15
Macaroni			191
Antarctic fur seals	48		115

(c) Characteristic foraging densities estimated for each species in each region. Each row is the characteristic foraging density as a function of distance for each of the species in each of the subareas. The values are distances (n miles) from the centre of the foraging distribution to the percentile for that column. For example, 75% of the foraging done by Adélie penguins in Subarea 48.1 occurs within 87.2 n miles of the centre of the foraging distribution.

Subarea/Species	Density as Proportion of Maximum Intensity					
	0.9	0.75	0.5	0.25	0.1	0.05
Subarea 48.1						
Adélie	87.2	87.2	87.5	91.4	95.7	95.7
Chinstrap	2.8	6.9	10.9	13.7	17.5	19.7
Gentoo	2.8	2.8	6.2	10.3	13.9	15.1
Antarctic fur seal	2.8	10.3	17.8	30.4	43.0	48.7
Subarea 48.2						
Adélie	87.2	87.2	87.5	91.4	95.7	95.7
Chinstrap	42.2	42.2	45.9	45.9	45.9	45.9
Gentoo	2.8	2.8	6.6	10.3	13.9	15.1
Subarea 48.3						
Gentoo	2.8	2.8	6.6	10.3	13.9	15.1
Macaroni	0	6.0	9.3	12.0	184.9	191.3
Antarctic fur seal	0	30.8	55.2	68.2	105.9	114.8

Table 11: Coordinates of central points of foraging areas for colonies that did not have this central point located at the site of the colony.

Subarea/Species	Colony Location		Centre of Foraging	
	Longitude	Latitude	Longitude	Latitude
Subarea 48.1				
Chinstrap	-59.70	-62.32	-59.75	-62.04
Chinstrap	-55.11	61.13	-55.12	-61.27
Chinstrap	-58.00	-61.90	-58.05	-61.63
Chinstrap	-58.37	-61.93	-58.42	-61.66
Chinstrap	-57.67	-61.90	-57.72	-61.64
Chinstrap	-60.18	-62.43	-60.23	-62.15
Chinstrap	-60.80	-62.47	-60.85	-62.18
Subarea 48.2				
Adélie	-45.58	-60.73	-45.58	-62.30

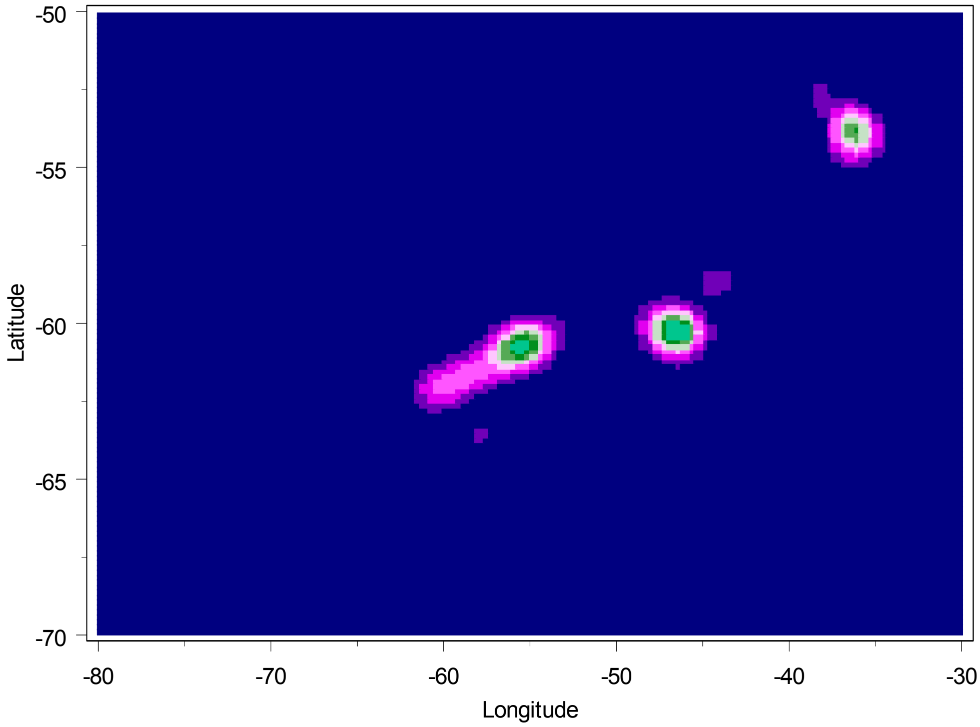


Figure 1*: Average importance of 10 x 10 n mile areas to the krill fishery from 1986 to 1990.

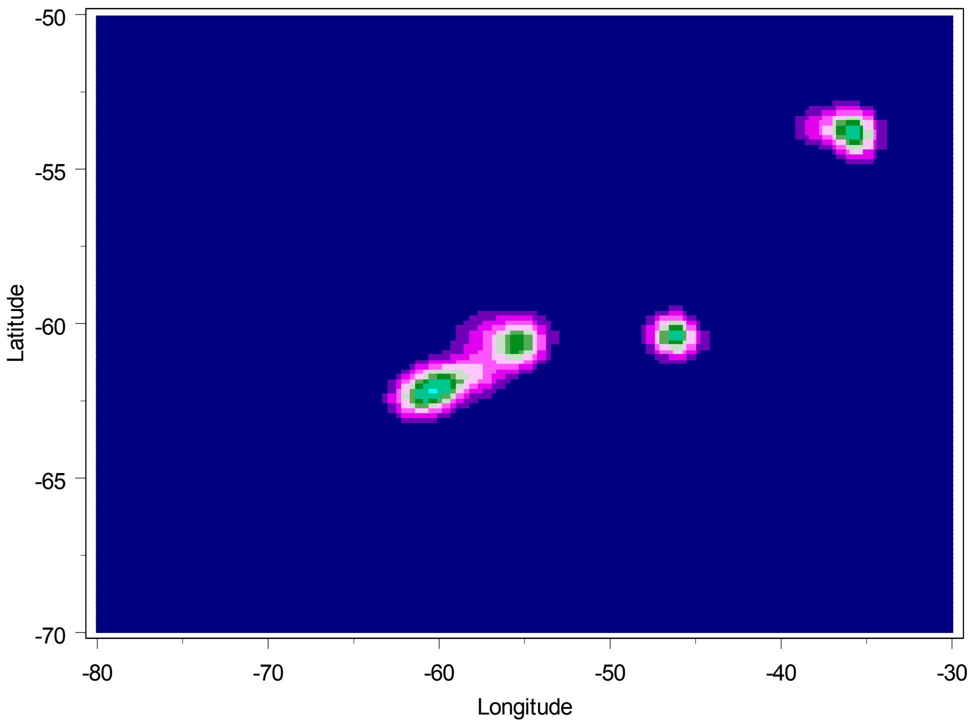


Figure 2: Average importance of 10 x 10 n mile areas to the krill fishery from 1996 to 2000.

* Figures 1 to 5 are presented in this publication in colour to ensure full representation of the dynamic range of data available. It should be noted that figures in working group reports are not customarily published in colour.

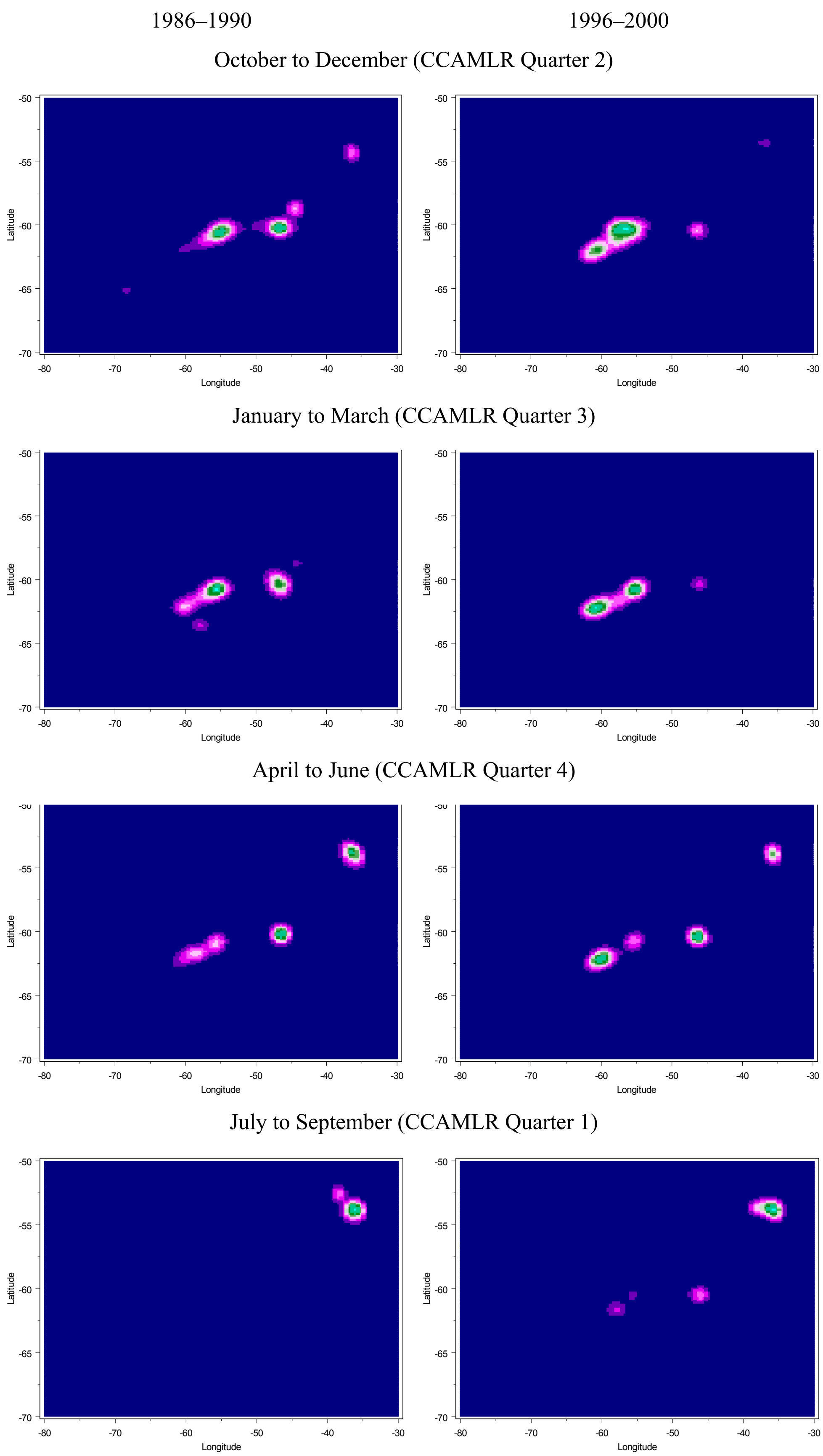
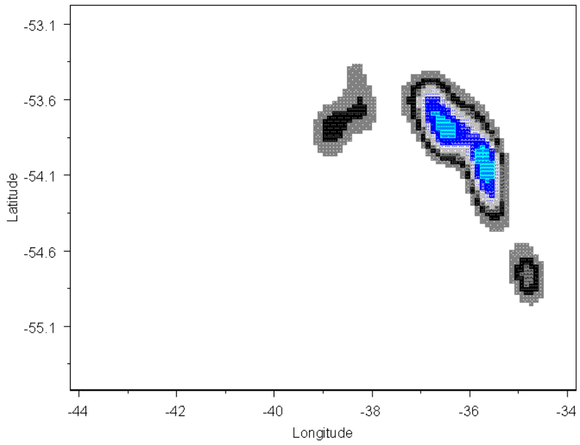
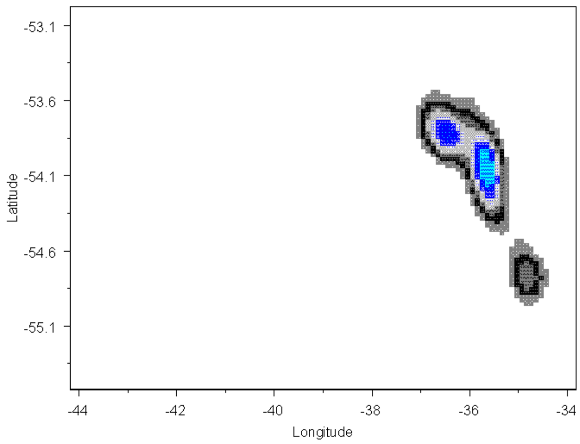


Figure 3: Average importance of 10 x 10 n mile areas for each quarter of two fishing periods.

(a)



(b)



(c)

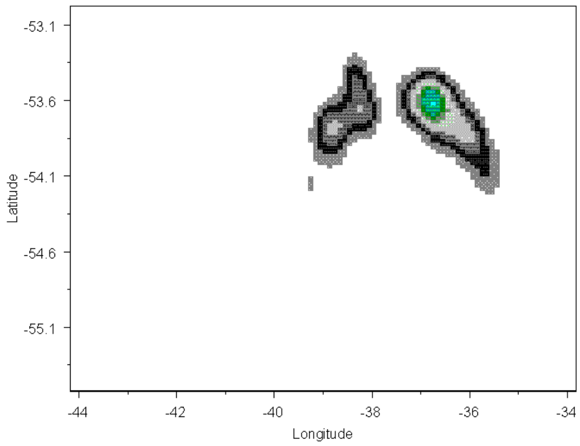


Figure 4: Average importance of 3 x 1.5 n mile areas to the USSR krill fishery: (a) from 1986 to 1990, (b) from 1986 to 1990 for the fourth quarter – April to June, and (c) from 1986 to 1990 for the first quarter – July to September. Grey indicates low importance, while light blue indicates high importance.

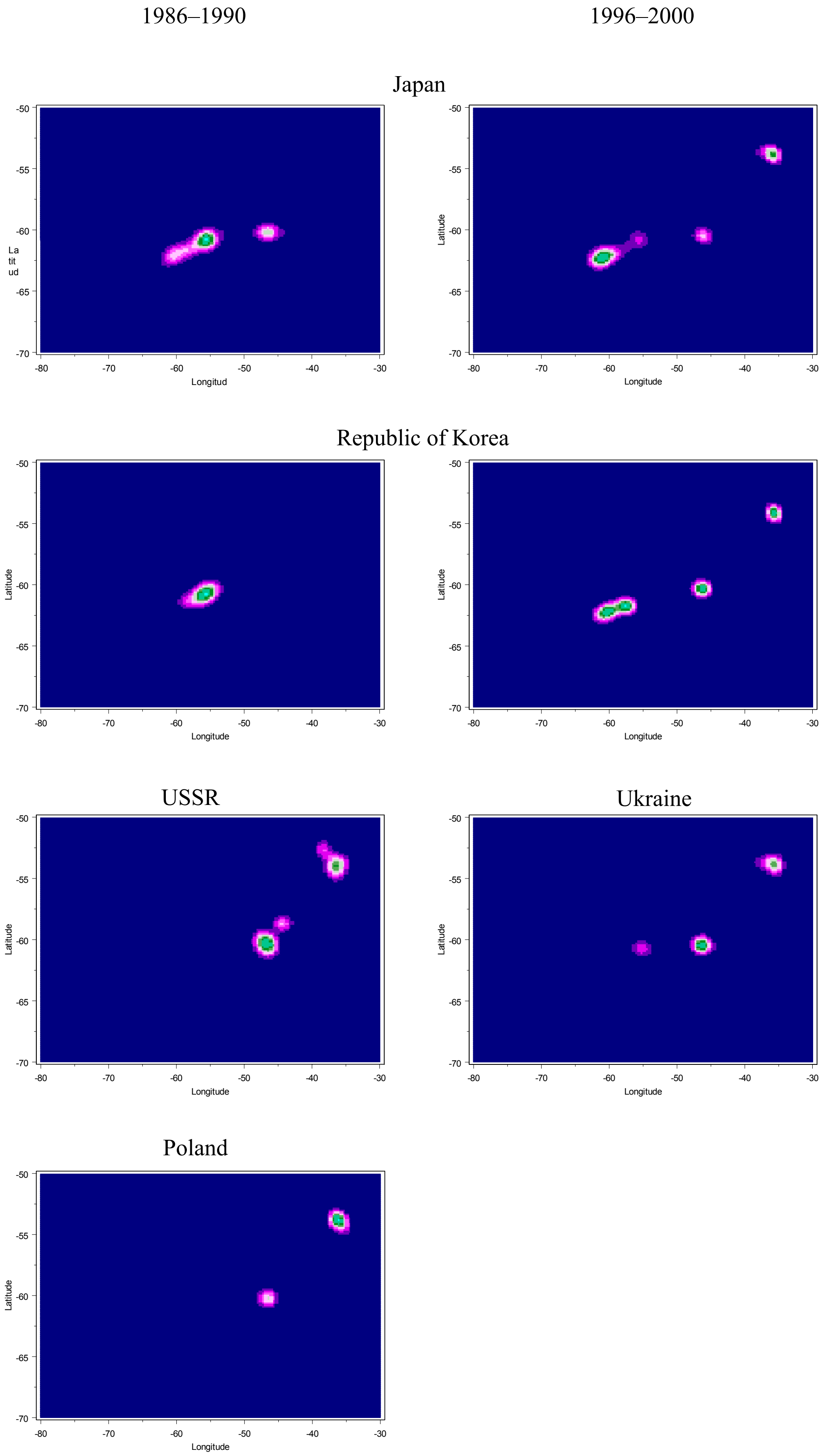


Figure 5: Average importance of 10 x 10 n mile areas for major krill-fishing countries during each of two fishing periods.

