

Review

Recent Development in Multi-national Marine Ecosystem Surveys along the Antarctic Peninsula

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Abstract : From an ecological point of view, the western part of the Atlantic sector is one of the most productive areas in the Southern Ocean. Antarctic krill (*Euphausia superba*) and krill-dependent predators such as fish, seals, and birds are abundant there, and most krill fisheries have operated in this area since 1970s. The hottest issues for the proper management of krill resources nowadays are to determine total biomass in this area, and to identify environmental forces controlling stock fluctuation. This paper reviews and collates information on ongoing oceanographic activities in the Antarctic Peninsula region concerning these issues. To delineate the status and function of Antarctic krill population in Antarctic marine ecosystems, multi-national researches along the Antarctic Peninsula area have been developing recently. Four member states of CCAMLR (Japan, Russia, UK, and USA) had conducted acoustic surveys in January-February 2000 (so-called CCAMLR-2000 survey), and krill standing stock at 120 kHz was estimated to be 44.29 million metric tonnes in the western Atlantic sector of the Southern Ocean. On the other hand, the Southern Ocean GLOBEC (SO-GLOBEC) Programme has prepared a serial winter survey to examine the factors that govern krill survivorship and distribution in relation to shelf circulation processes. Ship-based surveys using ice-breakers are being conducted by three nations (Germany, UK, and USA) around the Marguerite Bay during the austral fall and winter 2001 and 2002. In addition to these two large-scale surveys, some CCAMLR members have carried out joint oceanographic surveys near the South Shetland Islands to detect ecosystem changes since 1994. Especially from December 1999 to February 2000, in conjunction with CCAMLR-2000 survey, four nations (Japan, Korea, Peru, and USA) conducted acoustic surveys to produce time-series information on krill distribution and biomass near the South Shetland areas. Though the aims of each program and the approach to solve the scientific questions were different each other, the results from each program fill the gaps between programs. Further cooperation and exchange in these activities could be beneficial to each program.

Key words : CCAMLR-2000 survey, SO-GLOBEC, Antarctic Peninsula, Antarctic krill, international coordination.

1. Introduction

The remoteness of the area and the harshness of the environments are the typical characteristics of the Antarctic Ocean (or Southern Ocean) that occupies about 10 % of the world-ocean. Furthermore, the Antarctic Ocean contains many resource species in its water body. Antarctic ecosystem is called krill-centered ecosystem due to its huge biomass of Antarctic krill (*Euphausia superba*) in it (Everson 2000). The abundance of other predatory

species (i.e., dependent species) such as seals, penguins, and fish are much dependent on the recruit success and the fluctuation of krill population (Park *et al.* 1998). However, the condition and biology of Antarctic marine living resources is not much known due to the difficulties in research, though investigations by some scientific groups have carried out since 1970s. The areas are too large to be covered by a single nation, so that our knowledge on Antarctic marine ecosystem is very limited.

Generally, it has been known that the western Atlantic sector (Statistical subareas 48.1, 48.2, 48.3, and 48.4) is biologically very productive ocean, so that many marine

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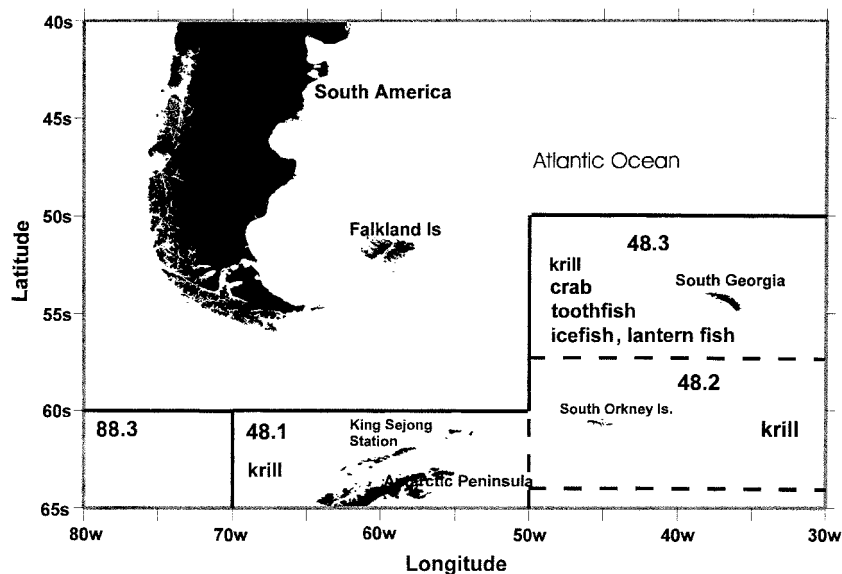


