CCAMLR Science, Vol. 8 (2001): 1–23

THE CCAMLR-2000 KRILL SYNOPTIC SURVEY: A DESCRIPTION OF THE RATIONALE AND DESIGN

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Abstract

The design of the CCAMLR-2000 Krill Synoptic Survey (CCAMLR-2000 Survey) is described. The primary objective of the survey was to improve estimates of the pre-exploitation biomass of krill which are used in models to estimate sustainable yield in Area 48. The survey design includes two large-scale oceanic strata: one in the southwest Atlantic located in the Scotia Sea, and the other to the north of the Antarctic Peninsula (CCAMLR Statistical Subareas 48.1, 48.2, 48.3 and 48.4). Within these large-scale strata, four mesoscale strata were included in the survey design; these were located close to the South Sandwich Islands, north of South Georgia, north of the South Orkney Islands and north of the South Shetland Islands. The rationale underlying the selection of the strata and survey boundaries is described. The methods used for selecting the location of each survey transect are explained and the planned cruise tracks for each of the four vessels participating in the survey are shown. Details are also described for adaptively modifying the survey during its execution. This includes information how net haul stations should be selected and how transects should be modified if the planned survey tracks cannot be completed.

The survey took place in January–February 2000 and involved ships from Japan, Russia, UK and the USA. Scientists from many more CCAMLR Member States and the International Whaling Commission (IWC) took part. The survey is by far the biggest single exercise ever carried out by Members in support of the Convention. Full analysis of the results of the CCAMLR-2000 Survey will take several years and will result in a significant increase in the knowledge of krill length frequencies, biomass and distribution in the area studied.

Résumé

Description de la campagne CCAMLR-2000 d'évaluation synoptique du krill (campagne CCAMLR-2000). L'objectif principal de la campagne d'évaluation était d'obtenir de meilleures estimations de la biomasse du krill antérieure à son exploitation car celles-ci sont utilisées dans les modèles d'estimation du rendement durable de la zone 48. La campagne est conçue de telle sorte qu'elle comporte deux strates océaniques à grande échelle : l'une au sud ouest de l'Atlantique, dans la mer du Scotia, l'autre au nord de la péninsule antarctique (sous-zones statistiques 48.1, 48.2, 48.3 et 48.4 de la CCAMLR). À l'intérieur de ces strates à grande échelle étaient incluses quatre strates à échelle moyenne situées à proximité des îles Sandwich du Sud et au nord de la Géorgie du Sud, des Orcades du Sud et des îles Shetland du Sud. Dans ce document sont décrites les raisons ayant déterminé la sélection des strates et les limites de la campagne. Les méthodes suivies pour sélectionner l'emplacement de chaque transect de la campagne sont expliquées et les trajets que suivront les quatre navires participant à la campagne sont indiqués. De plus, des explications détaillées sont également données sur les modifications qui seraient apportées à la campagne au fil des circonstances, à savoir, entre autres, comment les stations de chalutage seraient sélectionnées et comment les transects seraient modifiés si les trajets prévus ne pouvaient pas être entièrement suivis.

La campagne s'est déroulée en janvier-février 2000, avec des navires du Japon, de la Russie, du Royaume-Uni et des États-Unis. Par ailleurs, de nombreux scientifiques d'autres États membres de la CCAMLR ou de la Commission internationale baleinière (CIB) y ont pris part. Cette campagne représente de loin la plus grande entreprise jamais menée par des membres pour soutenir les objectifs de la Convention. L'analyse intégrale des résultats de la campagne d'évaluation CCAMLR-2000 prendra des années et permettra de grandement compléter nos connaissances dans le domaine des fréquences de longueurs, de biomasse et de répartition du krill dans la région étudiée.

Резюме

В статье приводится план синоптической съемки криля АНТКОМ-2000. Основной целью съемки было уточнение оценки девственной биомассы криля, используемой в моделях расчета устойчивого вылова в Районе 48. План съемки включал 2 крупномасштабных океанических зоны: одну – на юго-западе Атлантического океана (в море Скотия), и другую – к северу от Антарктического п-ова (статистические подрайоны АНТКОМа 48.1, 48.2, 48.3 и 48.4). В пределах этих крупномасштабных зон план съемки предусматривал 4 среднемасштабных зоны, расположенных у Южных Сандвичевых о-вов, к северу от Южной Георгии, к северу от Южных Оркнейских о-вов и к северу от Южных Шетландских о-вов. В статье дается обоснование выбора зон и границ проведения съемки, объясняются методы выбора местополо3жения каждого съемочного разреза и показываются запланированные маршруты каждого из 4 участвовавших в съемке судов. Также приводятся детали адаптивного изменения съемки по ходу ее проведения, где включена информация о выборе станций траления и модификации разрезов в случае, если невозможно выполнить запланированные разрезов.

Съемка проводилась в январе-феврале 2000 г. судами Японии, России, Соединенного оролевства и США. В ней также были задействованы ученые из многих других стран-членов АНТКОМа и Международной китобойной комиссии (МКК). Эта съемка представляет собой самое крупное мероприятие, когда-либо проведенное странами-членами в поддержку Конвенции. Полный анализ результатов съемки АНТКОМ-2000 займет несколько лет и приведет к значительному расширению знаний о частотном распределении длин, биомассе и распространении криля в исследуемом районе.

Resumen

Este documento describe el diseño de la prospección sinóptica de kril CCAMLR-2000 (Prospección CCAMLR-2000). El objetivo principal de la prospección fue mejorar las estimaciones de la biomasa de kril previa a la explotación, utilizadas en los modelos para estimar el rendimiento sostenible en el Area 48. El diseño de esta prospección comprende dos estratos oceánicos a gran escala: uno en el sector suroeste del Atlántico situado en el mar de Escocia y el otro al norte de la Península Antártica (Subáreas estadísticas 48.1, 48.2, 48.3 y 48.4 de la CCRVMA). El diseño de la prospección incluyó cuatro áreas de mediana escala situadas cerca de las islas Sandwich del Sur, al norte de Georgia del Sur, al norte de las islas Orcadas del Sur y al norte de las islas Shetland del Sur. Se describe el criterio sobre el cual se basó la selección de las áreas y el establecimiento de los límites. Se explican los métodos utilizados para seleccionar la posición de cada transecto de muestreo y se muestran las trayectorias establecidas para cada uno de los cuatro barcos que participaron en la prospección. También se explica en detalle las modificaciones necesarias durante su ejecución. Esto incluye información sobre cómo se deben seleccionar las estaciones de arrastre y modificar los transectos si las trayectorias planeadas originalmente no pueden llevarse a cabo.

La prospección se realizó en enero–febrero de 2000 con barcos de Japón, Rusia, Reino Unido y Estados Unidos. También participaron científicos de muchos otros Estados miembros de la CCRVMA y de la Comisión Ballenera Internacional (IWC). Esta prospección es sin duda la mayor campaña de investigación llevada a cabo por los miembros en apoyo de la Convención. El análisis completo de los datos de la prospección CCAMLR-2000 tomará varios años y aportará significativamente al conocimiento de la frecuencia de tallas, biomasa y distribución del kril en el área estudiada.

Keywords: krill, synoptic survey, design, Area 48, 2000, CCAMLR

INTRODUCTION

Antarctic krill (*Euphausia superba*), considered to be one of the key species in the Antarctic marine food web, is prey to a wide variety of dependent species and is harvested commercially. Commercial exploitation of krill is managed under the direction of CCAMLR, and regulated in accordance with a sustainable ecosystem approach. Management principles, which are still being developed, require fundamental knowledge about the abundance and distribution of krill.