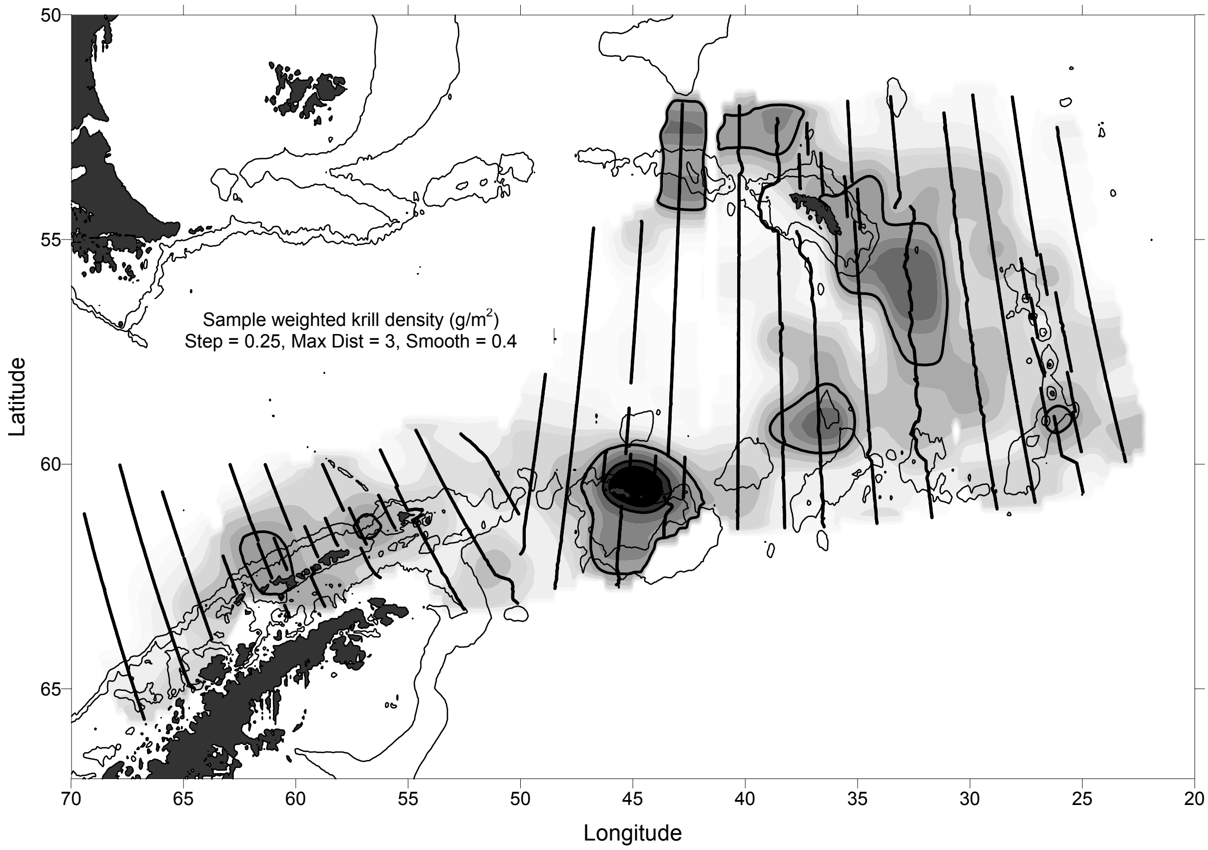


Figure 6: Sample weighted krill density (g m^{-2}) in Area 48 estimated from the CCAMLR-2000 Survey. Scale indicates relative density. Parameters show the values used in 'Tracks and Fields' for smoothing the data. Thin lines show the 500 m and 2 000 m isobaths. Thick lines denote areas where density is greater than 10 g m^{-2}.

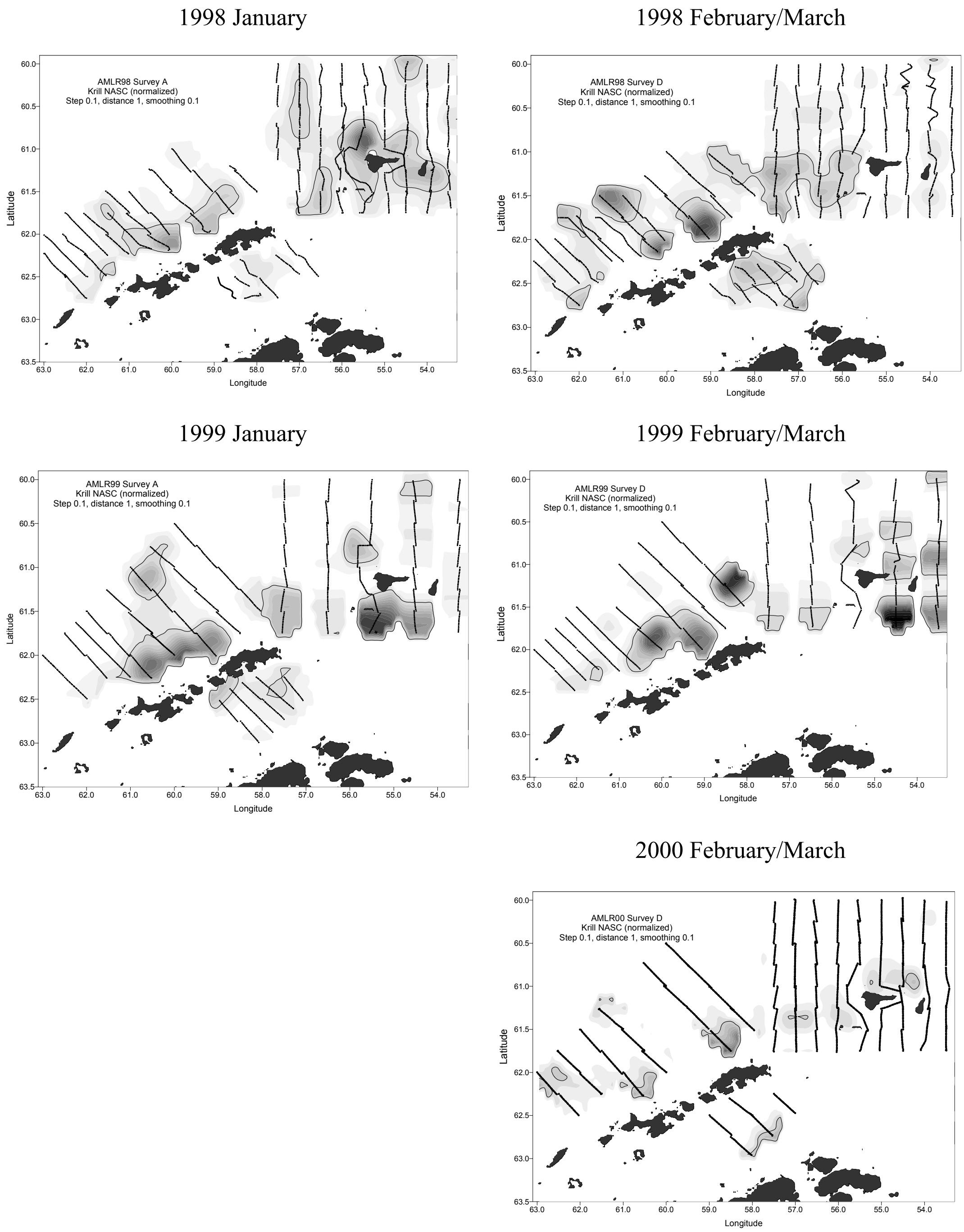
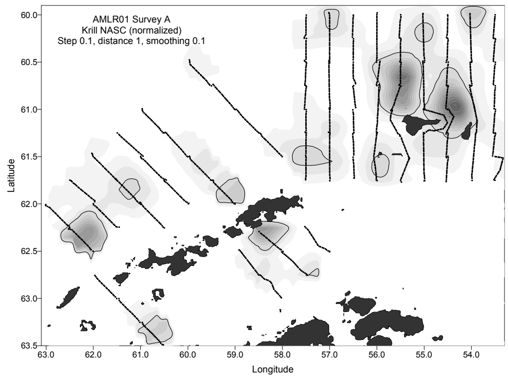


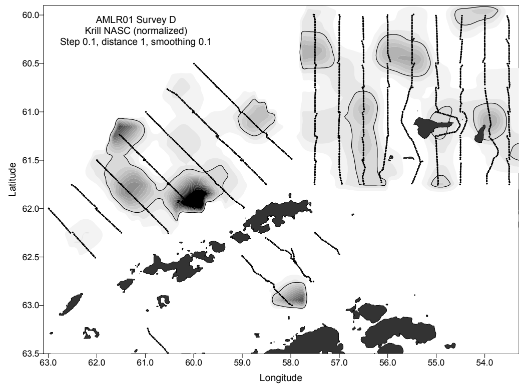
Figure 7: Relative densities of krill in Subarea 48.1 obtained from eight acoustic surveys by the US AMLR Program between 1998 and 2002. Thick lines indicate survey transects. Thin lines denote areas of relative high concentrations of krill. Parameters show the values used in 'Tracks and Fields' for smoothing and normalising the data.

Figure 7 continued

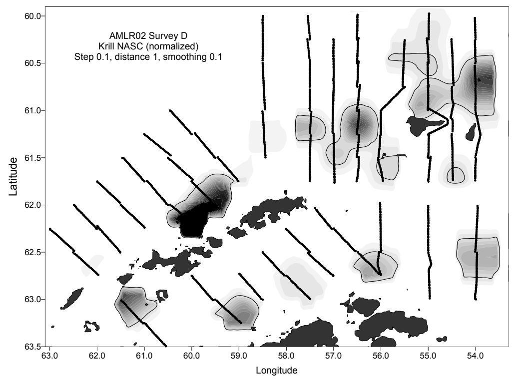
2001 January



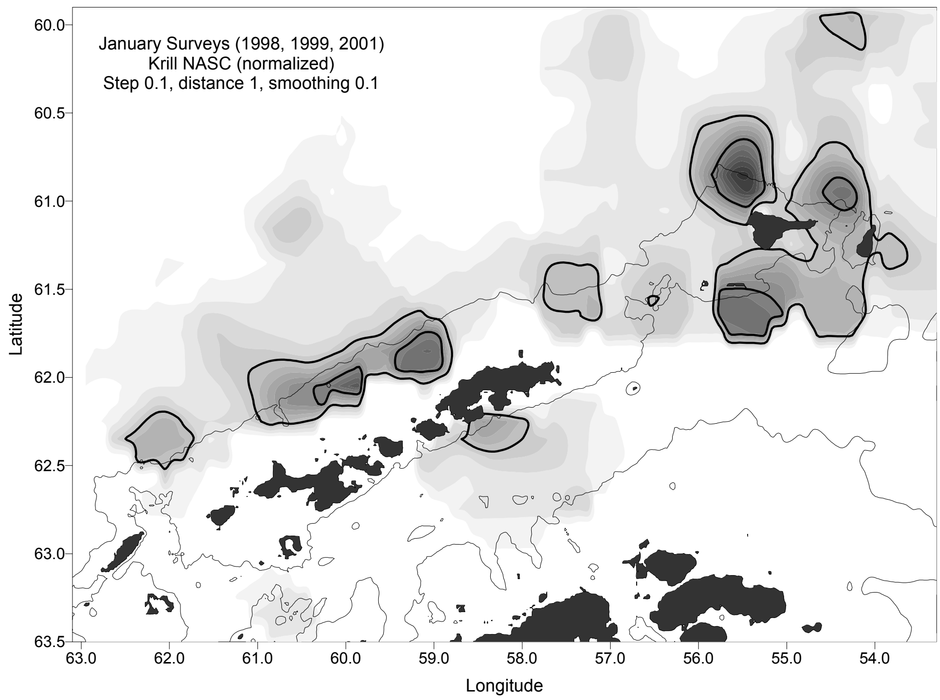
2001 February/March



2002 February/March



January (1998, 1999, 2001)



February–March (1998–2002)

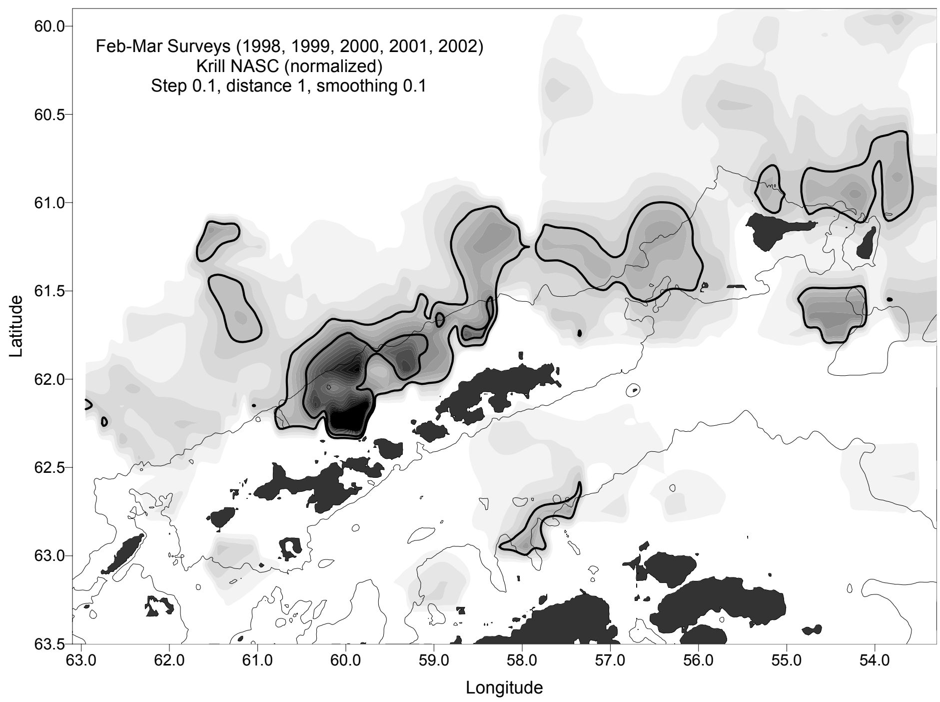


Figure 8: Relative densities of krill in Subarea 48.1 averaged over surveys by the US AMLR Program undertaken at the same time each year from 1998 to 2002. Thin lines indicate the 500 m isobath. Thick lines denote areas of relative high concentrations of krill. Parameters show the values used in 'Tracks and Fields' for smoothing and normalising the data.

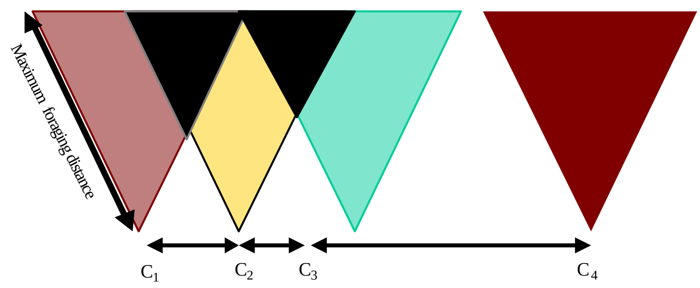
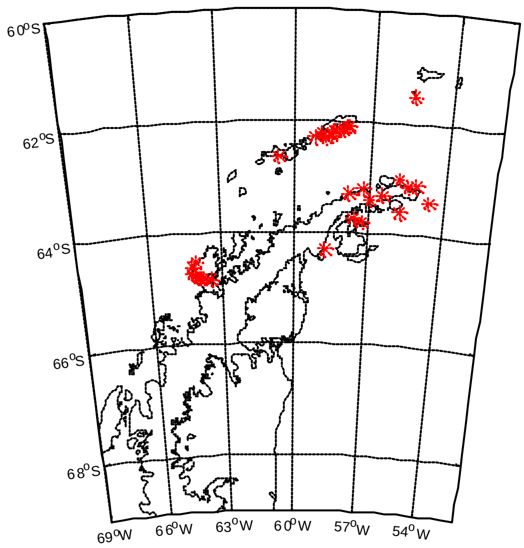


Figure 9: Colonies were considered to have a functional overlap where the distance between colonies was less than the maximum foraging distance. In this example, colonies C_1, C_2 and C_3 have a functional overlap.



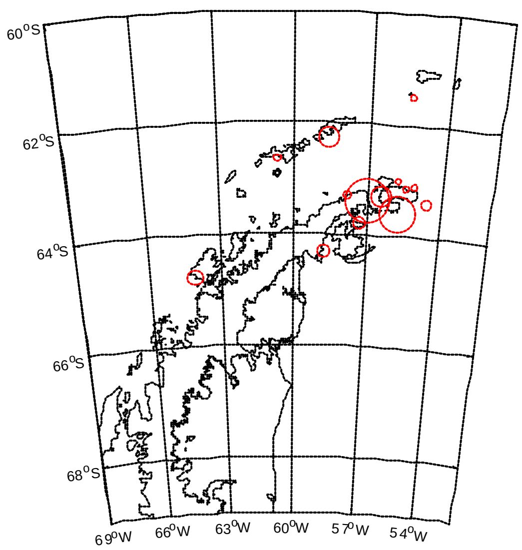


Figure 10: Adélie penguins in Subarea 48.1 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

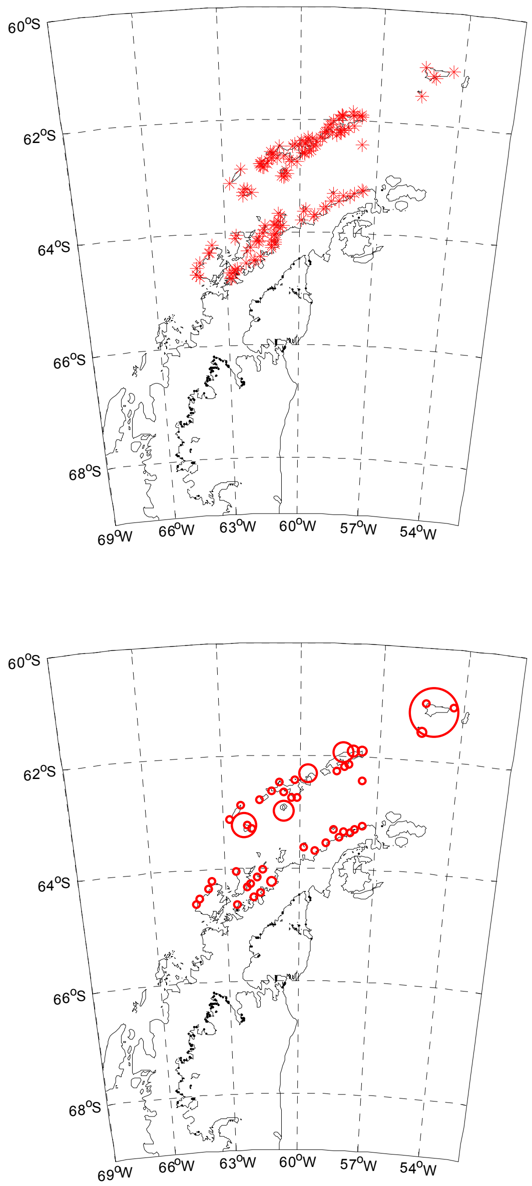


Figure 11: Chinstrap penguins in Subarea 48.1 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

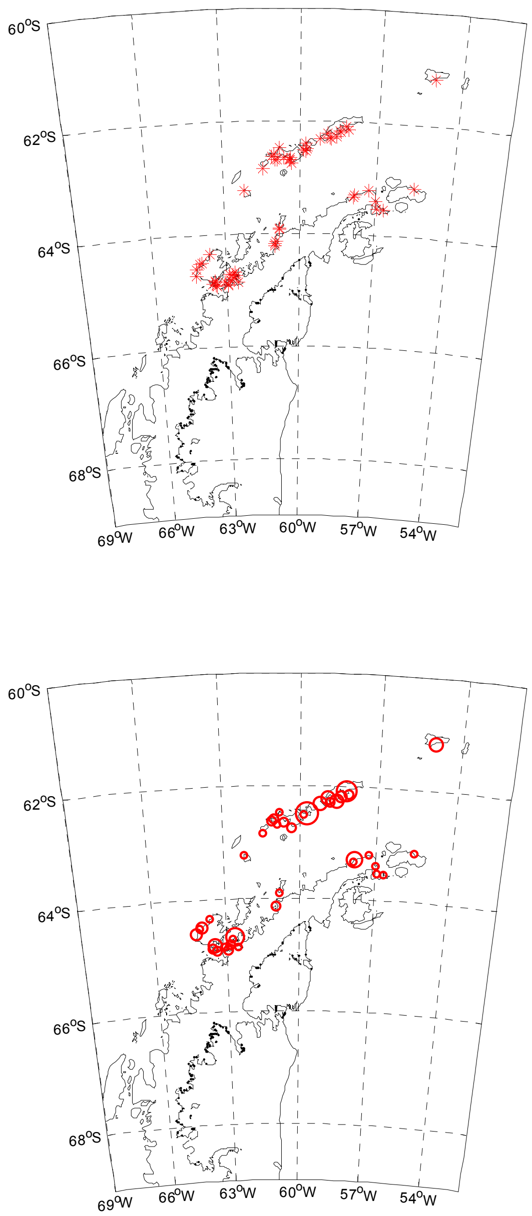
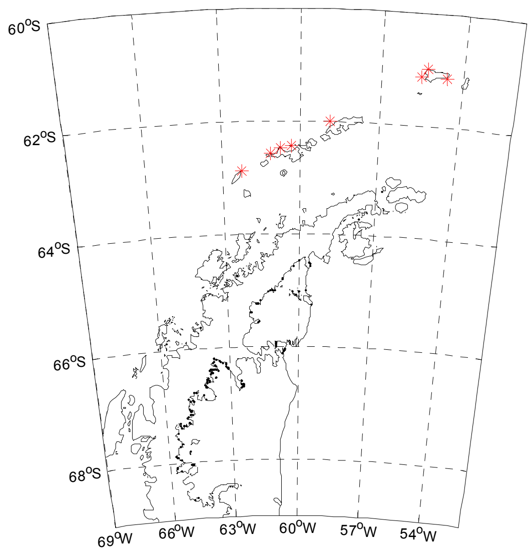


Figure 12: Gentoo penguins in Subarea 48.1 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).