Fig. 1. Distribution and availability of Antarctic marine living resources over the western Atlantic sector of the Southern Ocean.

living resources reside there. Typical example of resource distribution and availability is shown in Fig. 1. Also, it is generally acceptable concept among Antarctic scientists that the conveyor belt system from the South Shetland Islands to South Orkney, and to South Georgia is considered as a passage of krill swarm (Hofmann *et al.* 1998). Krill fisheries, consequently, concentrates in coastal area of this region due to high concentration of krill and good shelters nearby for krill fishing vessels in the event of adverse weather (Everson 2000). The Scientific Committee on Antarctic Research (SCAR) organized a large-scale krill biomass survey in this area during the early 1980s: the First International BIOMASS Experiment (FIBEX) of the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) program (Hempel 1983). However, since the completion of the FIBEX and the subsequent second experiment, SIBEX, no intensive multinational oceanographic cooperation has been conducted until the end of the last century.

Recently, several groups of Antarctic scientists have discussed joint research in the Antarctic Ocean to estimate krill biomass, and to find the relationships between krill recruitment and environmental factors. The major thrusting bodies/scientific programs for international cooperation are the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which came into force in 1982 as the inter-governmental organization, and International Global Ocean Ecosystem Dynamics (GLOBEC) Programme under the International Geosphere-Biosphere

Programme (IGBP). Some CCAMLR members (Germany, Japan, Korea, and USA) had accumulated experience in joint research near the Antarctic Peninsula to produce time-series data on marine ecosystem changes since 1994. Also, a large-scale multi-ship acoustic/oceanographic survey (called CCAMLR-2000 Survey) by Japan, Russia, UK, and USA was conducted jointly to estimate krill biomass and its associated variance in the western Atlantic sector of the Southern Ocean during the austral summer of 1999/2000. In conjunction with this large-scale activity, it was concluded by CCAMLR Subgroup on International Coordination that a repeated time-series acoustic survey could provide ancillary data to the CCAMLR-2000 survey. Japan, Korea, Peru, and USA, therefore, conducted five acoustic/oceanographic surveys (International Coordinated Survey) in the northern part of the South Shetland Islands in austral summer of 1999/2000. On the other hand, the Southern Ocean GLOBEC (SO-GLOBEC) Programme, one of the four regional programs of GLOBEC, has prepared a serial winter survey to examine the factors that govern krill survivorship and distribution in relation to shelf circulation processes. Ship-based surveys using four icebreakers are being conducted around the Marguerite Bay by three nations (Germany, UK, and USA) during the austral fall and winter 2001 and 2002. This paper aims to summarize those research activities on marine ecosystem conducted along the Antarctic Peninsula, and to help establishing the research direction and strategy that the Korean Antarctic Research

Program pursues in the future.

2. Recent development

CCAMLR-2000 survey

Recent catch statistics indicated that krill fisheries have mostly concentrated in the Atlantic sector of the Southern Ocean (Ramm and Appleyard 2001). For example, in 1999/2000 fishing season, a total of 104,259 tonnes of krill was caught from the Area 48 (Atlantic sector), and no fishing was reported from Area 58 (Indian sector) and Area 88 (Pacific sector). Updated estimate of krill biomass in the Atlantic sector, therefore, is an urgent requirement for the management of krill resource, because great improvement in acoustic survey methodology has been achieved in last two decades and population structure of krill already changed. It was agreed by member countries at the Working Group on Ecosystem Monitoring and Management (WG-EMM) meeting of the CCAMLR in 1999 that a large-scale synoptic survey should be conducted for the estimation of krill standing stock during January 2000 (SC-CAMLR 1999). Area covered was much of the western Atlantic sector of the Southern Ocean (Statistical Subareas 48.1, 48.2, 48.3, and 48.4; see Fig. 1) with randomly spaced transects. For planning and evaluation of the survey, the CCAMLR had opened several workshops

