Due south

RV "G. O. Sars" braves the notorious Southern Ocean in search of swarming *Euphausia superba*

*Expedition leader **Svein A. Iversen** and biologist **Georg Skaret** look back on the cruise and discuss Norway's growing contribution to the Convention on the Conservation of Antarctic Marine Living Resources.*

Krill is one of the most abundant and successful animal species on our planet. Its importance in the Southern Ocean is such that the ecosystem is often labelled "krill-centric". At the beginning of 2008, Norway, as the major krill fishing nation and member of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), conducted a research cruise to learn more about Antarctic krill (*Euphausia superba*) and the ecosystem which it inhabits.

The total biomass of Antarctic krill in the Southern Ocean is, as yet, unknown, but it is vast and it dominates the ecosystem. Krill feeds mainly on phytoplankton, but it is in its role as prey for fish, marine mammals, and seabirds that it earns its key status in the Southern Ocean.

The krill fishery is situated in the Southwest Atlantic sector of the Southern Ocean in the area surrounding South Georgia (FAO Area 48.3), the South Orkney Islands (FAO Area 48.2), the South Shetlands Islands, and the Antarctic Peninsula (FAO Area 48.1). Norwegian vessels began fishing Antarctic krill here in 2005 and have, in a few short years, established Norway as the major krill fishing nation with catches of 120 000 tonnes and 103 000 tonnes in 2010 and 2011, respectively, which accounts for more than 50 % of the total catch. At present, there are three active Norwegian vessels. A fourth license has been issued, but not yet activated.

Why fish krill?

Krill meal is used in aquariums and aquaculture. Human consumption of krill includes omega-3, medicine, and cosmetics.

At your service

Due to the significant Norwegian activity in the area, the Institute of Marine Research (IMR) in Bergen took the initiative to further the scientific work on which the management of the marine resources in the Southern Ocean was based. The management body, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), was established in 1980, with its headquarters in Hobart, Tasmania, and currently comprises twenty-four member states. Norwegian scientists have worked with CCAMLR since 1982, but this project was to be Norway's first major contribution. The Antarctic Krill and Ecosystem Survey (AKES), led by the IMR, was carried out with the RV "G. O. Sars" in 2008 as part of the International Polar Year (IPY), with major contributions from the University of Oslo and CCAMLR, and was funded by the Research Council of Norway, the Norwegian Petroleum Directorate, ABB, Norsk Hydro, and the IMR.

Management of the Antarctic krill fishery has, so far, been based on an acoustic survey carried out by Russia, USA, UK, and Japan in 2000 in FAO Areas 48.1–48.4. This survey estimated the krill biomass to be 44 million tonnes. However, it became clear that this estimate was associated with large uncertainties. In particular, there was a huge, uncertain bias related to the necessary conversion from acoustic backscatter to real krill biomass (Conti and Demer, 2006). With IMR's acoustic expertise and the RV "G. O. Sars" especially equipped for acoustic investigations, one of the main objectives of the AKES project was to investigate the acoustic properties of Antarctic krill in order to understand and reduce the uncertainty in the krill biomass estimates. A further aim was to investigate the acoustic properties of two other important organisms in the Southern Ocean ecosystem: salps (*Salpa thompsoni*) and mackerel ice fish (*Champsocephalus gunnari*). As the survey was to be extensive in terms of time at sea, coverage of latitudinal and longitudinal gradients, and expert competence from different scientific fields, broader research questions could also be posed. For instance, could different properties of the krill population, such as demography, distribution, and swarm dynamics, be related to hydrographical conditions, phytoplankton concentrations, and nutrients, and could the distribution of krill-dependent predators like birds and baleen whales be related to the distribution of krill? An array of Norwegian and international scientists representing biodiversity, paleoclimatology, fish physiology, birds, mammals, air pollution (aerosol), and hydrography also took part in the AKES survey. Studies of krill genetics and fish parasites were also carried out. Throughout the AKES project, there was continual progress in the use of acoustic frequency response to distinguish between targets such as krill and salps.