The CCAMLR methodology for the management of krill relies heavily on results derived from the CCAMLR Generalised Yield Model (GYM) (Constable and de la Mare, 1996) and, before that, the Krill Yield Model (Butterworth et al., 1991 and 1994). The GYM is used to estimate the long-term annual yield of krill in FAO Statistical Area 48 and the precautionary catch limit for the fishery (CCAMLR Conservation Measure 32/X; SC-CAMLR, 1991). A number of parameters are required to run the GYM, including estimates of the pre-exploitation biomass of krill (B_0) and its variance. Until recently the estimate of B_0 used in the GYM was that derived from the First International BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) Experiment (FIBEX) which took place from January to March 1981 (Trathan et al., 1992).

While recognising the value of the FIBEX-derived estimate of B_0, CCAMLR decided that a more up-to-date estimate of krill biomass was required (SC-CAMLR, 1993 – paragraphs 2.38 to 2.43). For example, in 1996 the CCAMLR Scientific Committee acknowledged the urgent need for a synoptic survey in Area 48 and noted that management advice for Area 48 could not be updated until such a survey had been conducted (SC-CAMLR, 1996 – paragraph 4.28). Later, a firm commitment was made to carry out a survey in the austral summer of 2000 (in January and February) (SC-CAMLR, 1997 – paragraphs 5.13 to 5.19). The primary objective of this survey was to improve the CCAMLR estimate of B_0 (SC-CAMLR, 1993 – paragraphs 2.39 and 2.41 to 2.47). Although additional survey objectives were also formulated, these were considered to be secondary to the estimate of B_0.

The CCAMLR-2000 Krill Synoptic Survey (CCAMLR-2000 Survey) set out to estimate B_0 in Subareas 48.1, 48.2, 48.3 and 48.4, and involved research vessels from four CCAMLR Member

States. In addition, vessels from two other nations carried out acoustic surveys in selected parts of the main survey area. The composition of the scientific parties on board the vessels was multinational and included experts from outside CCAMLR. The planning effort behind this survey was considerable.

The primary purpose of this paper is to describe the procedures used to design the synoptic survey, thereby forming a consolidated reference for future work. The paper also describes the rationale behind the CCAMLR-2000 Survey and documents the survey design details; it draws heavily from many CCAMLR documents and meetings.

SAMPLING STRATEGY

The synoptic survey design was the culmination of numerous decisions. These are reported in a number of separate working documents and reports, and are reproduced here to provide a single, ready source. The major design strategy decisions that needed to be made were:

(i) whether pre-planned or adaptive transect positions should be used;

(ii) whether transect separation should be regular and systematic or random;

(iii) whether the design should be stratified or unstratified; and

(iv) the definition of survey limits.

Pre-planned or Adaptive Transect Positions

An adaptive survey design would generally provide an increased understanding of the structure of the ecosystem and improve the coefficient of variation (CV) of the biomass estimate. However, the advantages of a more detailed description of the distribution of krill within high-density areas may be outweighed by increased complexity in terms of survey design, execution and subsequent analysis. In the light of these concerns, a more conservative approach utilising a pre-planned survey was adopted. Such an approach has been widely used in the past (for instance FIBEX – BIOMASS, 1980) and was considered to be statistically robust and defensible.

Systematic or Random Transect Positions

The main objective of the survey was to improve the estimate of B_0 used in the GYM. Although an improved estimate could have been obtained using a wide variety of survey designs, the chosen survey design had to be statistically defensible. Modern methods of statistical analysis are continually evolving and providing new opportunities for improved analysis. At present, however, no consensus exists with regard to some of the model-based geostatistical methodologies. Although an agreed methodology using model-based methods may become available in the future, CCAMLR agreed that for now a randomised design coupled to a design-based analysis would produce the most statistically defensible result (CCAMLR, 1998a and 1998b – Appendix 1; see also conclusions in Miller, 1994).

To achieve this aim the survey followed a design based on randomised parallel transects. The advantage of such a design is that it allows the use of classical design-based statistical methods (Jolly and Hampton, 1990) without precluding model-based geostatistical methods (e.g. Petitgas, 1993; Murray, 1996) during survey analysis. In contrast, the use of regular systematic transects would preclude the use of classical design-based statistical methods.

Stratified or Unstratified Design

There is still considerable uncertainty regarding the relative abundance of krill in the open ocean compared with that over the continental shelf areas around the Antarctic Peninsula and the sub-Antarctic islands in Area 48. Although the distribution is complex (illustrated by a variety of datasets and published papers e.g. Ichii et al., 1998; Sushin and Shulgovsky, 1998), it is important that the B_0 estimate be based on a survey that samples all areas considered to be important for the biomass assessment. The FIBEX survey was based on the premise that most of the krill biomass was close to, or over, shelf areas. However, if krill are also distributed in similar quantities in the open ocean, a design which gives a uniform density of sampling across the whole region should be used. In contrast, if krill are concentrated in particular predictable areas, an appropriate stratified sample design is likely to produce a lower overall CV. Although appropriate stratification may improve the overall estimate of CV, it will not change the expected estimate of mean biomass.

In view of the continuing debate over the relative importance of shelf and oceanic areas, a compromise survey design was deemed appropriate. Thus, the design allocated extra effort to areas of expected krill concentration, i.e. over shelf areas close to some of the sub-Antarctic islands forming part of the Scotia Arc.

Definition of Survey Boundaries

Given the complexity of the marine ecosystem (cf. Ichii et al., 1998; Sushin and Shulgovsky, 1998), natural limits to the survey area are difficult to define. In establishing appropriate boundaries, a variety of factors had to be considered. These included the known historical distribution of krill, the oceanographic structure within the region, the distribution of the commercial fishery, and the distribution of the summer pack-ice. However, these ecological boundaries do not necessarily coincide with the artificial limits of the subareas that define the management boundaries.

To achieve its management objectives, CCAMLR would require estimates of krill biomass from survey strata defined using both ecological and management-based criteria (for example, the Scotia Sea and Subarea 48.1); survey boundaries therefore had to be based on a compromise between ecological and management boundaries.

OUTLINE OF SELECTED SURVEY DESIGN

Taking into account the factors outlined in the previous section (sampling strategy), the following survey design was finally agreed. Participating vessels had to undertake a series of randomised transects located within predefined large-scale strata covering the area to the north of the Antarctic Peninsula and most of the Scotia Sea. The first of these strata covered most of Subarea 48.1, the second covered much of Subareas 48.2 and 48.3 and the western part of Subarea 48.4. In order to lie orthogonal to the main axis of the regional bathymetry, transects within these large-scale strata were oriented in different directions.

Within the large-scale strata, four regions were known to have a high abundance of krill and to be of importance to dependent species and commercial fishing fleets. In these areas additional mesoscale transects were surveyed in order to reduce the CV of the biomass estimate. The first of these mesoscale strata was to the north of the South Shetland Islands, the second was to the north of the South Orkney Islands, the third to the north of South Georgia and the fourth around the South Sandwich Islands. In these mesoscale strata the survey was designed to provide twice the transect density of the large-scale strata. The boundaries of the mesoscale strata were coincident with the boundaries of the large-scale sampling units that passed through the mesoscale strata; this ensured that the survey area was uniformly covered by primary sampling units (transects) for the purposes of randomisation. A series of randomised transects was located within each mesoscale stratum. Details of the cruise tracks of each participating vessel are shown in Figures 1, 2, 3 and 4.