before and after the survey. Four research vessels from Japan (R/V Kaiyo Maru), Russia (R/V Atlantida), United Kingdom (R/V James Clark Ross) and United States (R/V Yuzhmorgeologiya) had participated in the CCAMLR-2000 Survey. All participating vessels were equipped with the same multi-frequency echosounders (Simrad EK500) operating at 38, 120, and 200 kHz (SC-CAMLR 2000).

The survey area was divided into three strata. Within the large-scale area, four meso-scale regions (the north of South Georgia, north of the South Orkneys, north of the South Shetlands, and around the South Sandwich Islands) were considered as the area of high abundance of krill and therefore to be of importance to commercial fishing fleets. The survey tracks of all participating vessels are shown in Fig. 2. The area surveyed within each stratum was calculated from the nominal transect lengths and the 125 km wide zone within which each transect was placed. The estimated strata areas were as follows:

Large-scale strata:

Antarctic Peninsula	473,318 km ²
Scotia Sea	1,109,789 km ²
East Scotia Sea	321,800 km ²

Meso-scale strata:

South Shetland Islands	48,654 km ²
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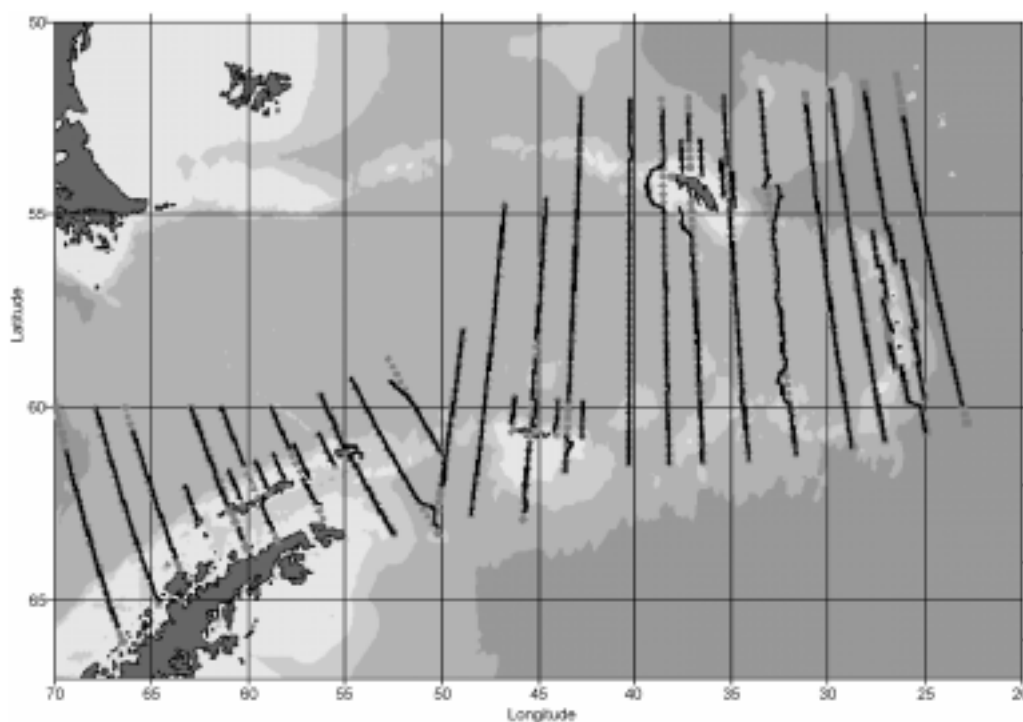


Fig. 2. Survey tracks of participating vessels in CCAMLR-2000 Survey during January-February 2000.