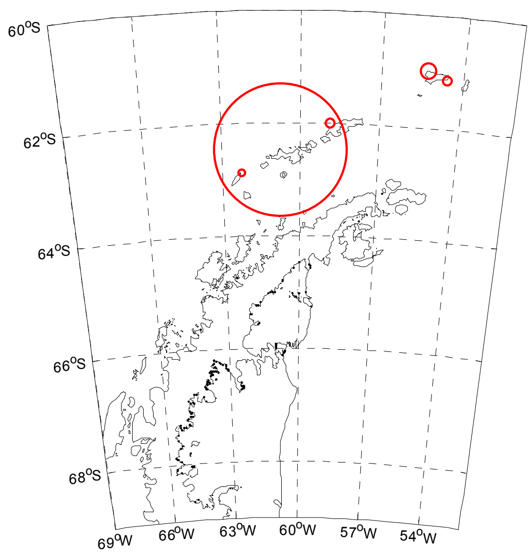


Figure 13: Antarctic fur seals in Subarea 48.1 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

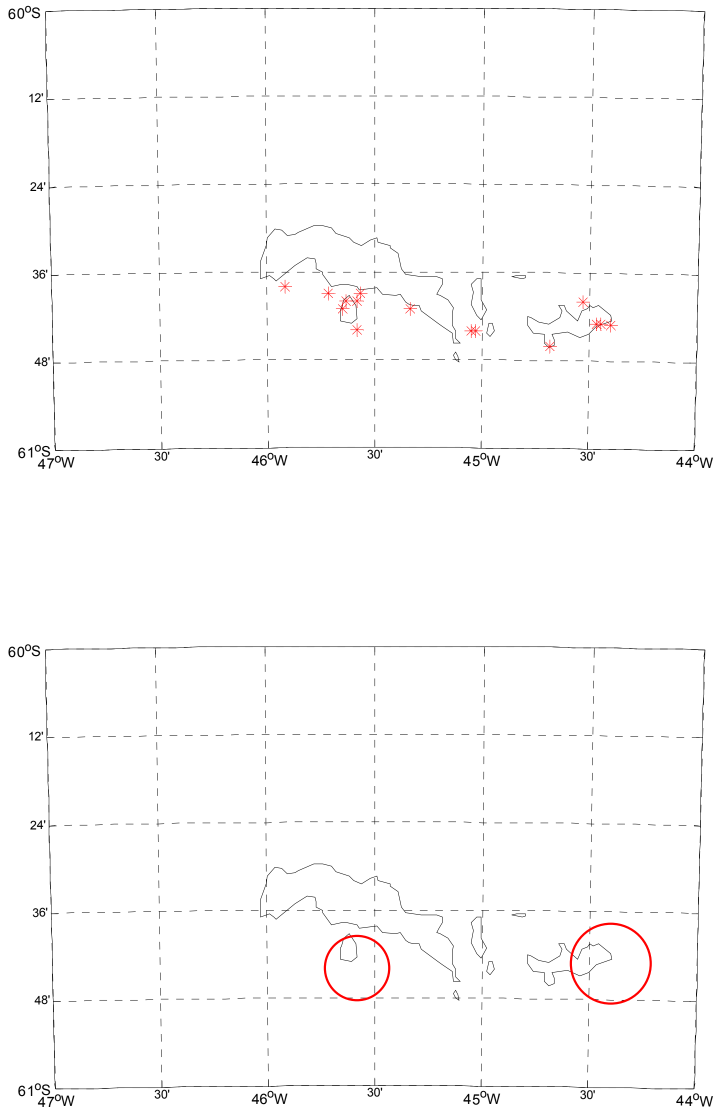


Figure 14: Adélie penguins in Subarea 48.2 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

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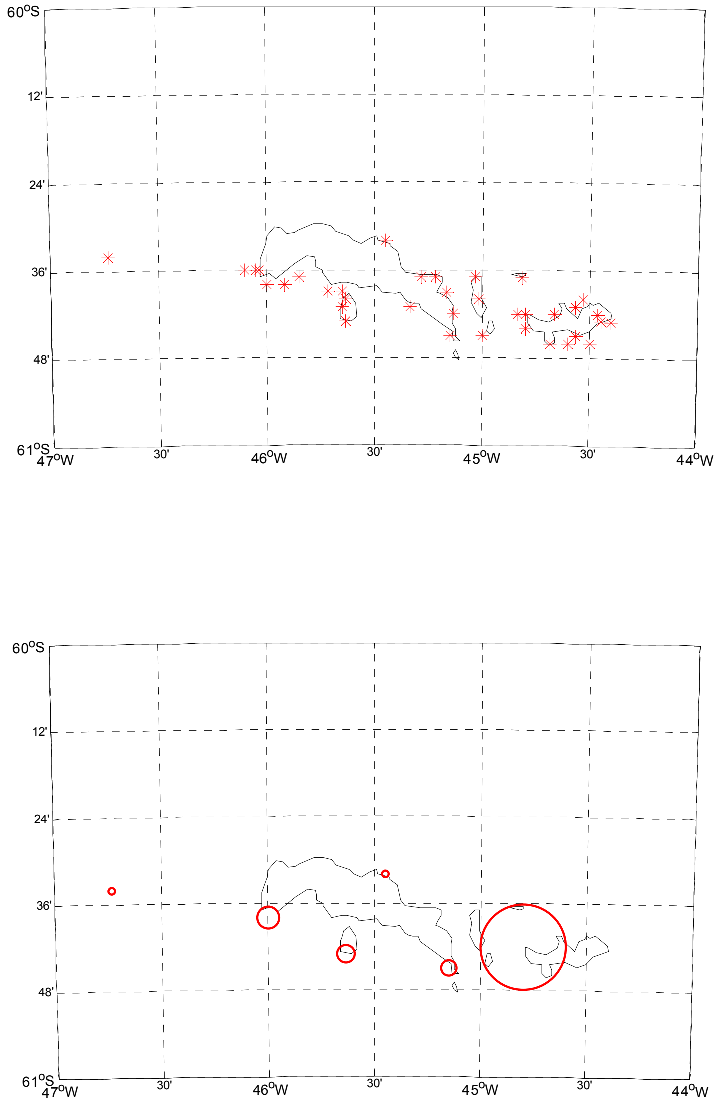


Figure 15: Chinstrap penguins in Subarea 48.2 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

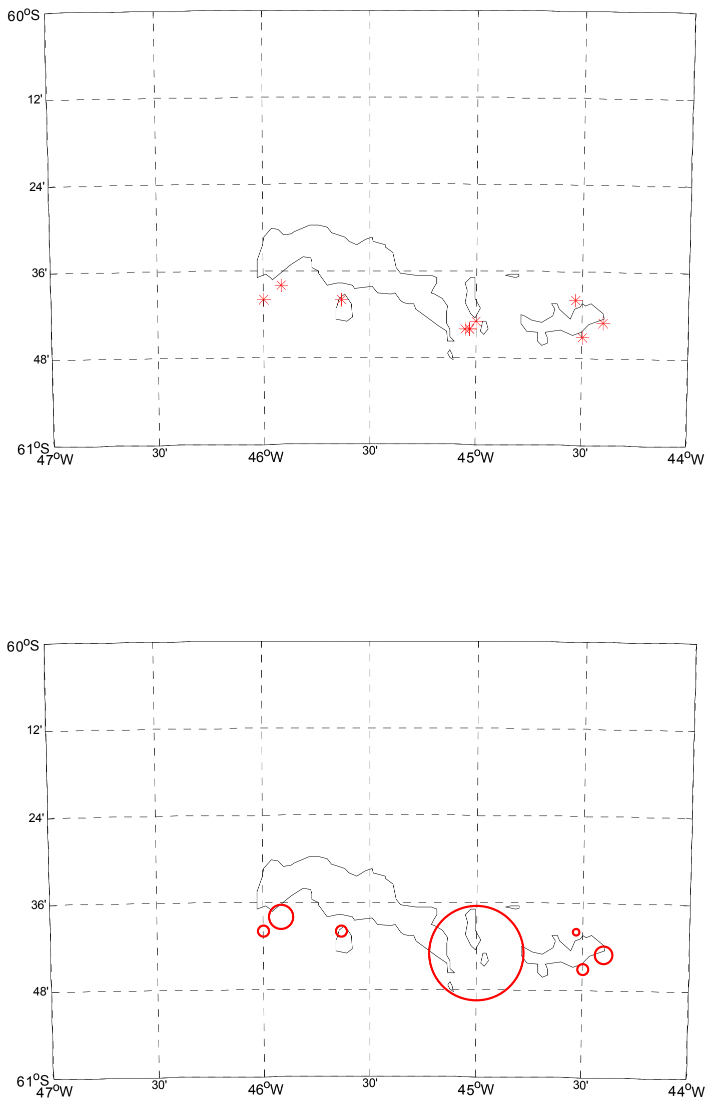


Figure 16: Gentoo penguins in Subarea 48.2 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

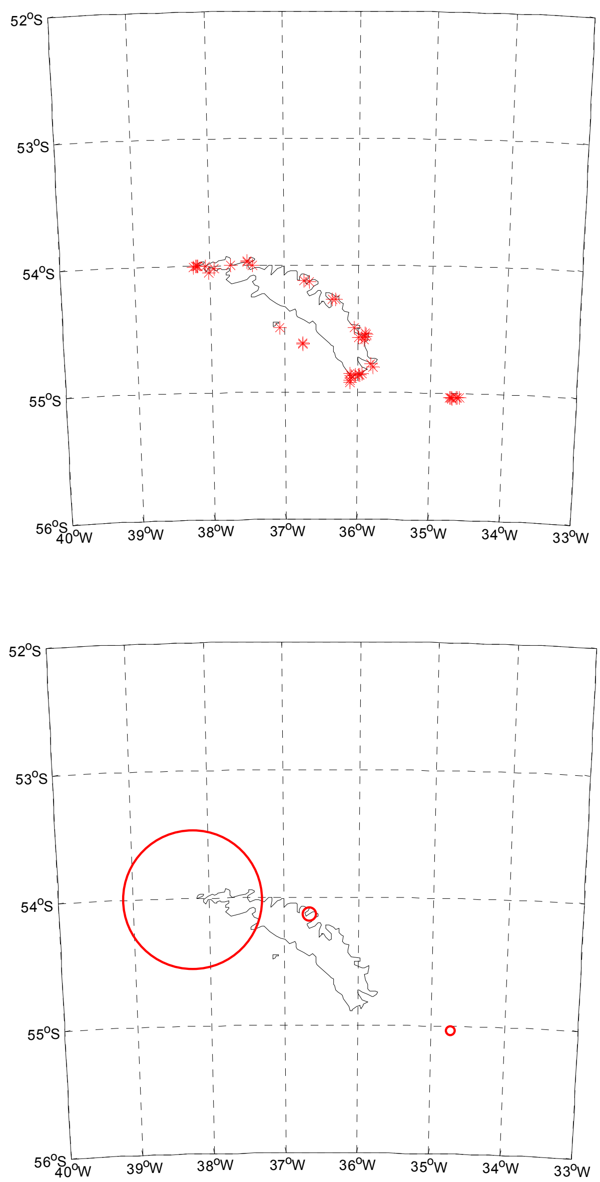


Figure 17: Macaroni penguins in Subarea 48.3 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

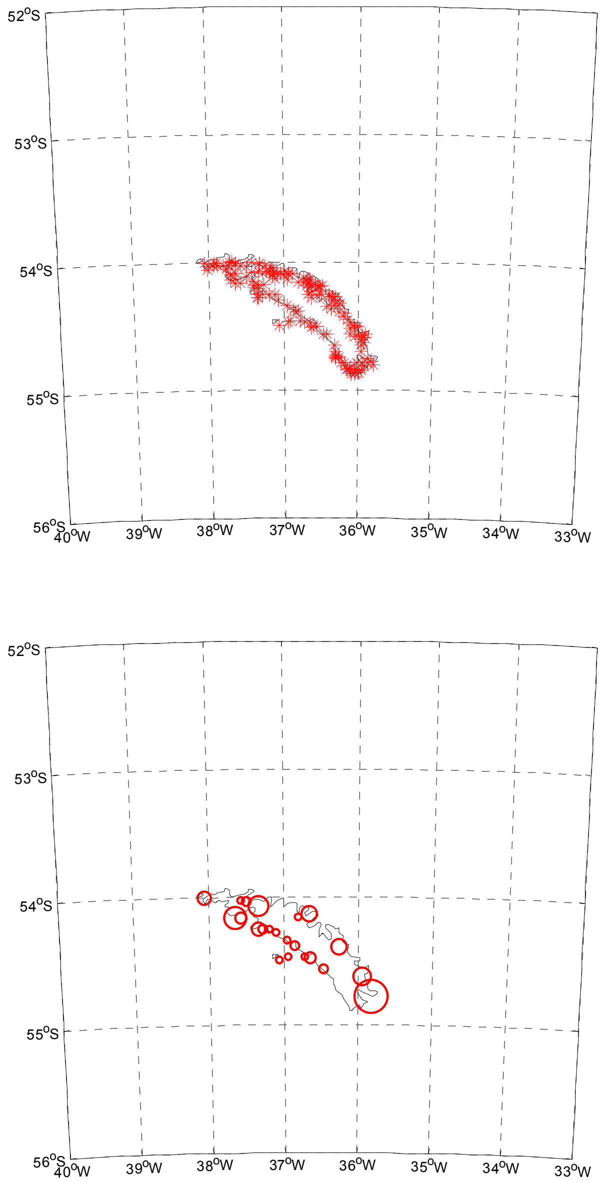


Figure 18: Gentoo penguins in Subarea 48.3 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

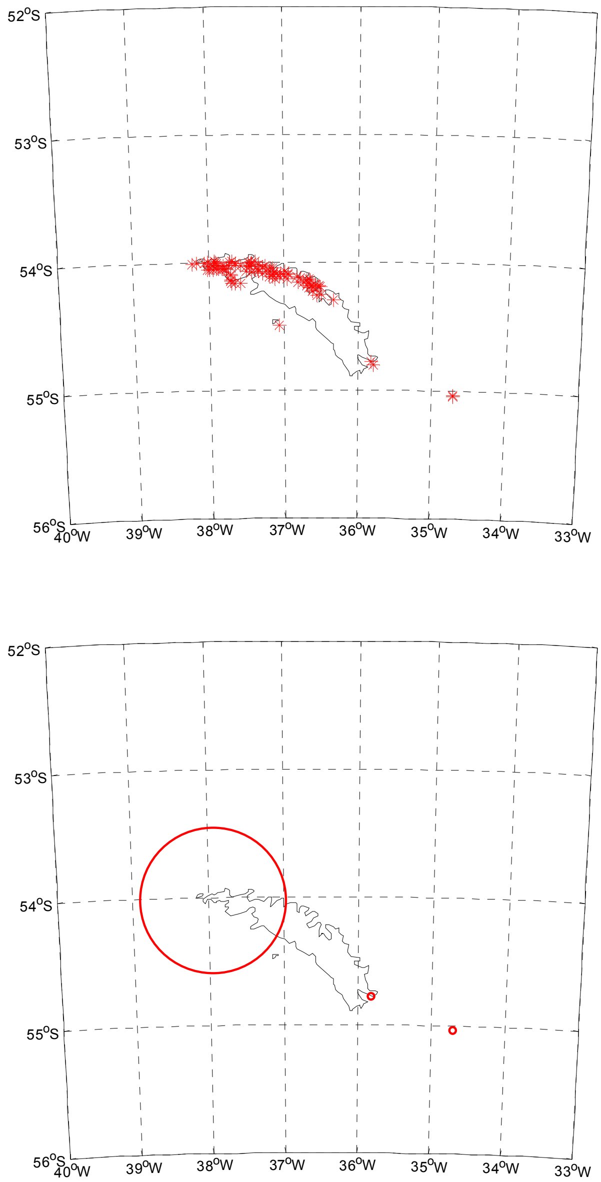


Figure 19: Antarctic fur seals in Subarea 48.3 – distribution of colonies and centres of biomass (stars indicate colony locations, size of circles indicates relative biomass).