METHOD OF RANDOMISATION

Transects were randomised within each stratum. The basic requirement for a truly randomised parallel-transect survey is that all potential transect lines in the survey area should have an equal probability of being sampled. However, one problem arising from a simple randomisation procedure is that the realised randomisation may give very uneven coverage of the survey area; this can result in an inefficient use of available effort. To overcome this, the CCAMLR-2000 Survey used a two-stage random-isation process (see also Brierley et al., 1997). First, the survey area was divided into a series of parallel zones, each of equal width and separated by alternating parallel inter-zones of the same width. Second, a survey transect was then randomly placed within each of the zones. The inter-zones contained no transects and acted to keep the transects a minimum distance apart. To comply with the requirement that any transect has an equal probability of being sampled, the location of the entire survey grid was then moved by a random distance equal to, or less than, the inter-zone width. Thus, using the two-stage process, all primary sampling units had an equal probability of being sampled; this gave the necessary condition for the validity of the design-based variance estimators.

An additional benefit of this randomisation scheme is that it minimises the loss of efficiency related to model-based geostatistical procedures and resulting from choosing a random rather than systematic design.

IMPLEMENTATION OF SURVEY DESIGN

The computer software package used to carry out the survey design was Arc/Info Version 7.1.1 (ESRI). The final design was checked in Arc/Info

Table 1: Limits of the 25 x 25 km base grids used as the foundation for the survey design.

Stratum	Origin of Grid	Rotation of Grid	Limit			
			Northern	Southern	Western	Eastern
Scotia Sea	62°S, 40°W	0°	49°S	62°S	56°W	20°W
Antarctic Peninsula	65°S, 50°W	330°	52°S	68°S	79°W	40°W

Table 2: Parameters used for the Lambert Conformal Conic Projections.

Stratum	Spheroid	Units	Standard Parallel 1	Standard Parallel 2	Central Meridian	Origin of Projection	X,Y Shift
Scotia Sea	WGS84	Metres	54°30'S	59°30'S	40°W	62°W	0, 0
Antarctic Peninsula	WGS84	Metres	59°30'S	64°30'S	50°W	65°W	0, 0

Table 3: Parameters used to determine the transect sampling zones.

Stratum	Eastern Edge of Stratum, Distance from Base Grid Origin (km)	Width of Grid Shift Inter-zone (km)	Number of Transects	Width of Transect Sampling Zone (km)	Width of Transect Sampling Inter-zone (km)
Scotia Sea	982.50 – east	62.50	13	62.50	62.50
South Sandwich Islands	857.50 – east	62.50	10	31.25	31.25
South Georgia	357.50 – east	62.50	4	31.25	31.25
South Orkney Islands	142.50 – west	62.50	4	31.25	31.25
Antarctic Peninsula	257.50 – east	62.50	9	62.50	62.50
South Shetland Islands	7.50 – east	62.50	8	31.25	31.25

Table 4: Random westward shift for transects within the sampling zones and for the grid shift.

Stratum	Random Shift from the Eastern Edge of the Transect Sampling Zones (km)													Random Shift for Grid (km)
	T-01	T-02	T-03	T-04	T-05	T-06	T-07	T-08	T-09	T-10	T-A	T-B	T-C	
Scotia Sea[1]	3.00	36.00	43.50	44.50	13.50	0.50	50.00	29.00	41.50	6.50	45.50	40.00	34.50	17.50
South Sandwich Islands[2]	30.00	6.25	4.50	15.75	22.50	23.00	13.50	28.25	29.25	9.25				17.50
South Georgia[2]	29.25	0.75	6.50	9.25										17.50
South Orkney Islands[2]	7.75	18.25	18.50	19.25										17.50
Antarctic Peninsula[1,3]	40.00	38.50	16.00	37.00	44.50	1.50	57.00	13.00	2.00					17.50
South Shetland Islands[2]	20.50	5.00	20.25	20.75	11.00	26.75	4.25	29.25						17.50

1 Randomisation was carried out with potential transect sampling units separated by 0.50 km.
2 Randomisation was carried out with potential transect sampling units separated by 0.25 km.
3 Transect number from 11 to 19.

and then validated using a separate software package (Proj4). The survey design generated six strata:

(i) the Antarctic Peninsula large-scale stratum (AP);

(ii) the Scotia Sea large-scale stratum (SS);

(iii) the South Shetland Islands mesoscale stratum (SSI);

(iv) the South Orkney Islands mesoscale stratum (SOI);

(v) the South Georgia Island mesoscale stratum (SGI); and

(vi) the South Sandwich Island mesoscale stratum (Sand).

The implementation of the two-stage randomisation process was carried out in seven steps for each stratum:

(i) regular 25 x 25 km base grids extending beyond the survey area were generated;

(ii) sampling zones and inter-zones were identified on the relevant base grid for each stratum;

(iii) a random shift within each sampling zone was selected for each transect;

(iv) a random grid shift for the sampling zones and inter-zones was selected for each stratum;

(v) the northern and southern limits of sampling were selected for each transect;

(vi) waypoints at 25 km spacing were generated for each transect; and

(vii) waypoints were projected into geographic coordinates for each transect.

Generate Regular 25 x 25 km Base Grids

Two regular 25 x 25 km grids that extended beyond the limits of the anticipated survey area were generated, one for the Antarctic Peninsula and one for the Scotia Sea. Each grid was oriented orthogonal to the general axis of the regional bathymetry. Thus, the base grid for the Antarctic Peninsula was designed to lie at 330° to the 50°W meridian. This grid was located parallel to the line between 65°00.0′S, 50°00.0′W and 60°00.0′S, 55°46.4′W. The base grid for the Scotia Sea was designed to lie parallel to the 40°W meridian. The limits of the regular base grids are shown in Table 1.

The base grids were generated using a Lambert Conformal Conic Projection with standard parallels placed approximately 25% from the top and bottom of the anticipated survey areas; scale errors for these parallels should be approximately 1%. The parameters used for the generation of the grids are shown in Table 2.

Identify the Survey Sampling Zones and Inter-zones

Following the criteria outlined above, transect sampling zones were generated on the two base grids. The zones were located at equal distances across the anticipated survey area and were separated by inter-zones of the same width. The parameters for setting up the sampling zones are shown in Table 3.

Identify the Random Transect Positions within the Sampling Zones

In order to assign random transect positions each sampling zone was subdivided into 125 potential positions, giving a sampling resolution of 0.5 km for the large-scale transects and 0.25 km for the mesoscale transects. Within each sampling zone, the actual transect position was determined by randomly selecting one of the potential transect positions. The random shift for each transect within each sampling zone is shown in Table 4.

Identify the Random Grid Shift

The second level of survey randomisation was carried out by subdividing the grid shift inter-zone into 125 potential grid positions, giving a sampling resolution of 0.5 km. The grid shift was chosen by picking one of these potential grid positions at random. The same grid shift was used for both base grids. This provided the second level of randomisation for both the large-scale and mesoscale transects and ensured that even sampling probability was maintained. The random shifts for the grids are shown in Table 4.

Table 5: Parameters used for the geographic projection.

Stratum	Spheroid	Units	X,Y Shift
Scotia Sea	WGS84	Decimal degrees	0, 0
Antarctic Peninsula	WGS84	Decimal degrees	0, 0

Table 6: Priority for omitting transects following periods of lost time; if a transect has already been surveyed, then the next highest priority transect should be omitted.