South Orkney Islands	24,409 km ²
South Georgia	25,000 km ²
South Sandwich Islands	62,274 km ²

The information collected should be the base of the efficient management of krill stock. At the WG-EMM meeting in 2000, the CCAMLR reached a conclusion indicating around 44.29 million metric tonnes of krill biomass in the western Atlantic sector (SC-CAMLR 2000). It was a milestone achievement in Antarctic krill research after the FIBEX involving 11 research vessels from 10 nations. The preliminary estimation of krill biomass from CCAMLR-2000 Survey was similar to that calculated from the FIBEX survey. Based on this estimate, Total Allowable Catch (TAC) of 4.0 million tonnes of krill catch as a potential yield was calculated in Statistical Area 48 using the CCAMLR Krill Yield Model (KYM). Before this new biomass estimation and methodology applied to the estimation of potential yield, precautionary catch limit (PCL) for Area 48 was 1.5 million tonnes. However, the potential yield as precautionary measure would be subdivided for small-scale management units such as predator units to avoid concentrating fishing effort. The WG-EMM considered several methods by which catch limits might be subdivided. A method to divide the PCL between such units will be developed in the future. Currently TAC or PCL in each subarea was allocated as follows (SC-CAMLR 2000):

- Subarea 48.1 – 1.008 million tonnes;
- Subarea 48.2 – 1.104 million tonnes;
- Subarea 48.3 – 1.056 million tonnes; and
- Subarea 48.4 – 0.832 million tonnes.

International coordinated survey

Antarctic marine ecologists have frequently discussed the needs of repeated sampling in the area of interest to monitor changes in ecosystem components over time. However, there was a difficulty to make a unified specific direction of research because each country has different scientific background and situation. One possible way to solve this difficulty is to keep their national programs in the area of interest, and to spend some efforts for the common interests. With this philosophy, some nations had conducted research cruises jointly to detect intra- and inter-annual ecosystem changes in marine environments in the Antarctic Peninsula region during 1994/95 austral summer. In 1995 during the CCAMLR Scientific Committee meeting, continuing cooperation effort was requested by

Table 1. The participating nations and period for the CCAMLR International Coordinated Survey during 1994/95, 1996/97, and 1999/2000 periods.

	Country	Period	R/V
1994/95	Germany	Dec. 2, 1995	Polarstern
	Japan	Dec. 15-16, 1994	Kaiyo Maru
	Korea	Jan. 7-8, 1995	Yuzhmoregeologiya
	Japan	Jan. 18-19, 1995	Kaiyo Maru
	USA	Jan. 24-25, 1995	Surveyor
	USA	Feb. 18-19, 1995	Surveyor
1996/97	Germany	Dec. 15	Polarstern
	Korea	Dec. 27-28	Yuzhmoregeologiya
	USA	Feb. 8-9	Yuzhmoregeologiya
	USA	Mar. 16-24	Yuzhmoregeologiya
1999/2000	Japan	14-18 December 1999	Kaiyo Maru
	Korea	10-15 January 2000	Onnuri
	Peru	24-28 January	Humboldt
	Japan	29 Jan. – 2 Feb. 2000	Kaiyo Maru
	USA	22-26 February 2000	Yuzmogeologiya

establishing ad hoc Subgroup on International Coordination (SC-CAMLR 1995). To examine interannual variation of ecosystem, the Subgroup conducted a second joint cooperation at the same area during 1996/97 season (Table 1).

For these two cooperative campaigns, the area of interest to the Subgroup was the northern part of the Elephant Island near the Antarctic Peninsula. In winter season, annual sea-ice usually covers this area, which provides a good shelter for over-wintering krill, and causes very high primary production while the ice edge is retreating toward the south in spring. Especially, a large portion of commercial catch of krill was contributed from this area. This Subgroup's activity was focused on identifying environmental factors and processes that affect the life forms, comparing these ecosystems with those in other subantarctic islands such as the South Georgia and Kerguelen Islands, and gaining experiences in international cooperation in the Antarctic Ocean.