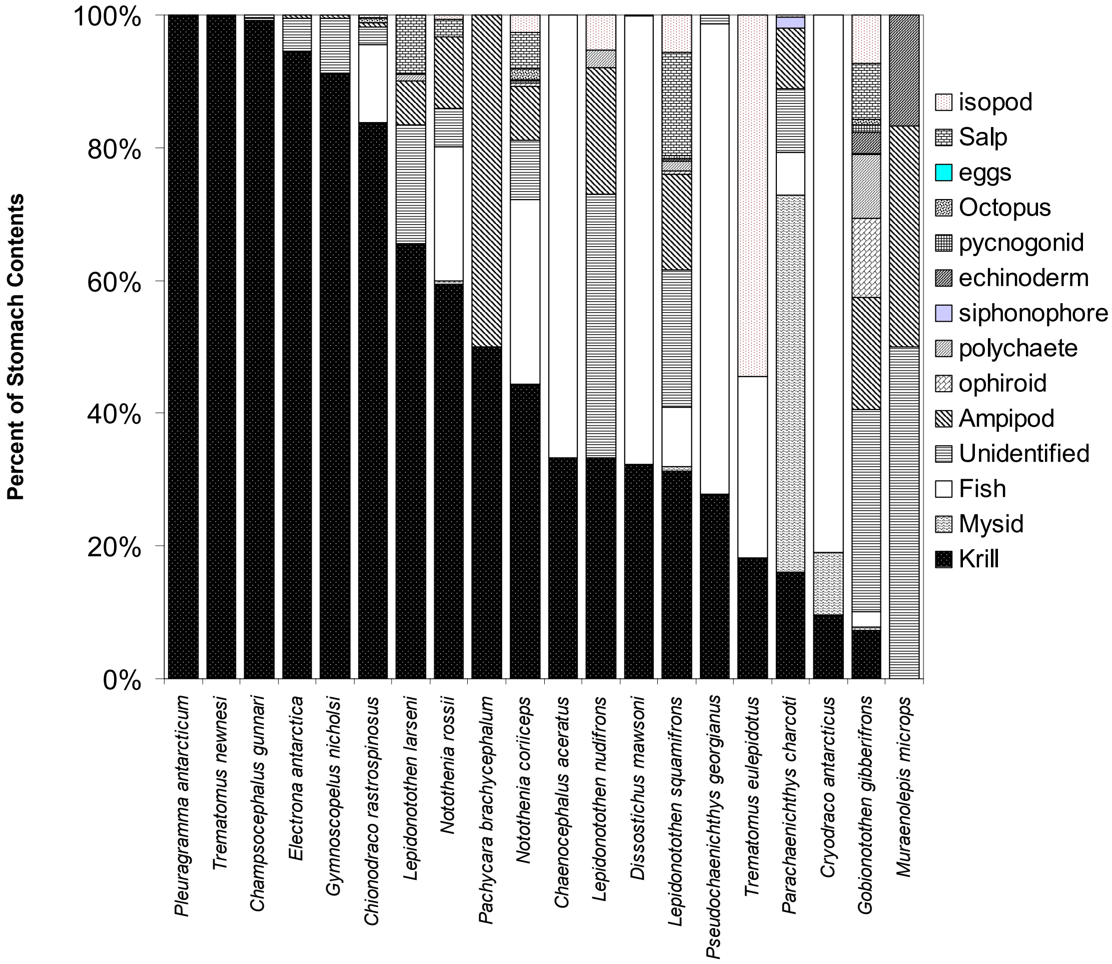
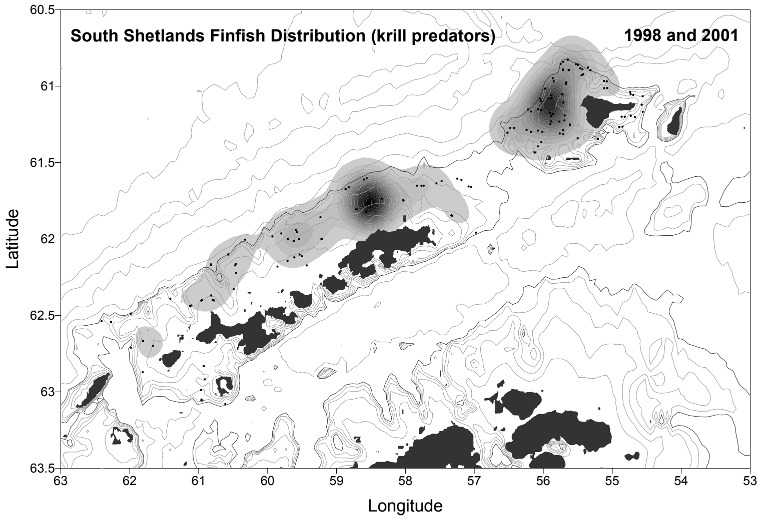
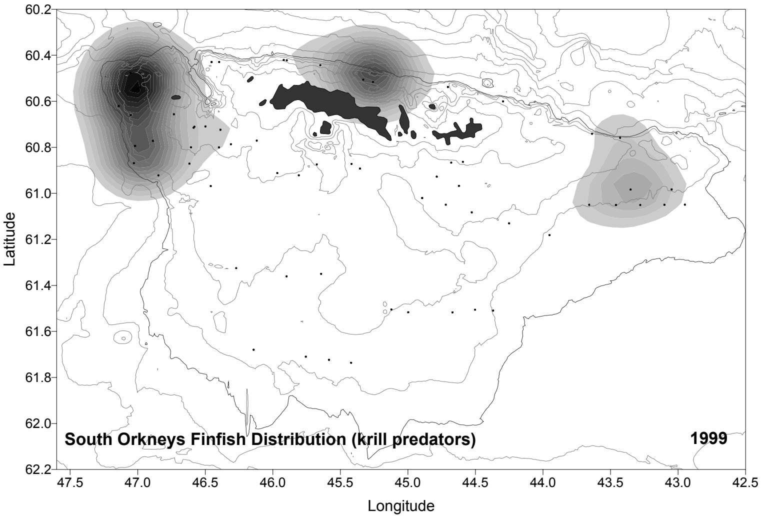


Figure 20: Summary of diet composition of 20 species of finfish, based on mean stomach content scores, from US AMLR finfish bottom trawl surveys conducted in the South Shetland Islands in 2001 (C. Jones, unpublished data).

(a)



(b)



(c)

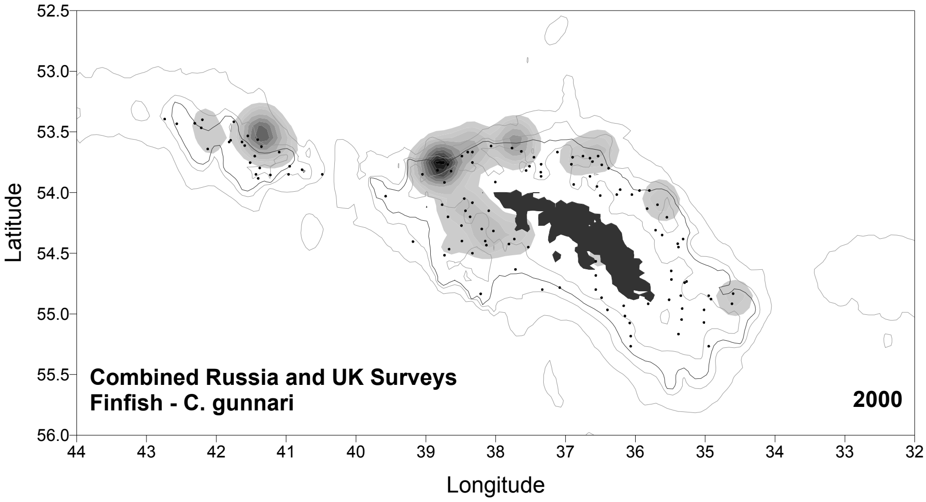


Figure 21: Spatial distribution of normalised krill-eating finfish around (a) South Shetland Islands (C. Jones, unpublished data), (b) the South Orkney Islands (C. Jones, unpublished data), and (c) South Georgia (CCAMLR database). Solid bathymetric line is the 500 m contour.

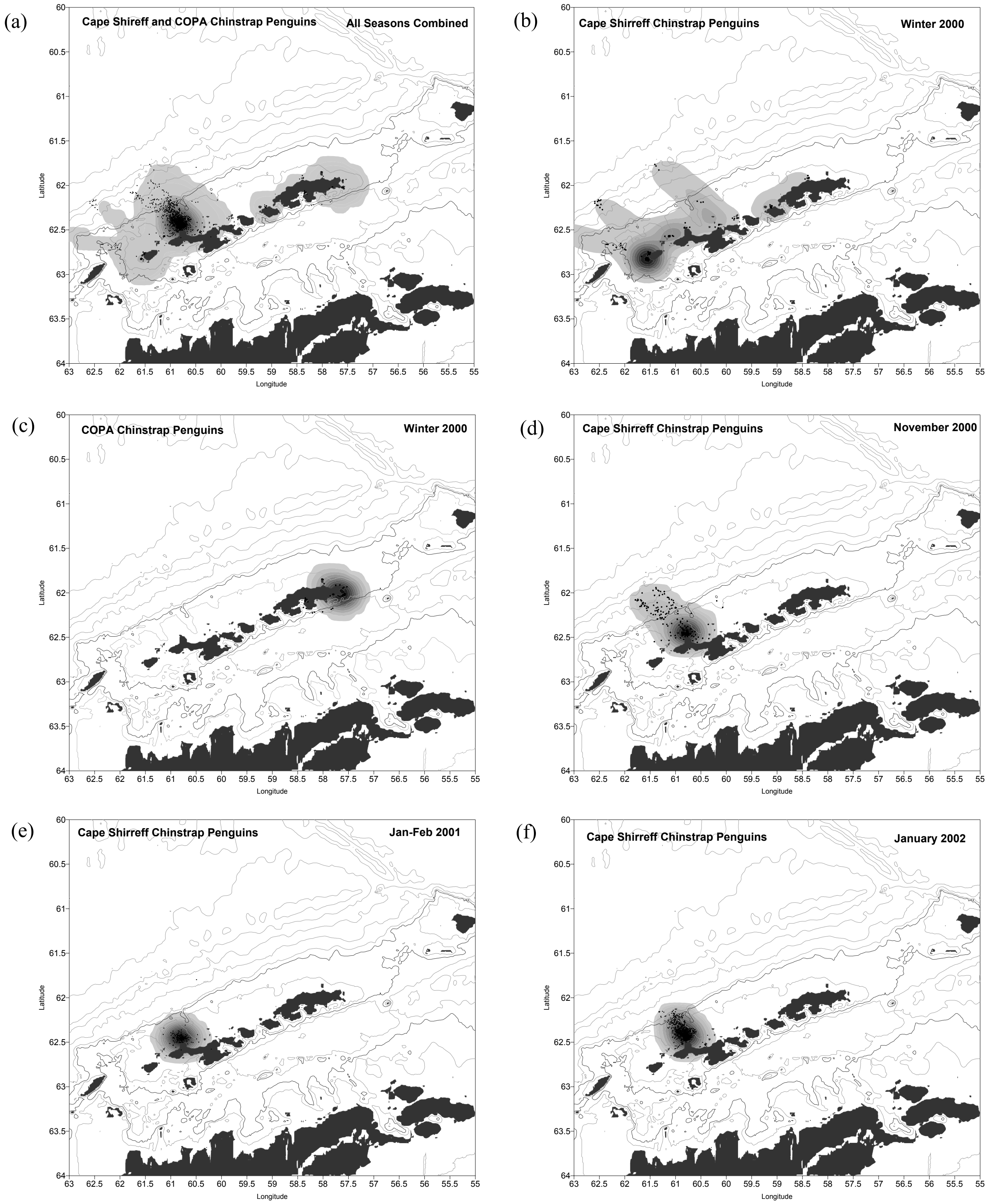


Figure 22: Foraging locations of chinstrap penguins in the South Shetland Islands (W. Trivelpiece, unpublished data): (a) Composite foraging distribution of penguins monitored at Cape Shirreff and Copa over the breeding and winter seasons from 2000 to 2002, (b) winter distribution (February to May 2000) of penguins tagged at Cape Shirreff, (c) winter foraging distribution of penguins from the Copa colony on King George Island from February to May 2000, (d) foraging distribution of penguins from Cape Shirreff during the incubation period in November 2000, (e) foraging distribution of penguins from Cape Shirreff during the chick-rearing stage in 2001, and (f) as for (e) but in 2002. Solid bathymetric line is the 500 m contour.

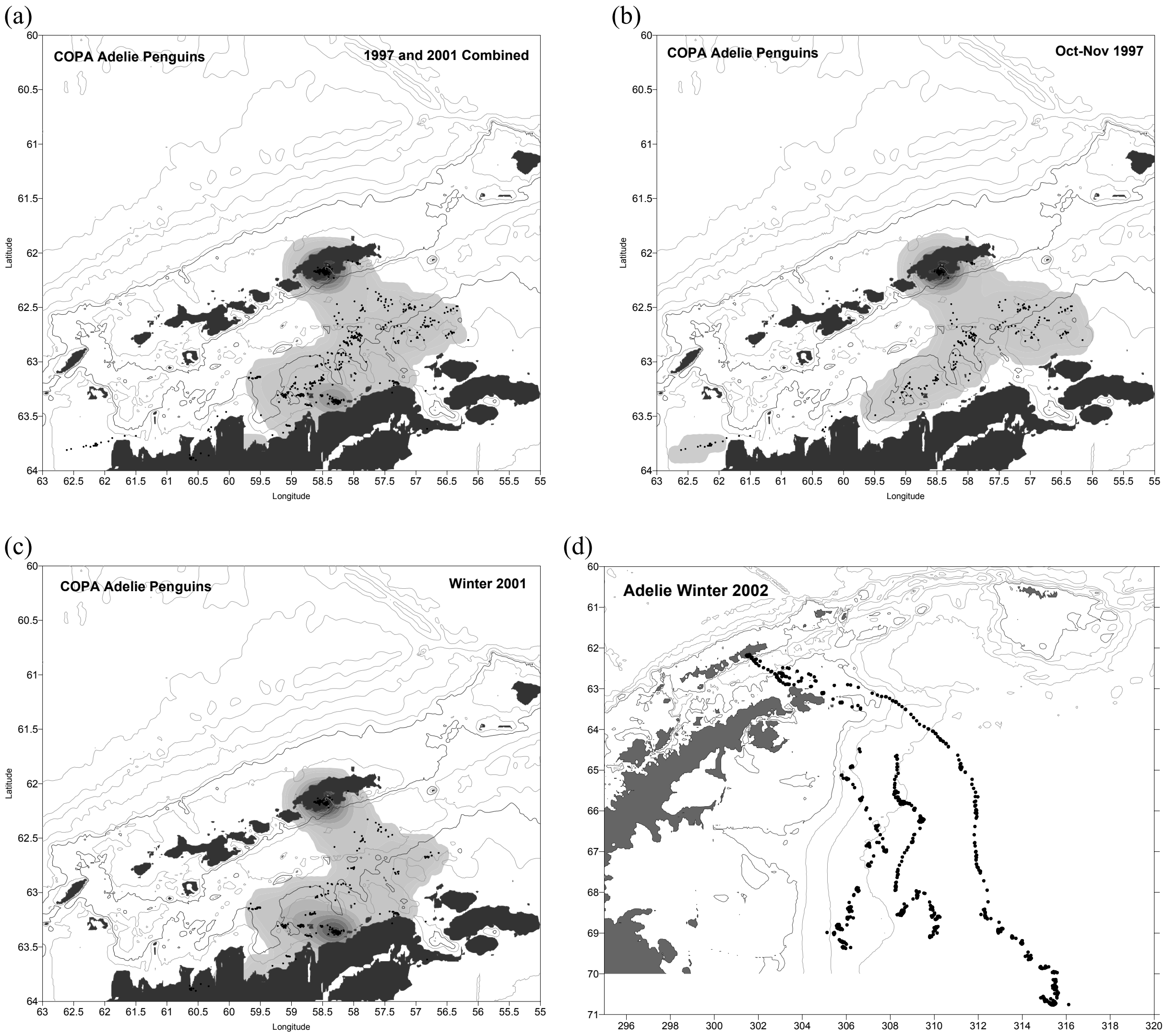


Figure 23: Foraging locations of Adélie penguins in the South Shetland Islands (W. Trivelpiece, unpublished data): (a) Combined winter and incubation period data for penguins at the Copa colony, King George Island, (b) foraging distributions of Adélie penguins from the Copa colony following clutch completion in November 1997, (c) early winter foraging distributions of penguins tagged at the Copa colony in 2001, (d) as for (c) but in 2002. Solid bathymetric line is the 500 m contour.

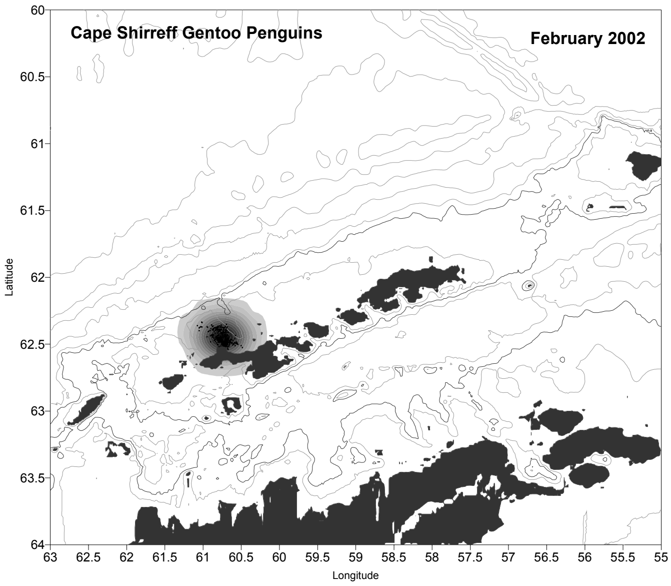


Figure 24: Foraging distribution of gentoo penguins in the South Shetland Islands during the chick-rearing period in 2002. Solid bathymetric line is the 500 m contour (W. Trivelpiece, unpublished data).