Vessel	Priority for Omission									
	1	2	3	4	5	6	7	8	9	10
Ship 1 (large-scale)	SS-07	AP-13	SS-10	AP-16	SS-01	SS-04	AP-19			
Ship 2 (large-scale)	SS-05	SS-08	AP-14	AP-11	SS-02	AP-17				
Ship 2 (mesoscale)	SGI-04	SGI-02	SGI-03	SGI-01						
Ship 2 (mesoscale)	SOI-02	SOI-04	SOI-01	SOI-03						
Ship 3 (large-scale)	AP-12	SS-03	SS-06	SS-09	AP-15	AP-18				
Ship 3 (mesoscale)	SSI-07	SSI-05	SSI-08	SSI-06	SSI-02	SSI-01	SSI-04	SSI-03		
Ship 4 (large-scale)	SS-A	SS-C	SS-B							
Ship 4 (mesoscale)	Sand-03	Sand-09	Sand-04	Sand-08	Sand-10	Sand-06	Sand-01	Sand-05	Sand-02	Sand-07

Table 7: Start and end dates for each vessel.

Vessel-ID	Nation	Vessel	Start Date	End Date
Ship 1	UK	RRS *James Clark Ross*	18 January 2000	10 February 2000
Ship 2	USA	*Yuzhmorgeologiya*	13 January 2000	4 February 2000
Ship 3	Japan	*Kaiyo Maru*	11 January 2000	2 February 2000
Ship 4	Russia	*Atlantida*	17 January 2000	1 February 2000

Identify the Northern and Southern Limits for each Transect

After randomly assigning transect positions on the X-axis of the base grid, Y-axis coordinates for the northern and southern ends of each transect were determined by extending the transects to the limits of the survey strata. The southern transect limits were identified with reference to nearby coastlines and the anticipated northern extent of the summer pack-ice, while the northern limits were identified with reference to the boundaries of Subareas 48.1, 48.2, 48.3 and 48.4, the existence of krill in Area 41, and the frontal structure of the Antarctic Circumpolar Current (ACC) (see Figures 5, 6 and 7).

Identify Waypoints along each Transect

As survey transects were parallel and did not follow meridians, transect orientation continually changed. Therefore, to aid vessel navigation during the survey, waypoints were created at regular intervals along each transect. These waypoints were generated from north to south at 25 km intervals.

Project the Transects into Geographic Coordinates

The transect waypoints were projected from the Lambert Conformal Conic Projection to geographic coordinates using the parameters shown in Table 5. These coordinates were supplied to the navigation officer of each participating vessel.

IMPLICATIONS FOR THE ANALYSIS OF SURVEY STRATA

A number of problems arose in setting the orientation of the large-scale grids orthogonal to the regional bathymetry. In particular, the two large-scale grids had an overlap between some of the primary sampling units to the east of the Antarctic Peninsula. This overlap led to a change in the sampling probability in that area. To overcome this, an *a priori* selection of sampling units for inclusion in the analyses was necessary; in this case it was agreed to omit data south of 59° on transect 10. Other areas of overlap presented no such problems and there was no ambiguity about which transect sections should be discarded.

ALLOCATION OF SURVEY EFFORT TO PARTICIPATING VESSELS

During the initial planning stages for the CCAMLR-2000 Survey it was assumed that three main survey vessels would be available. Effort was therefore allocated so that each ship occupied every third large-scale transect. This reduced the potential for bias and minimised the possibility of large areas of missing data in the event of equipment failure. However, during later planning stages an additional vessel was included in the survey. In order that the survey (by then already agreed by CCAMLR) did not have to be redesigned, this additional vessel was allocated survey transects in a continuous block. The allocation of effort for the survey is shown in Figure 8.

Four CCAMLR Member States (Japan, Russia, UK and the USA) were eventually able to contribute to the survey with each vessel contributing approximately 30 days of ship time. Other nations were also able to undertake smaller-scale regional acoustic surveys for krill during the austral summer of 2000; these included the Republic of Korea and Peru.

Transects within the Antarctic Peninsula (AP) and Scotia Sea (SS) large-scale strata were allocated to the four main survey vessels as follows:

Ship 1 (UK): transects SS-1, SS-4, SS-7, SS-10, AP-13, AP-16 and AP-19;

Ship 2 (USA): transects SS-2, SS-5, SS-8, AP-11, AP-14 and AP-17;

Ship 3 (Japan): transects SS-3, SS-6, SS-9, AP-12, AP-15 and AP-18; and

Ship 4 (Russia): transects SS-A, SS-B and SS-C.

The UK vessel (Ship 1) was not allocated any mesoscale sampling effort as it had a greater commitment to contribute effort at the large scale. However the other vessels were allocated transects within the mesoscale strata as follows:

Ship 2 (USA): transects SGI-1, SGI-2, SGI-3, SGI-4, SOI-1, SOI-2, SOI-3 and SOI-4;

Ship 3 (Japan): transects SSI-1, SSI-2, SSI-3, SSI-4, SSI-5, SSI-6, SSI-7 and SSI-8; and

Ship 4 (Russia): transects Sand-1, Sand-2, Sand-3, Sand-4, Sand-5, Sand-6, Sand-7, Sand-8, Sand-9 and Sand-10.

ADDITIONAL SURVEY EFFORT

The final survey design allowed for four main vessels, each operating within a restricted time period. However, because additional survey effort may have become available, plans were made to efficiently utilise such effort without compromising the validity of the basic design. Three feasible options were considered:

(i) to replicate one (or more) of the mesoscale survey areas;

(ii) to extend one (or more) of the large-scale survey areas; or

(iii) to replicate one (or more) of the large-scale survey areas.

Choosing between these options depended on the amount of additional effort. Therefore, it was agreed that logistic constraints would probably dictate which option was selected if other ships joined the survey.

REDUCTION OF SURVEY EFFORT DUE TO LOST TIME

In the southwest Atlantic it was highly likely that some survey time would be lost due to bad weather; contingency plans for lost time were therefore absolutely necessary. The following guidelines were provided in the event that weather and/or equipment failure caused serious delays. It was suggested that each vessel should check progress against the expected time at each station and make any necessary adjustments in the following order of priority:

- increase vessel speed without sacrificing quality of acoustic data; else,
- delete daytime net sampling and conductivity-temperature-depth sensor (CTD) casts.

In addition, a check was to be made against the expected time at the approximate mid-point of each major transect and adjustments made in the following order of priority:

- curtail the current transect and recommence surveying at the start of the next; else,
- curtail the current transect and recommence surveying at the most adjacent point on the next; else,
- omit an entire transect according to the randomly determined ranking given in Table 6.

DETERMINATION OF STATION POSITIONS ON TRANSECTS

In addition to undertaking a series of acoustic transects, it was agreed that each ship should undertake a series of net hauls to collect krill and zooplankton, and a series of CTD casts to characterise water masses. These plans were based on the following assumptions:

- that all acoustic transects would be run during daylight so that acoustic biomass estimates would not be biased by night-time migrations of krill to the surface (where they would not be sampled by hull-mounted echosounders);
- that 18 hours per day would be spent conducting acoustic transects; and
- that six hours per day would be required to sample two stations, one station would be sampled around local midnight, the other around local midday; at each station a CTD cast to 1 000 m and a net haul between 0 and 200 m were to be carried out.

A major implication of such a sampling regime was that station positions were not fixed locations but were dependent on the start time of each ship, the time and duration of the period of darkness and the actual progress the ship made along each transect.

The provisional position of each station was calculated in a series of stages:

(i) determine the approximate dates when each ship would steam each transect;

(ii) calculate the times of local dawn and dusk for the given dates for set positions on each transect; and

(iii) establish the station positions and the cruise plan based on the calculated steaming times.

To facilitate cruise planning, a PC-based spreadsheet was used to calculate steaming times around the survey grid. This spreadsheet was made available to all cruise leaders to help monitor expected progress around the survey transects.