Four countries (Germany, Japan, Rep. of Korea, and USA) had conducted oceanographic surveys with standardized sampling method. Data for nutrients, phytoplankton, zooplankton, acoustic, and water properties were collected. Data from the cruises were analyzed through workshops at Hamburg (Germany) in July 1995 and La Jolla (USA) in July 1997. The most important findings from these two cooperation were: 1) there was an interannual variation in krill distribution, spawning time, and demography, and 2) the location of front in coastal

area moved back and forth within a season, resulting in different pattern of animal distribution as well as primary productivity (Kim *et al.* 1998). The results from workshops were reported to the WG-EMM and Scientific Committee of the CCAMLR (SC-CAMLR 1995, 1997).

With such a success in cooperation CCAMLR Scientific Committee in 1997 requested to this Subgroup to develop multinational cooperation continuously. On the other hand, CCAMLR-2000 Survey was planned to estimate krill biomass in the Atlantic sector of the Southern Ocean during January 2000. In conjunction with this large-scale activity, it was concluded by the Subgroup that repeated time-series acoustic survey in the northern part of the South Shetland Islands would contribute to improving our understanding in the Antarctic marine ecosystem, and the results from cooperative research would be beneficial to every joining country. However, it was agreed that data arising from such surveys should not be included in the analyses leading to the estimation of biomass.

More specifically, Japan, Republic of Korea, and USA planned krill acoustic surveys (called International Coordinated Survey) using the same sampling protocol used in CCAMLR-2000 Survey. Later, Republic of Peru (non-CCAMLR nation) joined this activity, and members welcomed her involvement. Survey period in the north of the South Shetland Islands was from December 1999 to February 2000, which aimed to provide time-series data of krill biomass and distribution in the area. In addition to acoustic data, other biological and environmental components of marine ecosystem such as plankton and seawater properties were collected for the understanding of krill dynamics during the austral summer in this area. The surveys had been carried out five times from December 1999 through February 2000 (Table 1). CCAMLR Scientific Committee in 2000 endorsed them to organize a workshop during the intersessional period (SC-CAMLR 2000).

With this background, the Korea Ocean Research and Development Institute (KORDI) and the Pukyong National University jointly organized a workshop in 2001. The Workshop for the International Coordinated Survey aimed to analyse the acoustic data sets for determining the change of krill biomass and distribution during the austral summer of 2000 in the South Shetland Islands area. Three important findings were identified from the workshop: 1) krill density ranged about 40-50 g/m², resulting in the biomass of about 1.5 million tonnes in the north of the South Shetland Islands during 1999/2000 austral summer, and it showed low variability over the nine-week period,

2) three consistent areas of high krill density were suggested; near the east end of Elephant Island, mid-way between Elephant and King George Island, and near Cape Shirreff on the north side of Livingston Island, and 3) Highest densities of krill seem to move closer to the shelf break as the season progresses, and this apparent movement is complemented by a change in the demographic structure of the population.

SO-GLOBEC survey

The typical characteristic of the Antarctic Ocean ecosystem is the process of freezing and melting within a year. This seasonal advance/retreat of sea-ice must influence on production and behavior of biological community: phytoplankton productivity becomes high at the ice edge during spring, and Antarctic krill use sea-ice as a winter refuge and feeding ground. Recently published papers indicated that climate change, which might happen in the Southern Ocean, would have influences on sea-ice formation, success of krill recruitment, and population of krill predators (Loeb *et al.* 1997; Reid and Croxall 2001). A decreased sea-ice concentration in the Southern Ocean, with other economic as well as operational reasons, may contribute southward expansion in fishing ground of krill (Anon 2001).

The SO-GLOBEC programme was designed to investigate the population dynamics of zooplankton, especially krill, and their predators by examining year round life cycle of zooplankton. Main focus of SO-GLOBEC is to understand how physical forces such as current, ice-cover, seawater properties, and UV-B radiation influence population dynamics and prey-predator interactions between key species. It includes regional differences in over-wintering strategies of Antarctic krill in relation to physical environment, successful reproduction of krill between seasons, and population dynamics of selected zooplankton species and major krill predator both sea-ice related (or ice-based) and pelagic species (Anon 1997).