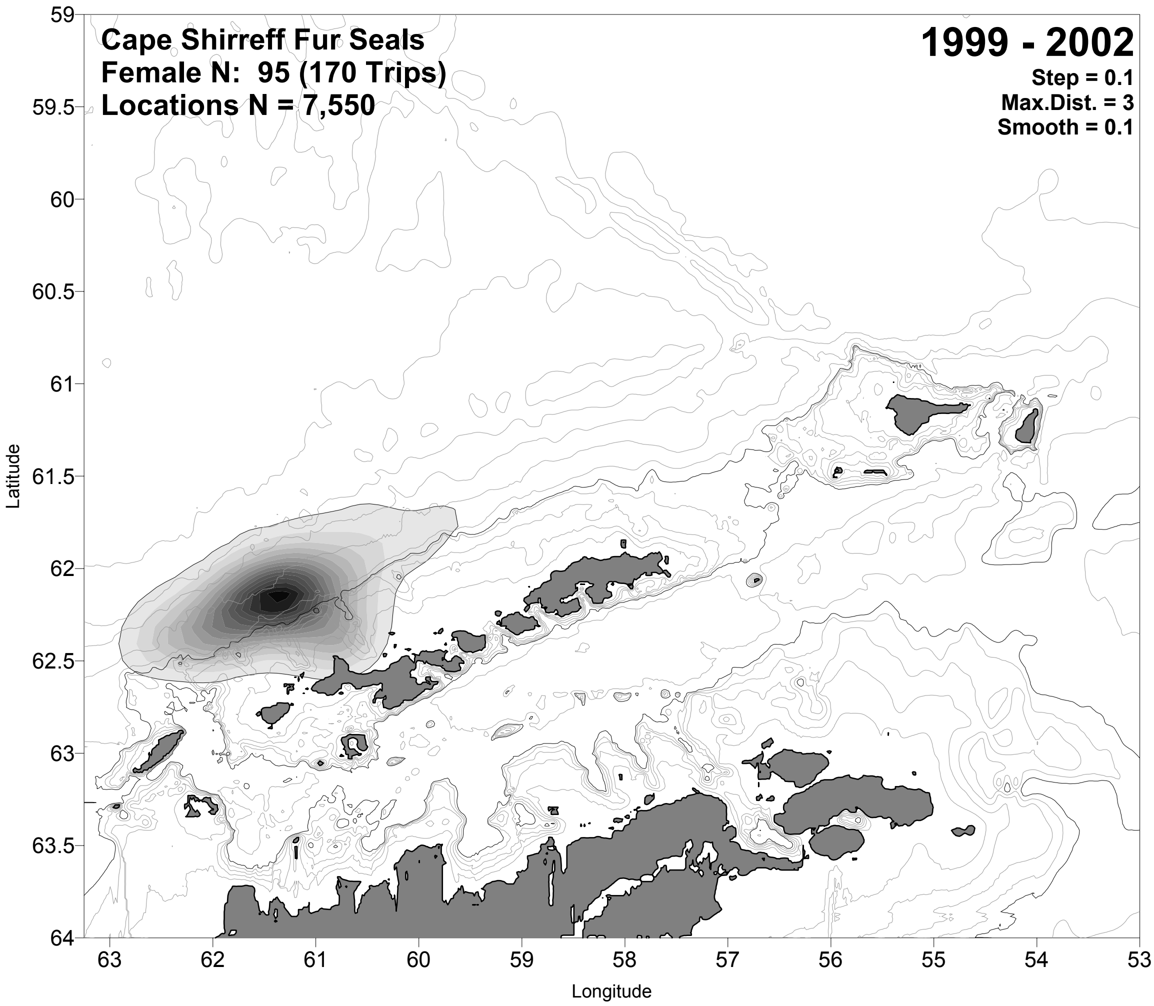


Figure 25: A shaded smoothed density plot for all at-sea locations of female Antarctic fur seals from 1999 to 2002 (N = 7 550 locations). The South Shetland Islands and the Antarctic Peninsula (lower right) are shaded dark grey. Isobaths are plotted for every 100 m up to 500 m and from every 1 000 m thereafter. The continental shelf break at 500 m is plotted with a heavier line. Fur seal locations were centred at the continental shelf slope and the highest densities of locations were found approximately 40 km northwest of Cape Shirreff. A line is drawn around the smoothed density plot at the 95 percentile.

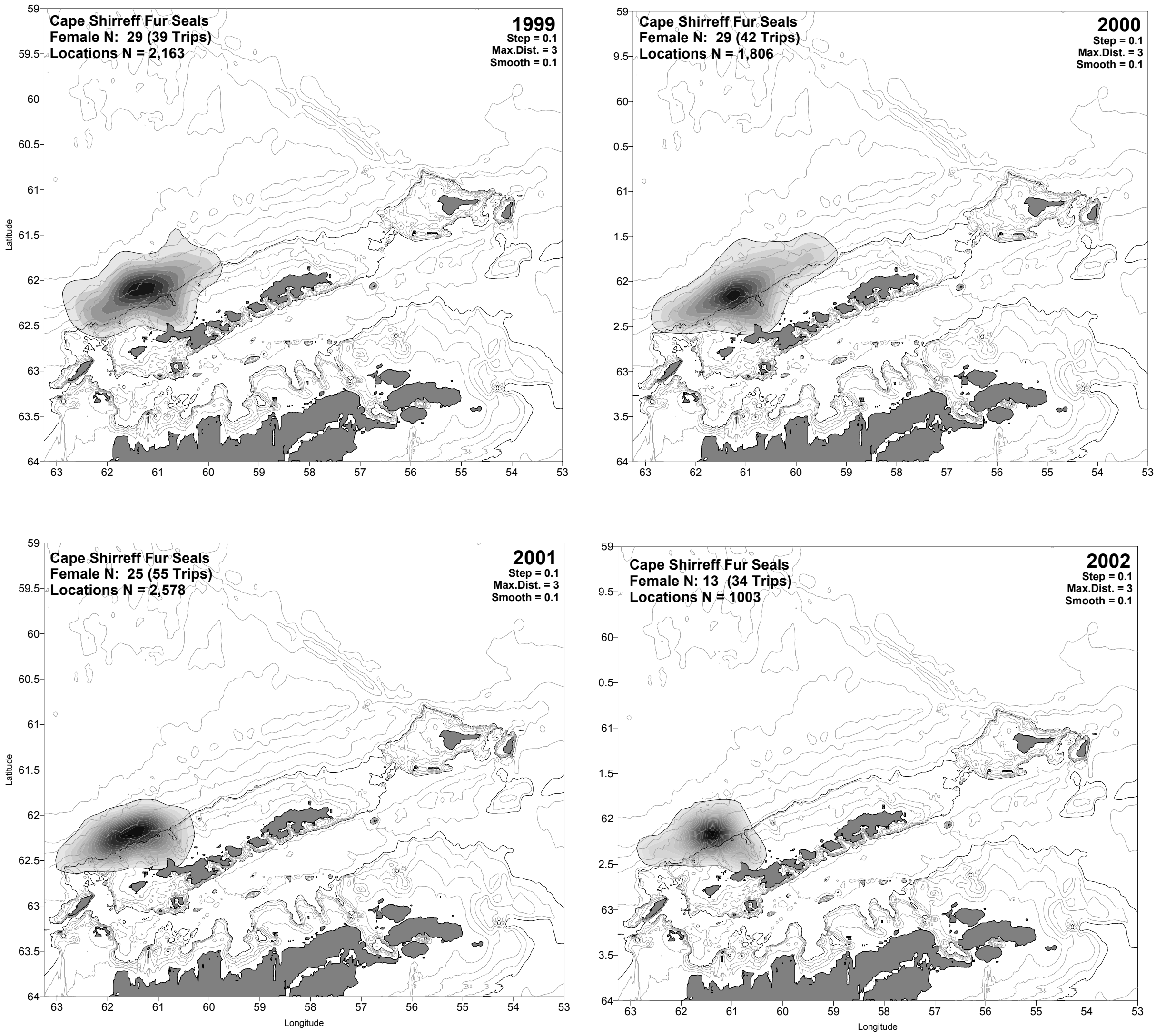
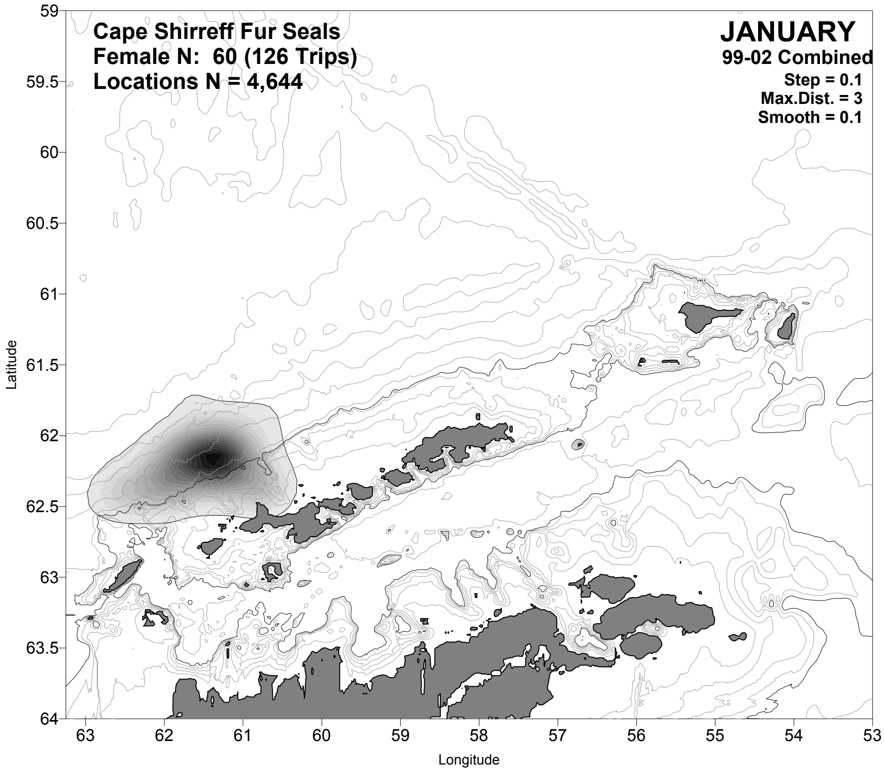


Figure 26: Shaded smoothed density plots of foraging areas as in Figure 25 for Antarctic fur seals tagged at Cape Shirreff in each year of the study. The year is identified at the top right in each plot. Although distributions and mean ranges varied by year, all four years had their highest densities of fur seal locations in the same general area (i.e. the continental shelf slope area) ~40 km northwest of Cape Shirreff.



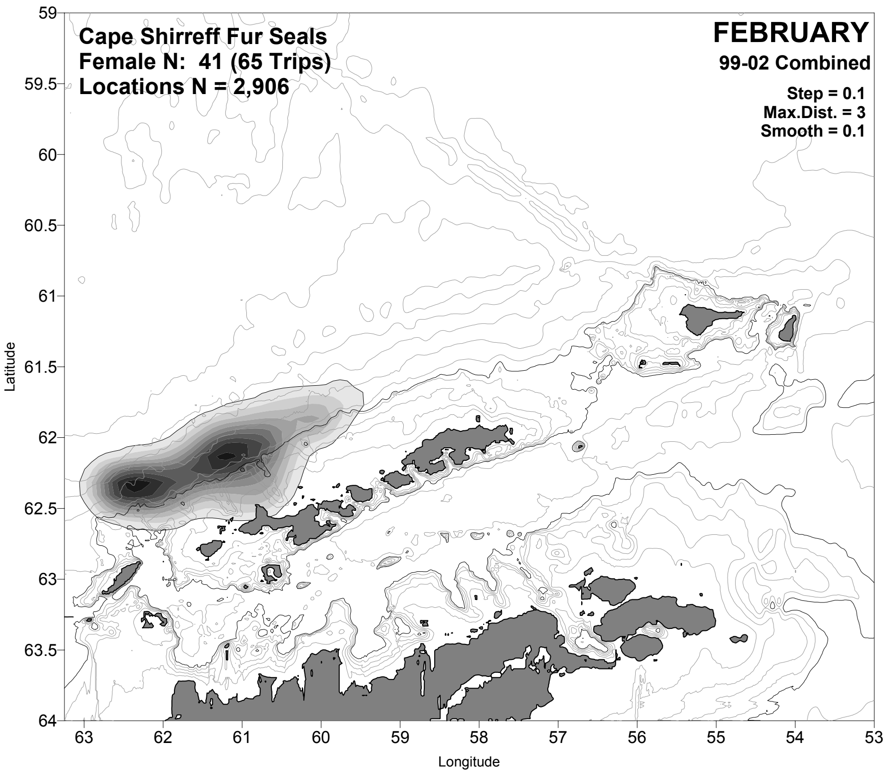


Figure 27: An intra-seasonal comparison of foraging fur seal locations at sea from seals tagged at Cape Shirreff, Livingston Island. All years (1999–2002) are combined; data for each year are normalised. The month is identified at the top right in each plot. The distribution of locations in February was broader than in January, was bimodal and was on average further west. However in both months the highest densities of fur seal locations were centred over the continental shelf slope area.

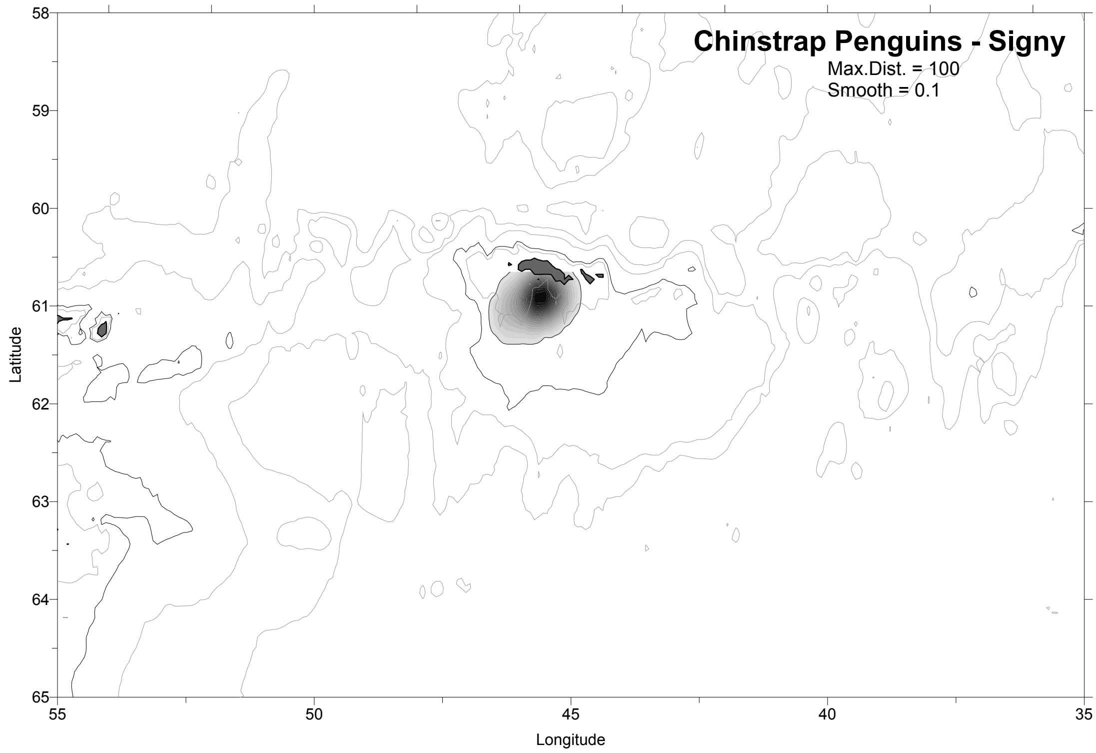


Figure 28: Average summer foraging distribution of chinstrap penguins tagged at Signy Island between 2000 and 2001 (see Table 6). The solid bathymetric line is the 500 m contour. A line is drawn around the smoothed density plot at the 95 percentile.

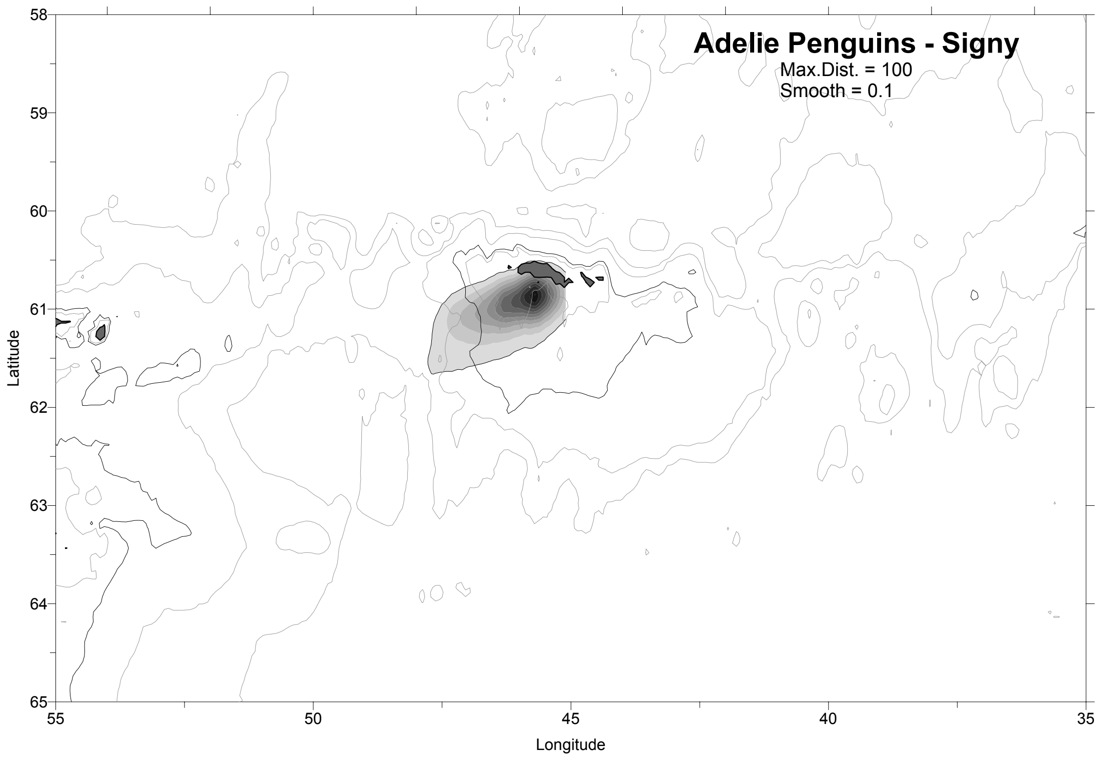


Figure 29: Average summer foraging distribution of Adélie penguins tagged at Signy Island between 2000 and 2001 (see Table 5). The solid bathymetric line is the 500 m contour. A line is drawn around the smoothed density plot at the 95 percentile.

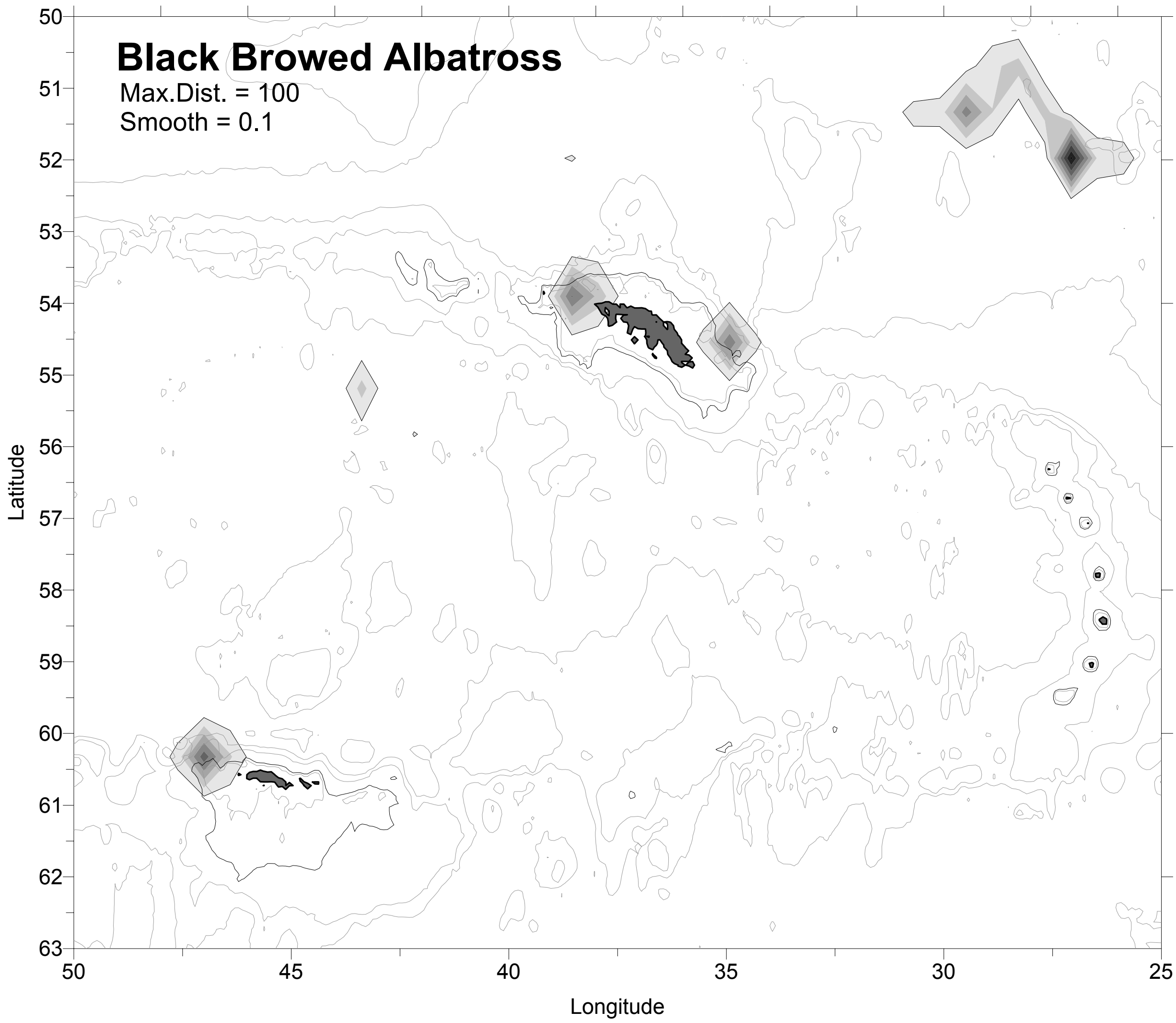


Figure 30: Average summer foraging distribution of black-browed albatrosses tagged at Bird Island during the breeding season between 1992 and 1997 (see Table 8). The solid bathymetric line is the 500 m contour. A line is drawn around the smoothed density plot at the 95 percentile.