Start Date for each Vessel

The provisional station sampling positions were calculated assuming that each ship started on time. The actual start dates for each vessel are shown in Table 7.

Times of Dawn and Dusk for each Vessel on each Transect

The times of civil twilight (where the sun is more than 6° below the horizon) were calculated for each transect based on the estimated rate of vessel progress. Three positions per transect were estimated for initial planning purposes. Inspection of the twilight times for these positions revealed that part of the survey area was in regions where the sun was below the horizon (more than 6°) for more than four (up to six) hours per day. This restricted the time available for night-time station activities. Several conditions were therefore required to ensure that the survey transects could be completed in the time available. These conditions were:

- that transecting started at local civil dawn and extended until local civil twilight;
- that daytime net and CTD activities were completed within a two-hour period; and
- that ships steamed at 10.5 knots along transects and at 12 knots between transects.

Unless these conditions could be met, the survey would take longer than originally anticipated. Provisional station positions were therefore calculated on the basis of these time allocations. The provisional positions for each of the stations were made available to all cruise leaders to help monitor expected progress around the survey transects.

REGIONAL SUPPORT AND SIGNIFICANCE OF THE SYNOPTIC SURVEY

Given the costs and logistic complexity of conducting multiship operations, future surveys such as the CCAMLR-2000 Survey must be considered as relatively rare. As a consequence, the results from the synoptic survey should be considered in the context of the many smaller-scale regional surveys that have been and will be undertaken. Of particular importance are those surveys that were undertaken close to the time of the synoptic survey and which form part of long time series. These include the BAS Core Programme (UK), the US AMLR survey (USA), and the cruises fostered by the CCAMLR Subgroup on International Coordination. At present, the importance of regional surveys in the assessment of krill biomass across Area 48 remains undefined. However, if these regular, regional surveys can be linked to the large-scale synoptic survey in time and space, it may be possible to interpret temporal variability in the regional surveys with respect to the larger area. If this is feasible, then it may become possible to use smaller-scale regional surveys to monitor long-term trends in krill biomass.

POSTSCRIPT

The synoptic survey was undertaken, as planned, in the summer of 2000. The resultant value of B_0 was calculated at a multinational workshop and has now been incorporated into the GYM. This has subsequently led to revised management procedures and a new precautionary catch limit for the krill fishery (CCAMLR Conservation Measure 32/XIX; SC-CAMLR, 2000).

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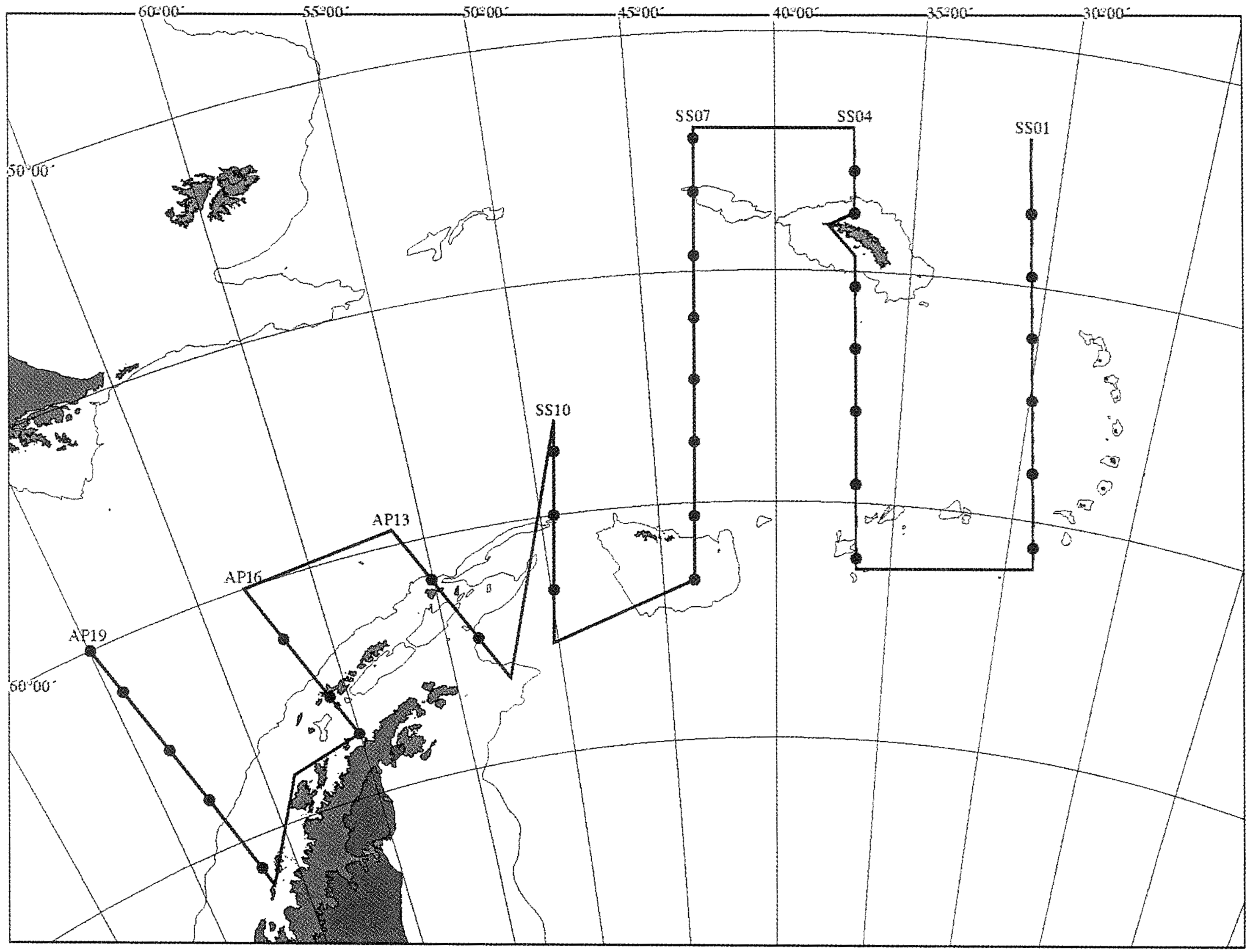

Figure 1: CCAMLR-2000 Survey cruise track of Ship 1 (UK vessel).