Above of all, the SO-GLOBEC Programme will have special efforts on studying over-wintering strategy of zooplankton and top predators. Process-oriented approach on krill ecology in winter Southern Ocean is a major distinguishable feature of SO-GLOBEC from other activities. In this regard, field operation during winter season is an essential component of the Programme. In the Antarctic Peninsula area, krill survivorship and distribution at the Marguerite Bay will be investigated in relation to shelf circulation processes. Field studies consist of two elements: a synoptic meso-scale survey, and process studies aimed at

Table 2. Schedule of research vessels involving in the SO-GLOBEC Programme around the Antarctic Peninsula areas.

Period	Name of vessel	Country
March – May 2001	Polarstern	Germany
April – May 2001	Gould & Palmer	USA
July – August 2001	Gould & Palmer	USA
January-February 2002	not determined yet	Tentative Korea, Spain, Peru
April – May 2002	Gould & Palmer	USA
July – August 2002	Gould & Palmer	USA
October – November 2002	James Clark Ross	Tentative UK
December 2002 – January 2003	James Clark Ross	UK

understanding phenomena and mechanisms. To reach this study area (i.e., Marguerite Bay) during winter season, ice-breaking capability of research vessel is prerequisite. Four icebreakers from Germany, UK, and USA will be operated for winter cruises in 2001-2003 (Table 2). The summer study will focus on foraging and recruitment processes along the Peninsula regions.

To predict the impact of climate change on marine ecosystem adequately, improved modeling technique as well as data collection is specially required. Existing conceptual, circulatory, and biological models must be evaluated as a point of departure for SO-GLOBEC efforts. A variety of new technologies will be used and tested for sampling and analysis, and the application of sampling technology, coupled with advanced modeling capabilities, provides the necessary tools to accomplish the SO-GLOBEC goals.

3. Prospect

According to its Article 2, the CCAMLR has focused on issues of conservation of the ecosystem as well as rational use of marine living resources around the Antarctica. CCAMLR conservation measures establishes for the management of Antarctic marine living resources and ecosystem every year based on the recommendations from its Scientific Committee. Therefore science-based advice to ecosystem management is the essence of CCAMLR activity. Due to the difficulties in collecting scientific data from the entire Antarctica, however, CCAMLR encourages member countries to cooperate with each other. Also, communication between international programs or organizations (i.e., CCAMLR, GOOS, IWC, GLOBEC, etc.) is essential to compensate and fill the gaps between programs, and would contribute to improving our understanding in the Antarctic marine ecosystem. In this regard, the international cooperation in scientific research is becoming more important and essential parts in the Antarctic activities. Such cooperation, however,

requires much extra effort and some sacrifice of participants.

The Korean Antarctic Research Program (KARP) may get geographic advantage for studying krill-centered ecosystem. The western Atlantic sector of the Southern Ocean is currently the most important commercial fishing ground in the Southern Ocean. Krill catch from the vicinity of the South Shetland Islands region (Subarea 48.1) consisted of around 70 % (69,954 tonnes) of total catch from the Antarctic waters at the turn of the century (Ramm and Appleyard 2001). Korean fishing vessel has operated commercial krill fishery in this area since mid 1990. Also, the location of Korean Antarctic Research Station, the King Sejong, is another advantage to study krill-related ecosystem research for Korean marine ecologists, because rookeries of krill predators such as penguins and seals are located nearby. In this regard, CCAMLR's holistic approach to ecosystem management, which has been recognized as the pioneering work from the fisheries society around the world, can be a good model case that the KARP pursues in the future. Through multi-disciplinary efforts on Generalized Yield Model, krill availability, vital rate of dependent species, and overlap between commercial fishing and predator foraging, as identified as important research items to elaborate ecosystem management scheme by Everson (2001), the KARP might achieve a better reputation from the various scientific communities and public.

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