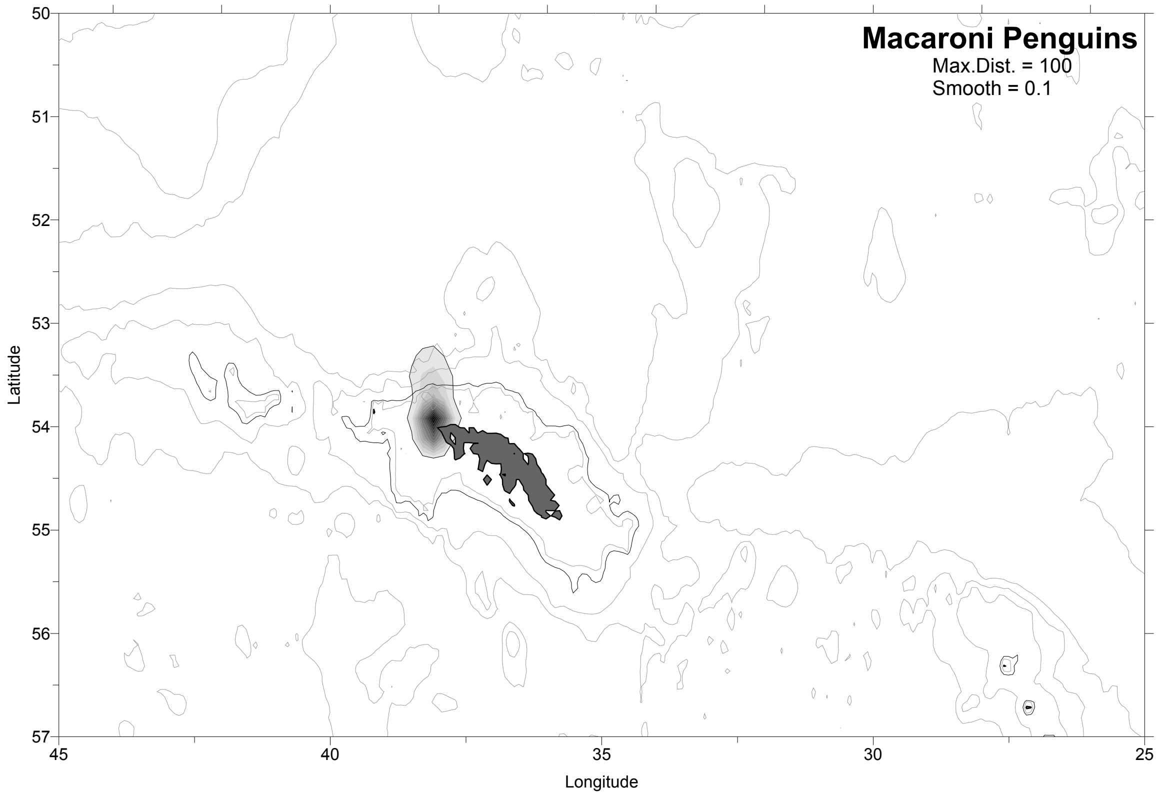


Figure 31: Average summer foraging distribution of macaroni penguins tagged at Bird Island between 1999 and 2001 (see Table 7). The solid bathymetric line is the 500 m contour.

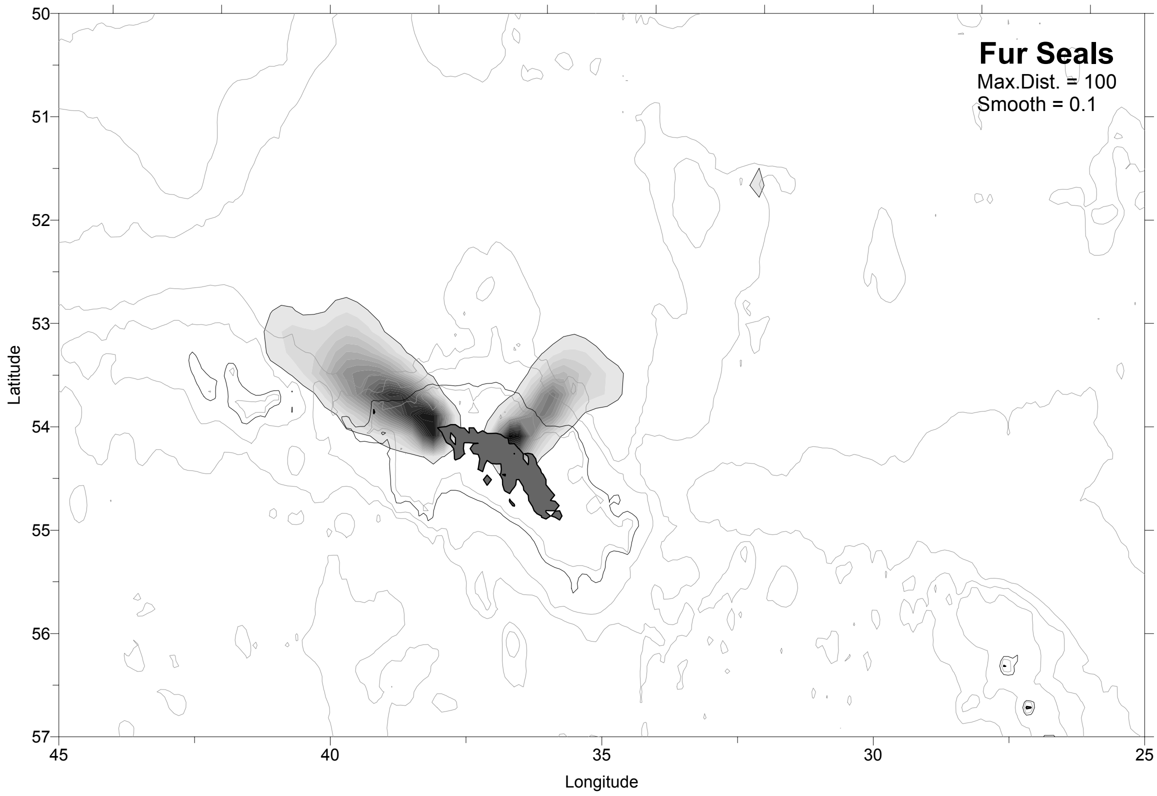
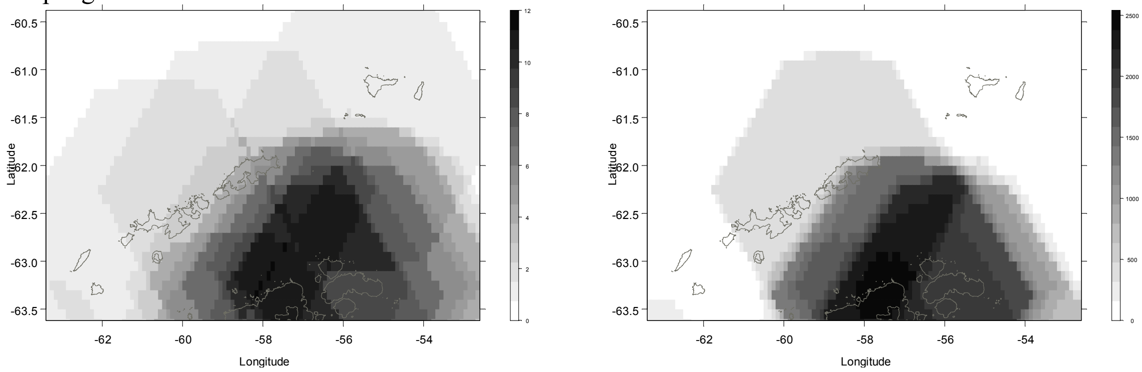


Figure 32: Average summer foraging distribution of Antarctic fur seals tagged at South Georgia between 1996 and 2001 (see Tables 4 and 9). The solid bathymetric line is the 500 m contour.

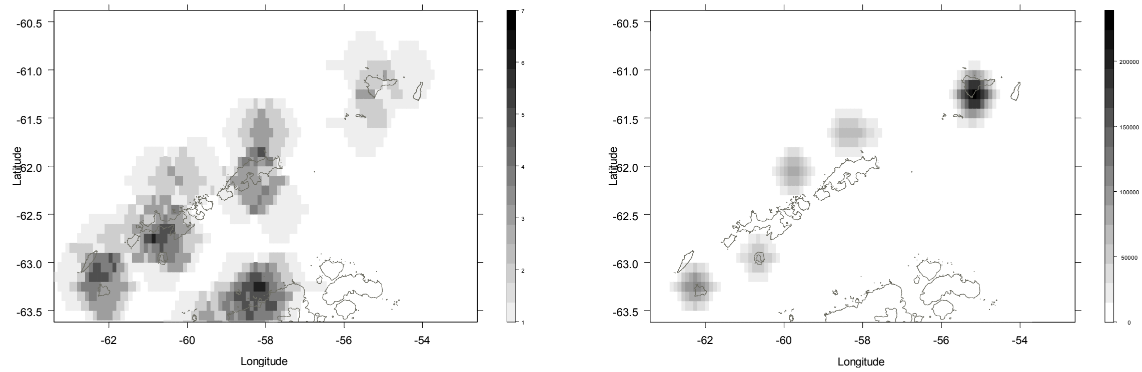
Overlap of foraging ranges (uniform weight across range)

Biomass-weighted foraging areas (each foraging range weighted by centre of biomass and foraging density within range)

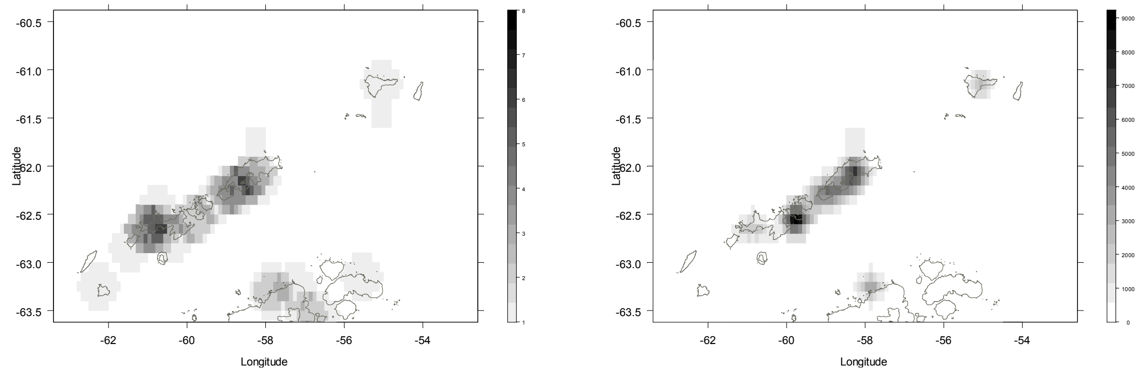
Adélie penguins



Chinstrap penguins



Gentoo penguins



All penguins combined

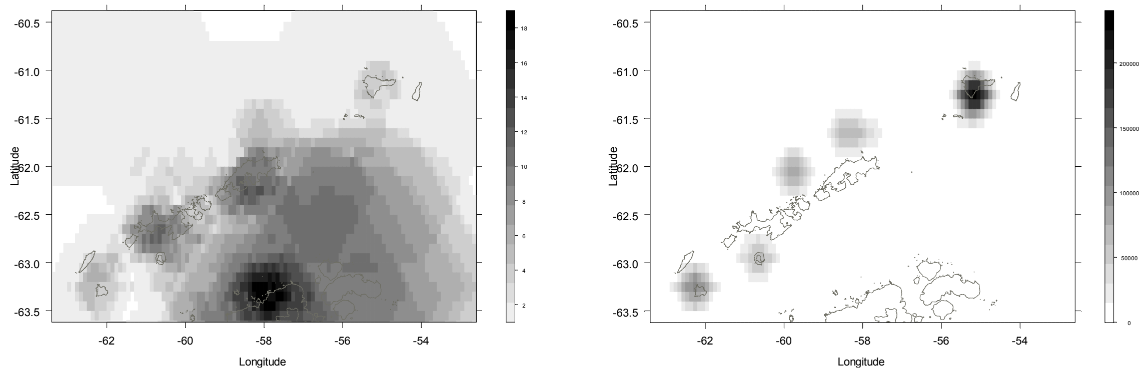


Figure 33: Extrapolated foraging areas for three land-based predator species in Subarea 48.1.

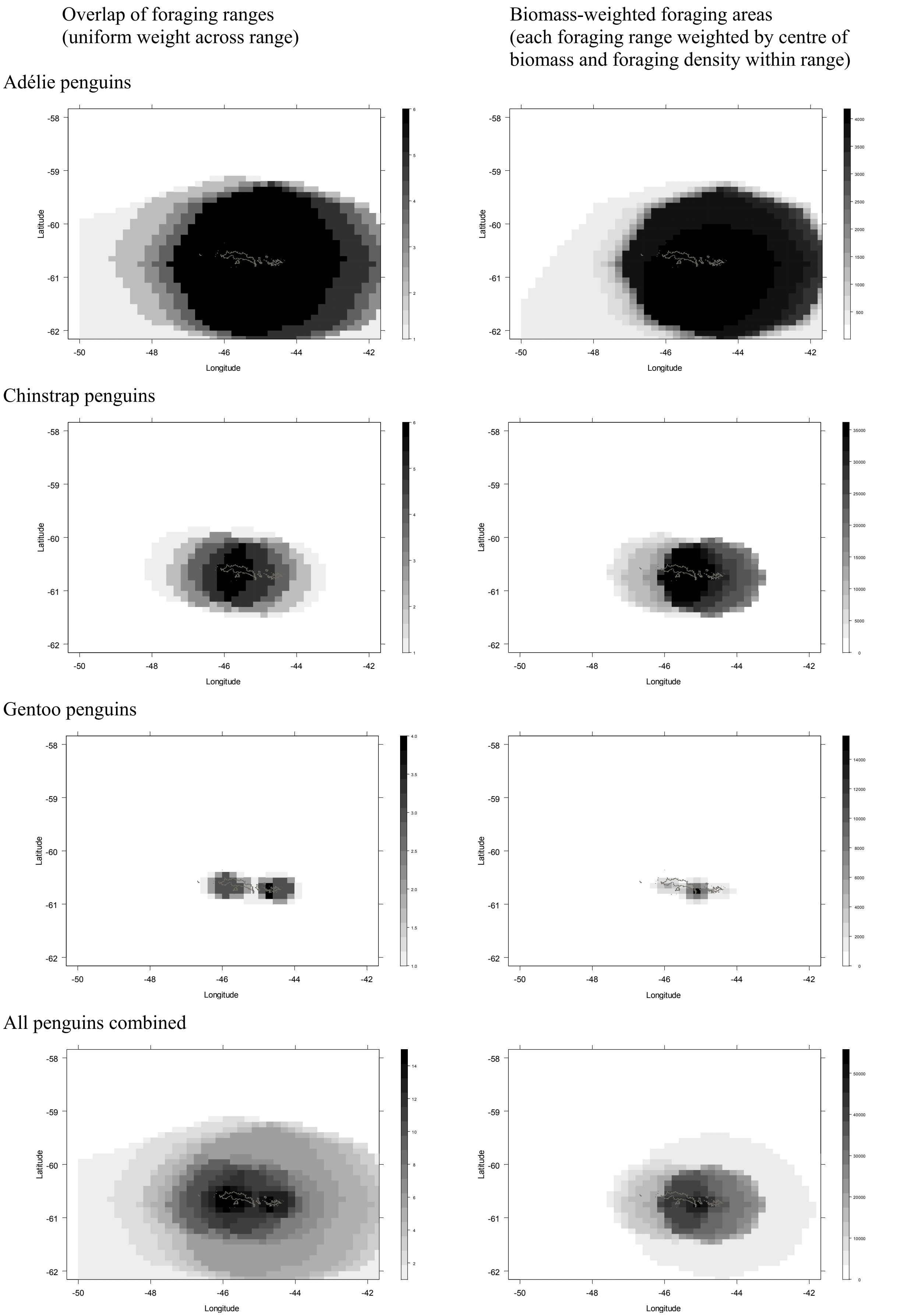


Figure 34: Extrapolated foraging areas for three land-based predator species in Subarea 48.2.