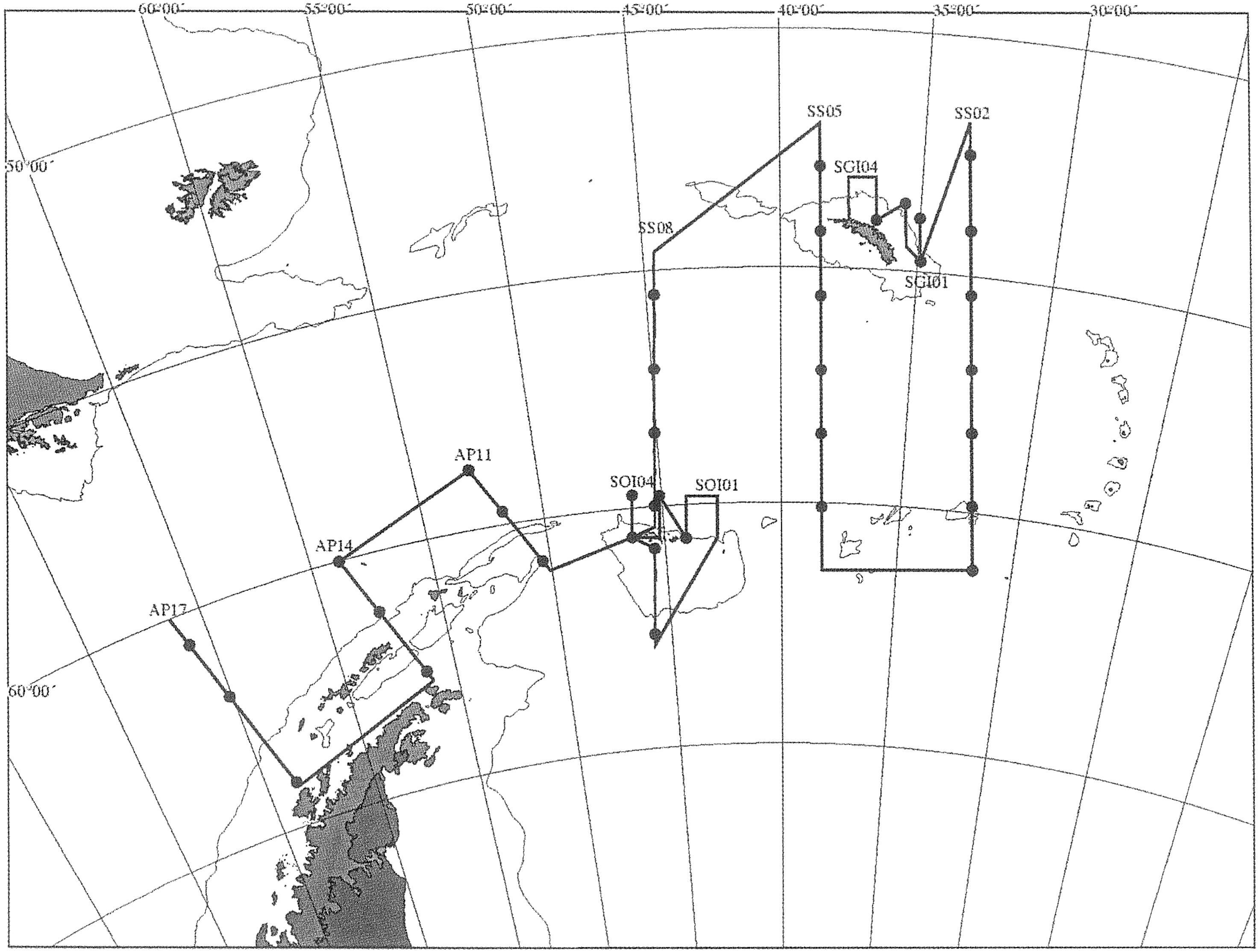

Figure 2: CCAMLR-2000 Survey cruise track of Ship 2 (US vessel).

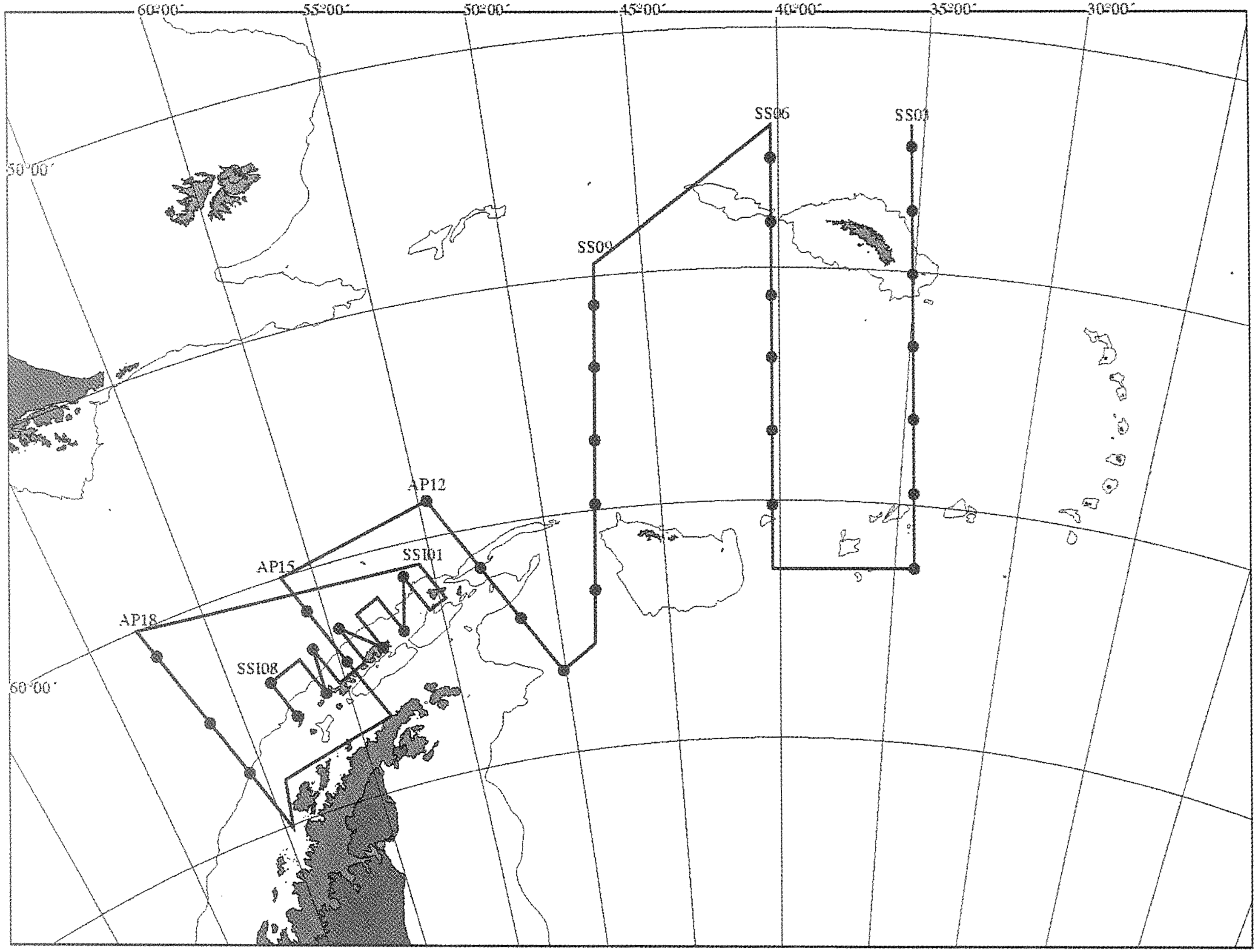

Figure 3: CCAMLR-2000 Survey cruise track of Ship 3 (Japanese vessel).

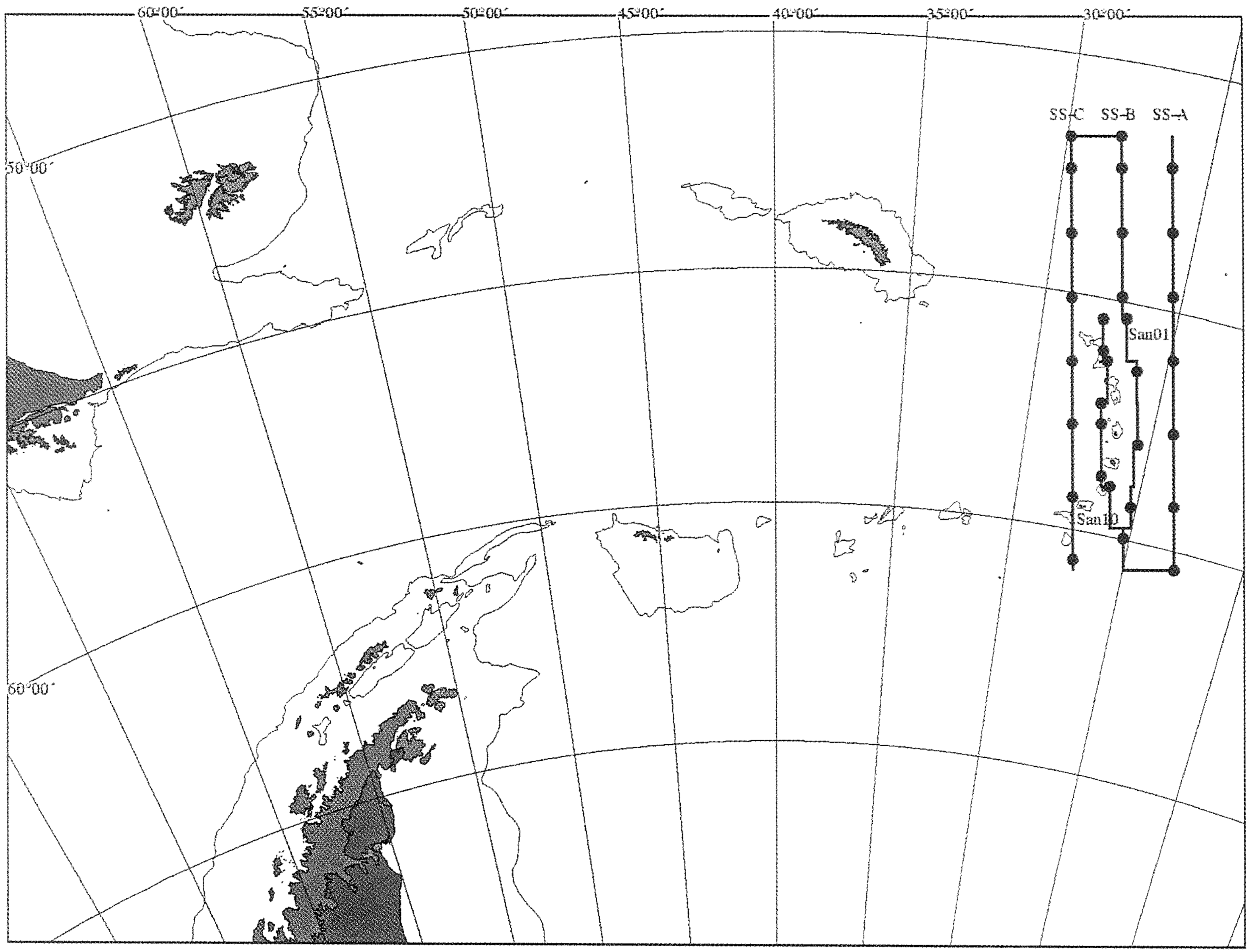

Figure 4: CCAMLR-2000 Survey cruise track of Ship 4 (Russian vessel).

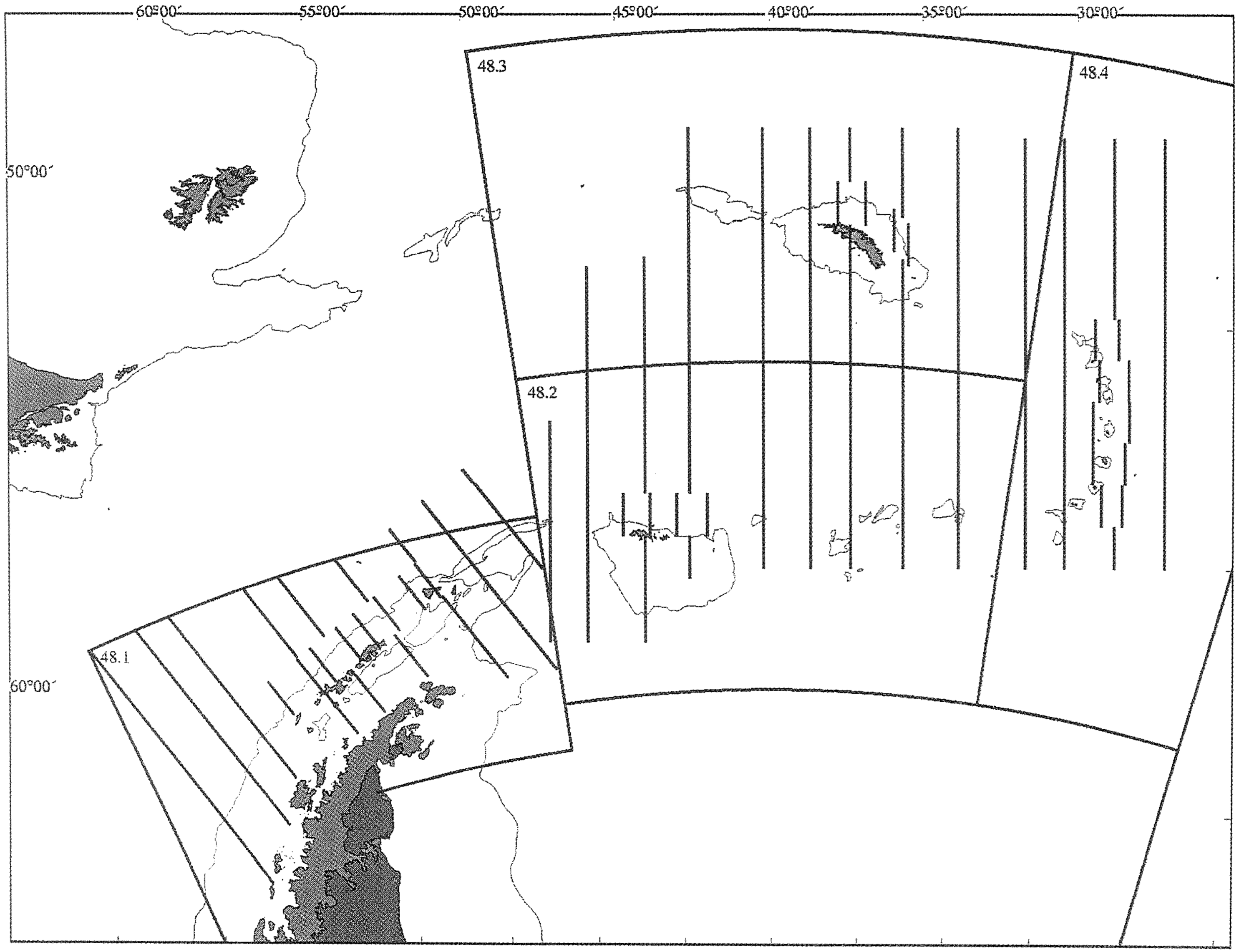

Figure 5: CCAMLR-2000 Survey cruise tracks with the boundaries shown for Subareas 48.1, 48.2, 48.3 and 48.4.

Figure 6: CCAMLR-2000 Survey cruise tracks with positions where krill catches have been reported during the period from 1986 to 1992 (CCAMLR, 1997).