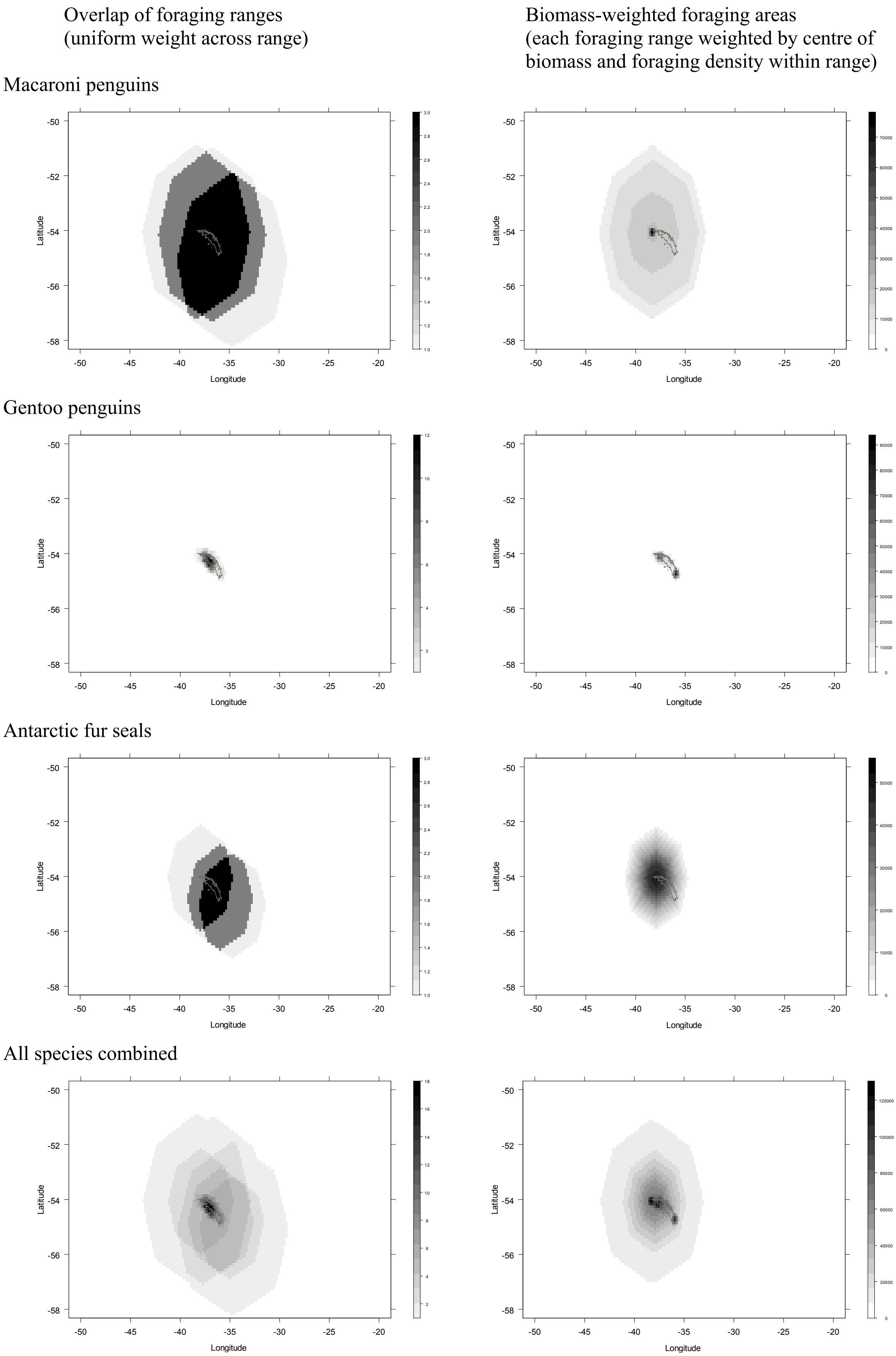


Figure 35: Extrapolated foraging areas for three land-based predator species in Subarea 48.3.

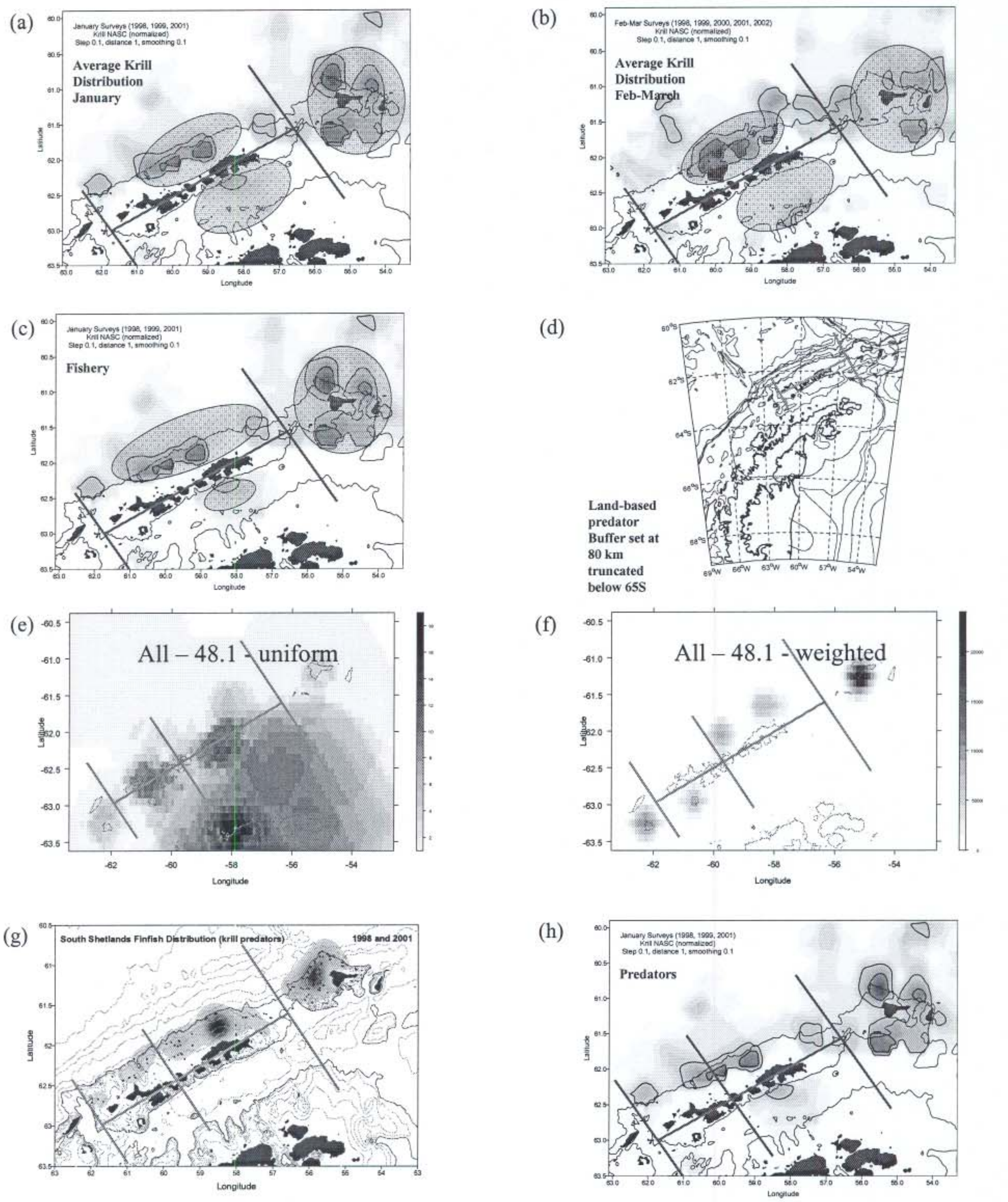


Figure 36: Subdivision of Subarea 48.1 based on: (a,b) krill aggregations (ovals show primary areas of aggregation), (c) the krill fishery (ovals show the primary locations of the krill fishery), (d) the maximum foraging distance and buffer for land-based predators around the land areas in Subarea 48.1, (e) the combined foraging ranges of land-based predators, (f) the aggregated foraging grounds of land-based predators (noting that known dominance of Cape Shirreff is not shown in this figure), (g) the aggregations of krill-eating finfish, and (h) the combined predator divisions and the krill distribution. Solid lines indicate divisions.

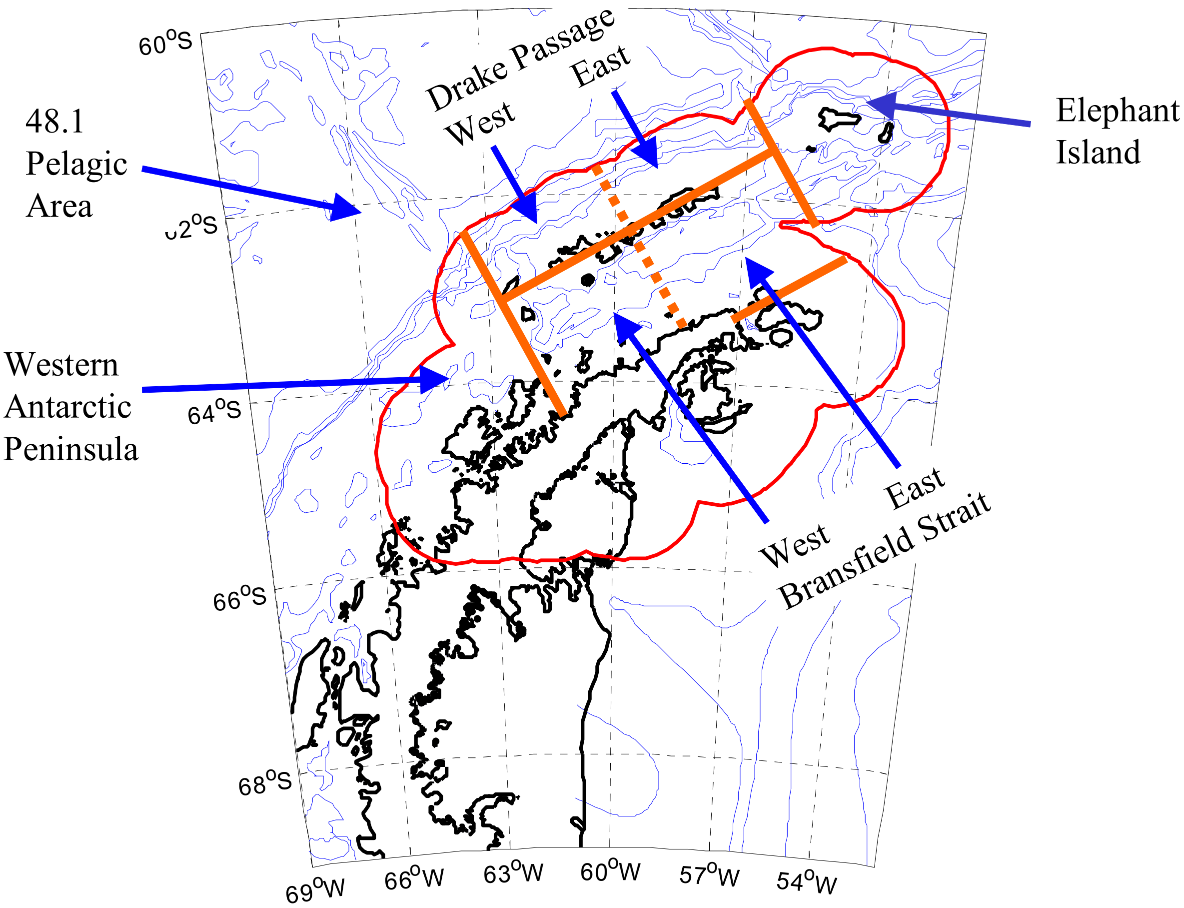


Figure 37: Proposed small-scale management units for Subarea 48.1. The subarea is divided between a pelagic area and the land-based predator area, with the latter area divided into four main units: Drake Passage, Elephant Island, Bransfield Strait and the Western Antarctic Peninsula. The Drake Passage and Bransfield Strait units are proposed to be divided into east and west components to delineate different foraging grounds of land-based predators.

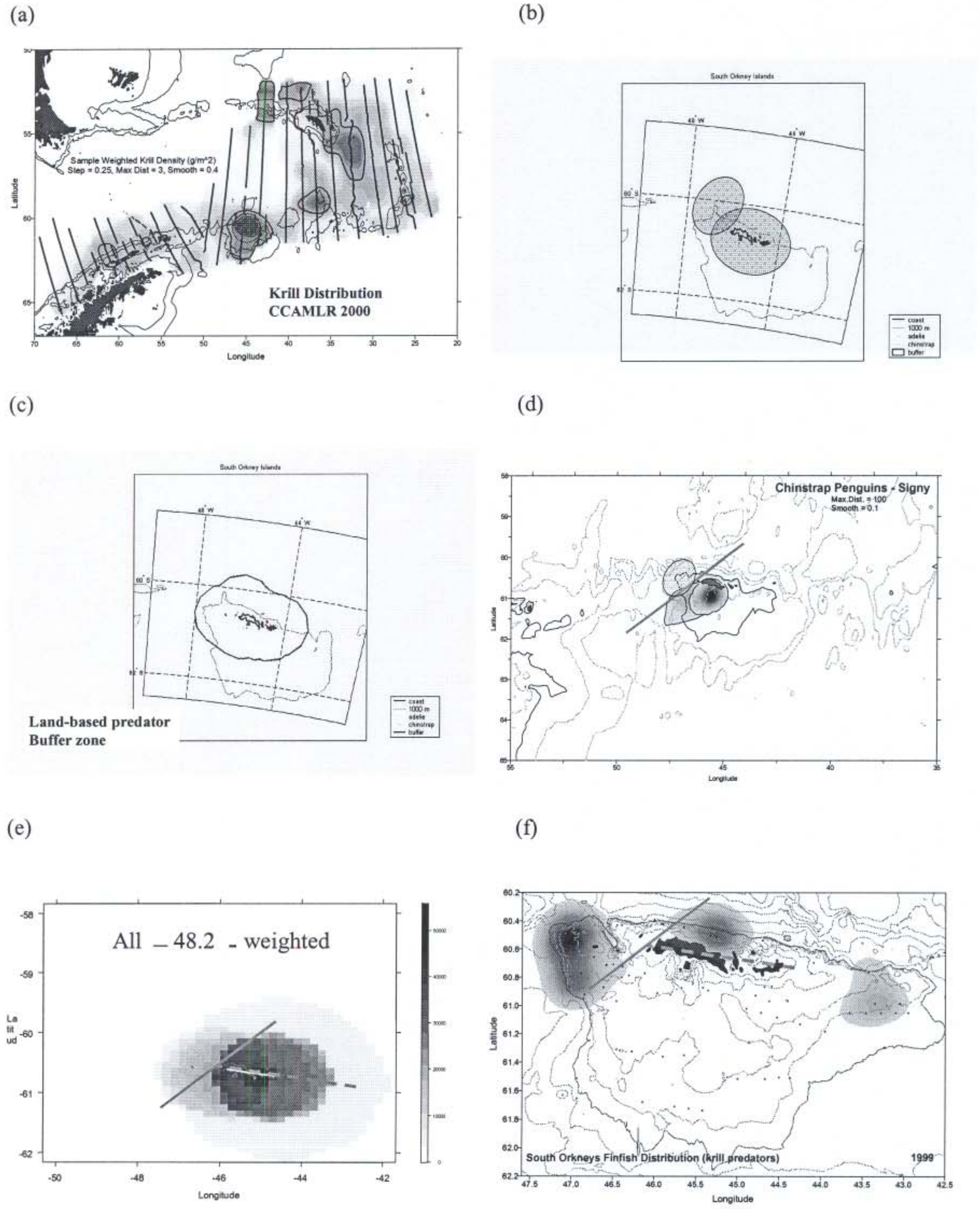


Figure 38: Subdivision of Subarea 48.2 based on: (a) krill aggregations (oval shows primary area of aggregation), (b) the krill fishery (right oval shows the observed krill aggregation while the left oval shows the primary location of the krill fishery), (c) the maximum foraging distance and buffer for land-based predators around the land areas in Subarea 48.2, (d) the combined known foraging ranges of land-based predators, including black-browed albatrosses, and chinstrap and Adélie penguins, (e) the aggregated extrapolated foraging grounds of land-based predators, and (f) the aggregations of krill-eating finfish. Solid lines indicate divisions.

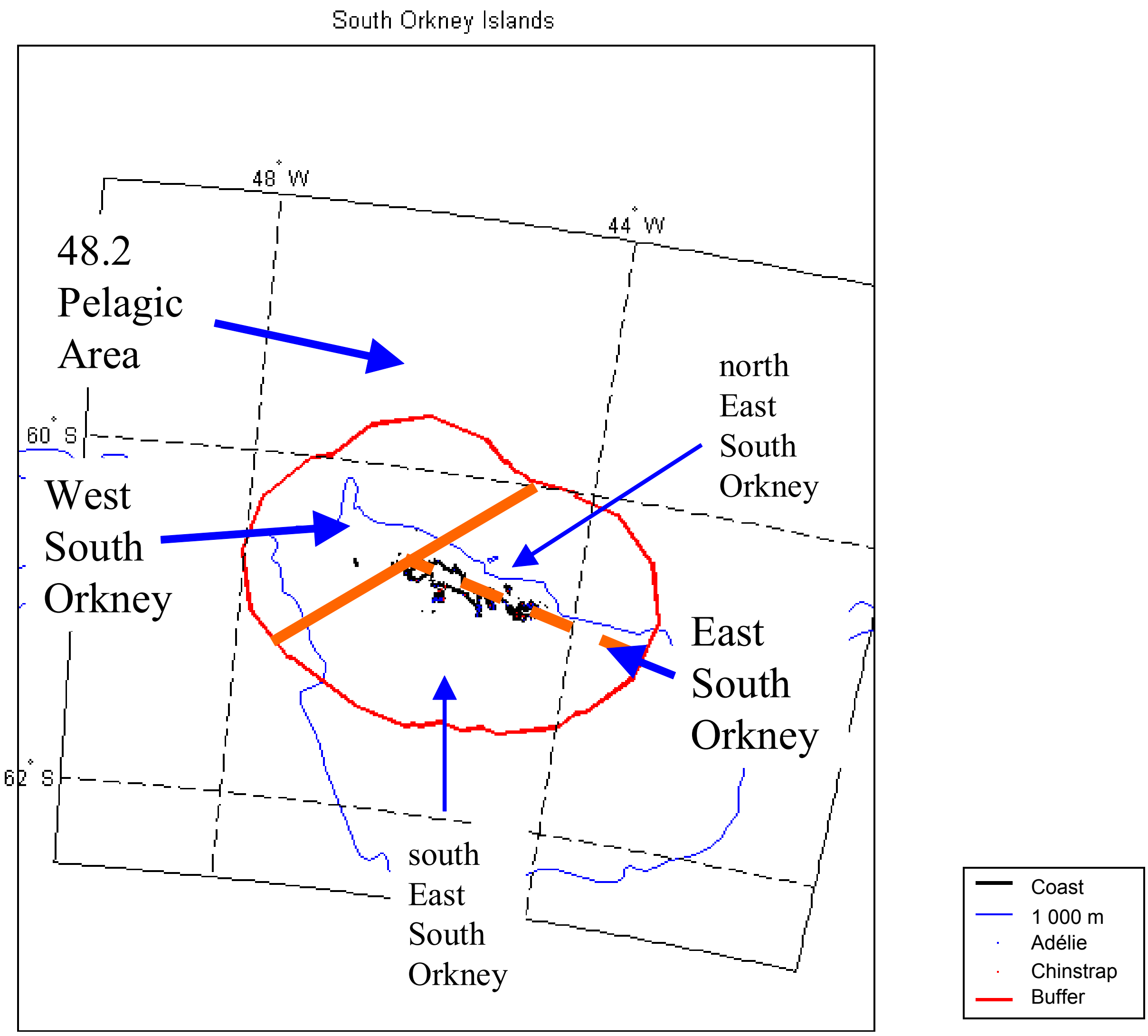


Figure 39: Proposed small-scale management units for Subarea 48.2. The subarea is divided between a pelagic area and the land-based predator area, with the latter area divided into two main units – West South Orkney and East South Orkney. The division between north and south East South Orkney areas is proposed in the interim, pending further information on foraging of penguins from the Laurie and Powell Islands.