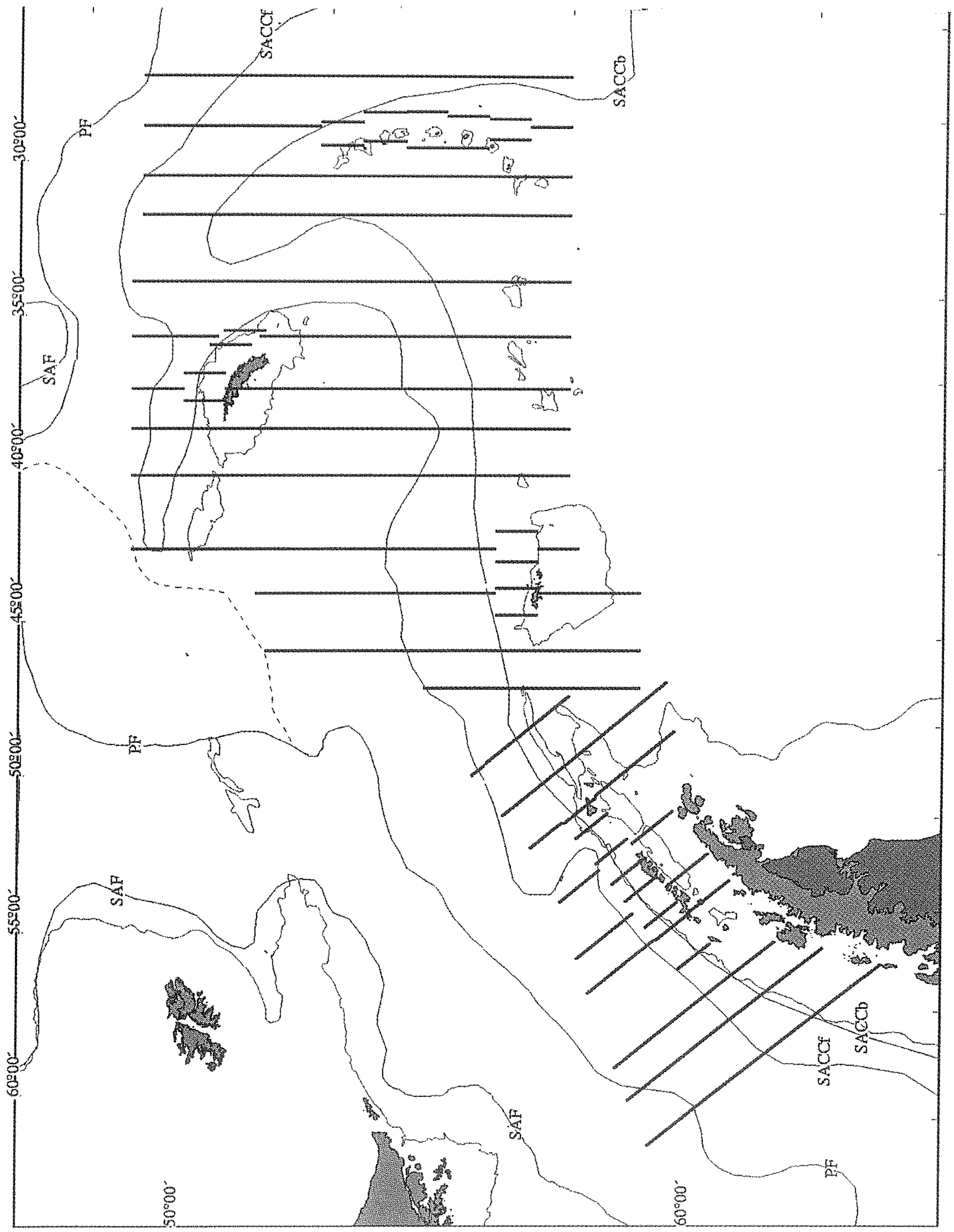

Figure 7: CCAMLR-2000 Survey cruise tracks with climatic positions of the major fronts in the Antarctic Circumpolar Current. SAF – Sub-Antarctic Front; PF – Polar Front; SACCf – Southern ACC Front; SACCb – Southern ACC boundary. Positions of fronts after Orsi et al. (1995), with the Polar Front modified after Trathan et al. (1997).

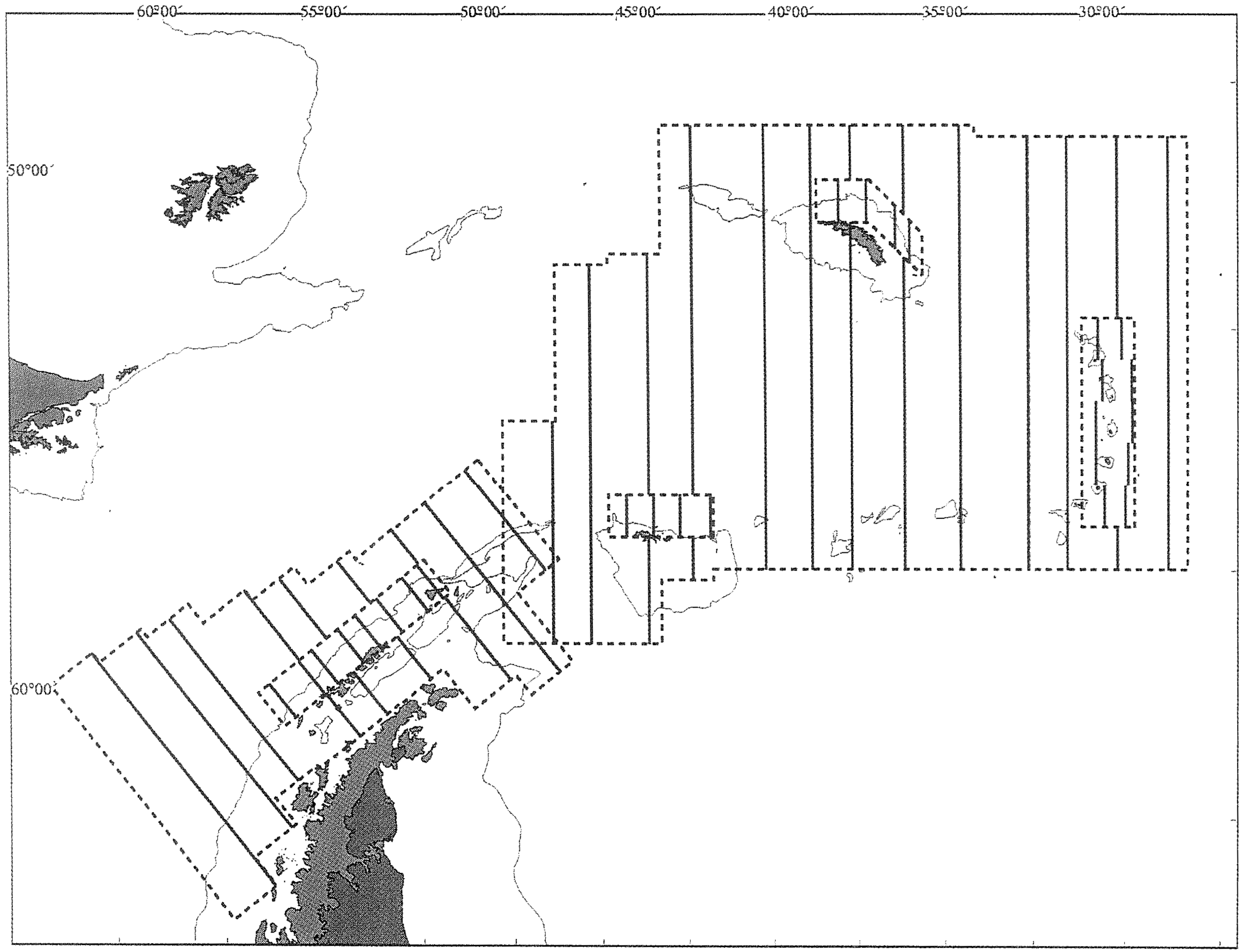

Figure 8: CCAMLR-2000 Survey design with stratum boundaries.

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Figura 8: Diseño de la prospección CCAMLR-2000 con los límites de los estratos.