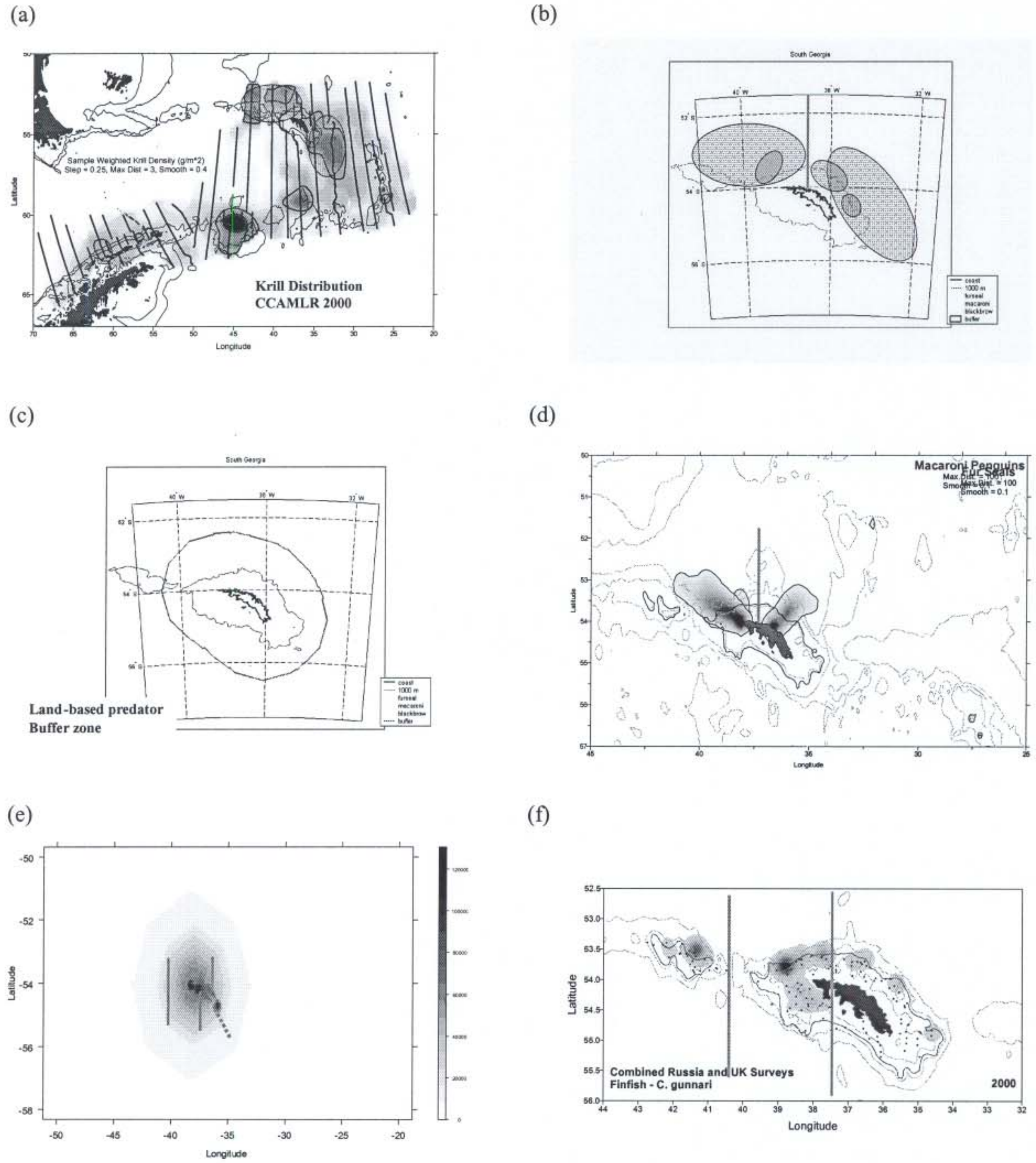


Figure 40: Subdivision of Subarea 48.3 based on: (a) krill aggregations approximated from the CCAMLR-2000 Survey (ovals show primary areas of aggregation), (b) krill aggregations approximately located according to CCAMLR-2000 Survey and experience from UK surveys (large ovals show expected primary areas of aggregation) and the winter krill fishery from 1986 to 1990 (small ovals show the primary locations of the krill fishery), (c) the maximum foraging distance and buffer for land-based predators around the land areas in Subarea 48.3, (d) the combined known foraging ranges of Antarctic fur seals and macaroni penguins (noting that black-browed albatrosses have foraging areas to the east and west of South Georgia), (e) the aggregated extrapolated foraging grounds of land-based predators, and (f) the observed aggregations of *Champsocephalus gunnari* in the 2002 surveys. Solid lines indicate divisions.

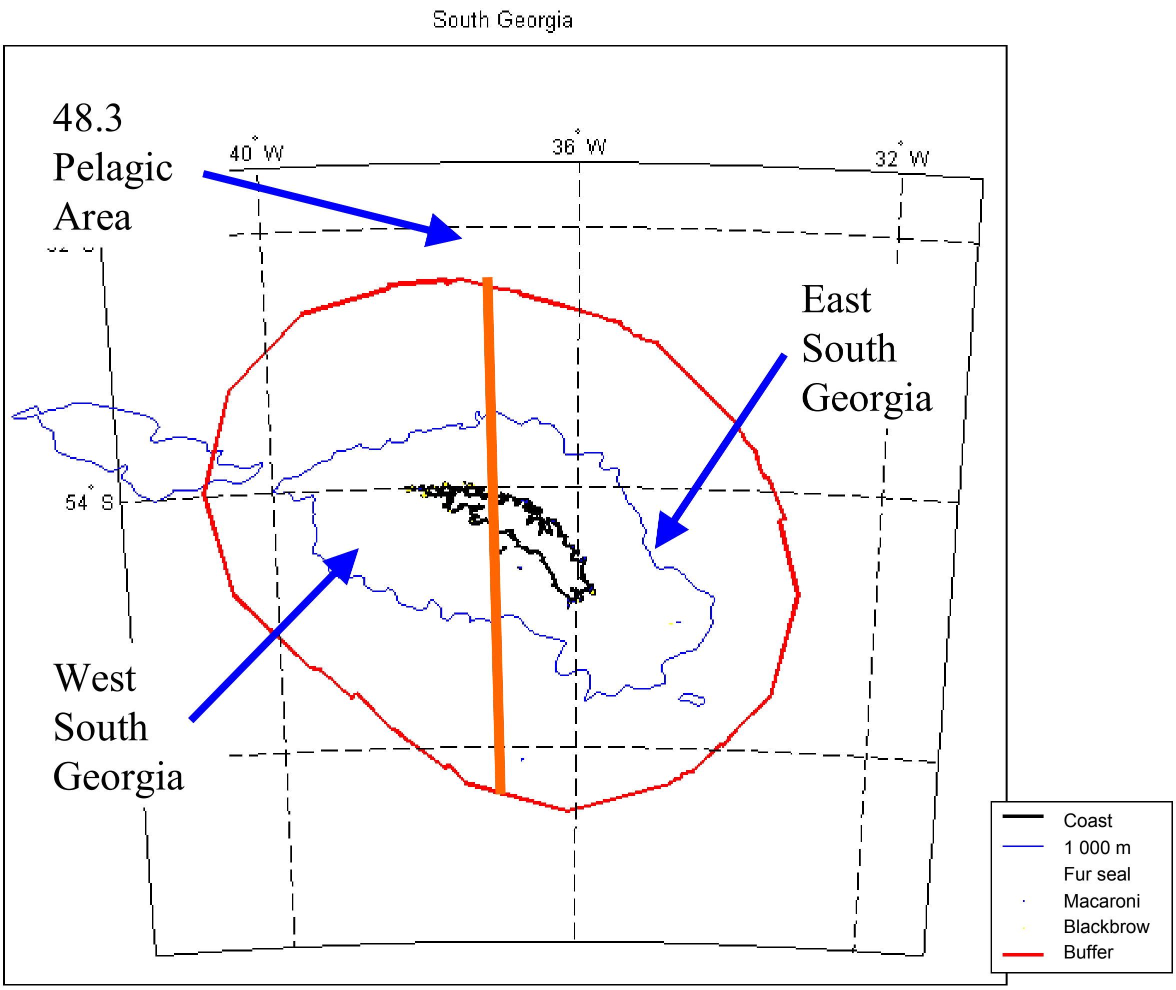


Figure 41: Proposed small-scale management units for Subarea 48.3. The subarea is divided between a pelagic area and the land-based predator area, with the latter area divided into two main units: East South Georgia and West South Georgia.

ATTACHMENT 1

AGENDA

Workshop on Small-scale Management Units, such as Predator Units
(Big Sky, Montana, USA, 7 to 15 August 2002)

1. Opening
   (a) Agenda
   (b) Work plan
   (c) Rapporteurs

2. Principles on the development of predator units

3. Krill predators
   (a) Patterns of distribution and abundance
   (b) Spatial patterns of foraging
      (i) Penguins
      (ii) Flying birds
      (iii) Seals
      (iv) Other species including whales, fish and squid
   (c) Seasonal and interannual variation
   (d) Criteria for defining foraging/feeding grounds
   (e) Analysis and methods

4. Krill fishery
   (a) Patterns of fishing
   (b) Interannual variation
   (c) Criteria for defining fishing grounds
   (d) Analysis and methods

5. Krill
   (a) Patterns of abundance
   (b) Dynamics of distribution
   (c) Criteria for defining spatial distribution
   (d) Analysis and methods

6. Environment
   (a) Spatial patterns of the physical environment
   (b) Interannual variability
   (c) Points to be considered in the development of integrated units
   (d) Analysis and methods

7. Synthesis
   (a) Spatial relationships between predators and the krill fishery
   (b) Methods for determining integrated predator units
   (c) Development of a proposal

8. Advice to WG-EMM.

BIOMASS CENTRES FOR LAND-BASED PREDATORS IN SUBAREAS 48.1, 48.2 AND 48.3

Subarea	Species	Centre No.	Long.	Lat.	Number*	Biomass
48.1	Adélie penguin	1	-57.8333	-63.3000	1 100	9 900
		2	-56.4833	-63.3000	35 000	315 000
		3	-55.8333	-63.0000	100	900
		4	-55.5167	-63.1333	1 000	9 000
		5	-55.1667	-63.1000	25	225
		6	-54.6333	-63.4000	15 000	135 000
		7	-57.0000	-63.3833	124 150	1 117 350
		8	-55.4833	-61.5000	2	18
		9	-64.0667	-64.7667	43 921	395 289
		10	-58.6167	-62.2667	55 691	501 219
		11	-55.7667	-63.5833	100 000	900 000
		12	-58.7500	-64.3000	21 954	197 586
		13	-60.6167	-62.6500	2	18
		14	-57.2833	-63.8000	10 320	92 880
	Chinstrap penguin	15	-61.0833	-62.6333	8 115	64 920
		16	-59.7000	-62.3167	214 636	1 717 088
		17	-58.6667	-63.3000	3 445	27 560
		18	-57.5333	-63.2333	930	7 440
		19	-55.1167	-61.1333	571 230	4 569 840
		20	-54.4000	-61.0167	2 200	17 600
		21	-55.4833	-61.5000	40 890	327 120
		22	-58.0000	-61.9000	62 158	497 264
		23	-58.1333	-62.1333	10	80
		24	-58.3000	-62.1833	2 083	16 664
		25	-58.3667	-61.9333	149 082	1 192 656
		26	-57.6167	-62.4333	16 278	130 224
		27	-57.6667	-61.9000	41 034	328 272
		28	-62.5667	-64.0500	5 250	42 000
		29	-62.5667	-64.6333	7 276	58 208
		30	-61.1333	-64.2333	16 882	135 056
		31	-64.2500	-64.6000	7 199	57 592
		32	-64.1167	-64.5000	24	192
		33	-61.9833	-64.2667	25	200
		34	-61.4667	-64.0167	1 620	12 960
		35	-61.7000	-64.1500	2 510	20 080
		36	-60.3333	-62.7500	10 260	82 080
		37	-60.6167	-62.9833	164 610	1 316 880
		38	-60.6167	-62.6500	1 500	12 000
		39	-60.1833	-62.4333	7 000	56 000
		40	-60.8000	-62.4667	3 000	24 000
		41	-58.9667	-63.5500	1 010	8 080
		42	-59.3833	-63.6833	152	1 216
		43	-59.8333	-63.6333	515	4 120
		44	-62.7333	-63.1167	5 000	40 000
		45	-62.1167	-64.3333	425	3 400
		46	-62.2167	-63.2333	285 000	2 280 000
		47	-62.3000	-62.8667	2 500	20 000
		48	-61.9167	-63.3000	10 000	80 000

Subarea	Species	Centre No.	Long.	Lat.	Number*	Biomass
48.1	Chinstrap penguin (continued)	49	-61.5833	-62.7833	6 550	52 400
		50	-62.0833	-63.2333	50	400
		51	-61.6000	-64.4333	40	320
		52	-60.1167	-62.7500	3	24
		53	-58.6167	-62.2667	495	3 960
		54	-55.4167	-60.9833	1 000	8 000
		55	-61.8500	-64.5167	550	4 400
		56	-63.5500	-64.2167	800	6 400
		57	-63.7000	-64.3500	8 500	68 000
		58	-58.0167	-63.3500	1 280	10 240
		59	-58.2833	-63.3500	15 000	120 000
		60	-58.4500	-63.4333	35	280
		61	-57.8333	-63.3000	9 400	75 200
	Gentoo penguin	62	-59.7500	-62.5000	9 257	111 084
		63	-60.8667	-62.6833	400	4 800
		64	-55.5167	-63.1333	200	2 400
		65	-57.0000	-63.3833	86	1 032
		66	-61.0000	-62.6000	904	10 848
		67	-61.0833	-62.6333	750	9 000
		68	-58.2500	-62.0833	5 944	71 328
		69	-59.8500	-62.5167	45	540
		70	-57.2833	-63.2000	50	600
		71	-55.0000	-61.1667	2 600	31 200
		72	-63.6000	-64.8833	1 500	18 000
		73	-62.8667	-64.8167	900	10 800
		74	-60.8083	-63.9083	600	7 200
		75	-60.9667	-64.1500	1 180	14 160
		76	-64.2500	-64.6000	1 600	19 200
		77	-58.9333	-62.2167	3 105	37 260
		78	-62.6333	-64.6833	7 918	95 016
		79	-62.7667	-64.7167	200	2 400
		80	-62.9500	-64.9000	740	8 880
		81	-58.8500	-62.2833	850	10 200
		82	-58.1333	-62.1333	1 105	13 260
		83	-60.3333	-62.7500	776	9 312
		84	-63.4333	-64.9167	1 200	14 400
		85	-60.8000	-62.4667	300	3 600
		86	-62.5333	-64.8500	250	3 000
		87	-61.4333	-62.8500	150	1 800
		88	-62.2167	-63.2333	250	3 000
		89	-60.6167	-62.6500	1 016	12 192
		90	-58.6167	-62.2667	2 584	31 008
		91	-63.5167	-64.8167	2 663	31 956
		92	-58.4500	-62.1833	2 254	27 048
		93	-63.0833	-64.8500	150	1 800
		94	-57.9000	-63.3333	6	72
		95	-57.8333	-63.3000	3 500	42 000
		96	-63.6833	-64.3500	42	504
		97	-64.1167	-64.5000	61	732
		98	-59.2333	-62.3167	3 347	40 164
		99	-56.6667	-63.5500	300	3 600
		100	-56.9167	-63.5333	200	2 400
		101	-64.0000	-64.5000	2 000	24 000

Subarea	Species	Centre No.	Long.	Lat.	Number*	Biomass
48.1	Antarctic fur seal	F1	-60.7417	-62.4680	9 131	319 585
		F2	-55.3422	-60.9908	562	19 670
		F3	-54.6332	-61.1274	188	6 580
		F4	-58.8577	-62.0045	158	5 530
		F5	-62.2836	-62.8840	7	245
48.2	Adélie penguin	102	-45.5833	-60.7333	95 675	861 075
		103	-44.4000	-60.7167	119 062	1 071 558
	Chinstrap penguin	108	-44.8000	-60.7000	420 877	3 367 016
		109	-45.6333	-60.7167	88 544	708 352
		110	-45.1500	-60.7500	76 230	609 840
		111	-45.4500	-60.5333	5 000	40 000
		112	-46.0000	-60.6333	111 244	889 952
		113	-46.7333	-60.5667	1 000	8 000
	Gentoo penguin	114	-44.4000	-60.7167	1 000	12 000
		115	-44.5000	-60.7500	430	5 160
		116	-46.0000	-60.6667	320	3 840
		117	-45.0000	-60.7167	7 907	94 884
		118	-45.6333	-60.6667	378	4 536
		119	-45.9167	-60.6333	2 185	26 220
		120	-44.5333	-60.6667	10	120
48.3	Macaroni penguin	121	-36.6636	-54.1304	144 960	1 304 640
		122	-34.7383	-55.0352	33 700	303 300
		123	-38.2128	-54.0038	3 166 805	28 501 245
	Gentoo penguin	127	-37.6443	-54.1575	21 344	256 128
		128	-37.3452	-54.2502	6 877	82 524
		129	-38.0516	-54.0042	5291	63 492
		130	-37.3437	-54.0701	12 784	153 408
		131	-37.4960	-54.0359	3 032	36 384
		132	-37.5722	-54.0254	752	9 024
		133	-36.6636	-54.1304	8 579	102 948
		134	-36.8087	-54.1602	376	4 512
		135	-37.2800	-54.2476	1 504	18 048
		136	-37.5746	-54.1578	4 500	54 000
		137	-37.0988	-54.2726	752	9 024
		138	-37.1918	-54.2469	752	9 024
		139	-36.2687	-54.3941	7 969	95 628
		140	-36.9616	-54.3354	926	11 112
		141	-36.8571	-54.3805	1 576	18 912
		142	-35.9507	-54.6175	16 363	196 356
		143	-36.6529	-54.4742	4 481	53 772
		144	-36.7200	-54.4656	407	4 884
		145	-36.9413	-54.4673	202	2 424
		146	-37.0685	-54.4890	376	4 512
		147	-36.4746	-54.5591	1 528	18 336
		148	-35.8239	-54.7779	30 979	371 748
	Antarctic fur seal	124	-37.9375	-54.0220	457 540	16 013 900
		125	-35.8239	-54.7779	4 500	157 500
		126	-34.7148	-55.0356	60	2 100

* For penguins – number of breeding pairs; for fur seals – number of pups