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Cruising for krill

On 4 January 2008, "G. O. Sars" sailed out of Montevideo, Uruguay. The first leg of the survey brought the crew and scientists via the Falkland Islands to South Georgia where instrument calibration and the first acoustical investigations of krill and mackerel ice fish were carried out before heading east to Bouvetøya. Cape Town marked the halfway point for the survey and an exchange of crew and scientists. The second leg of the journey travelled south from Cape Town, along 15°E to the Astrid Ridge and then north along 7°E to Walvis Bay, Namibia, where the survey ended on 27 March. The total distance sailed was 12 500 nautical miles. Predeparture worries concerning the infamous weather in the survey area proved to be almost unfounded. Work on board the ship during the first six weeks was hampered by only one hurricane, but during the second part of the survey, the Bouvetøya area had to be evacuated prior to schedule due to adverse weather forecasts.

Hydrographical data were collected with a CTD equipped with fluorometer and an oxygen sensor. Phytoplankton samples were collected from water samples and vertical net hauls. Zooplankton and fish were collected by MOCNESS, krill trawl, Juday-, and WP-2 nets. Marine mammal sighting surveys were also performed during the second part of the survey. To investigate acoustic properties, a Simrad EK60 equipped with six frequencies (18–333 kHz) was applied. In the southernmost part of the investigated area, the Astrid Ridge, the bottom was mapped for the Norwegian Petroleum Directorate using a 30-kHz multibeam echosounder.

Despite the extensive coverage of west–east and north–south gradients throughout the survey, swarms or layers of Antarctic krill were only detected along the transect of their habitat range, south of 52°S, with the highest concentrations observed in the vicinity of shelves and ridges. Demography varied between regions investigated (Krafft *et al*., 2010), and the frequency of swarms was much higher west of Bouvetøya than east. The results show that environmental factors, particularly currents, strongly influence swarm properties (Krafft *et al*., In revision). Genetic samples from krill were also collected throughout the survey period to obtain more information about the stock's genetic structure and composition. Based on these investigations, CCAMLR has opened the Bouvetøya area (Area 48.6) to an exploratory krill fishery.

A total of 82 species from 29 families of fish were caught during the survey; however, in comparison to krill, the fish catch was small and dominated by the small mesopelagic lantern fish. 227 fish were fully examined for external macroparasites. 620 individual metazoan parasites were collected, and several new microscopic parasite species were discovered in the digestive systems of fish specimens.

An ecosystem-based approach

CCAMLR was established on the premise that a krill fishery should not inadvertently or disproportionately affect the ability of land-based krill predators to feed. For example, model simulations suggest that penguins might be adversely affected if too much krill were caught in a concentrated area (Watters *et al*., 2009). Building on this, CCAMLR has developed a management regime which is considered to be the most progressive ecosystem-based approach in the world today. This includes the identification of a catch trigger level whereby once reached, all fishing is stopped to avoid interference with predators that are dependent on krill.

Rising salp

Salps are another significant species in the Southern Ocean ecosystem. They live in an environment similar to that of Antarctic krill and also feed on phytoplankton. Research appears to indicate that salps are more tolerant of increasing temperatures than krill and may, therefore, surpass the krill population in areas where water temperatures are rising. While salps also feed on algae, they are not an important food source for other animals and are often regarded as something of a nuisance species because of their explosive population levels.

According to CCAMLR, fishing beyond the trigger level can only be allowed by moving the fishing vessels out into open waters (outside the primary catch areas) and allocating catch limits in small-scale managements units (SSMUs). As this SSMU management regime is not yet in place, the trigger level remains as the actual TAC. Since 1992, krill catches have varied between 100 000 and 220 000 tonnes, which is far below the trigger level of 620 000 tonnes that is divided between the four FAO Areas 48.1–48.4. Based on the results from the AKES project, the krill estimate from 2000 has now been revised to 60 million tonnes.

Future work

Lack of funding and ship time has prevented CCAMLR from repeating the survey carried out in 2000. Therefore, it is not known how the krill biomass has evolved over the past decade. Based on an analysis of all available scientific net hauls, Atkinson *et al*. (2004) found a significant decline in krill densities in the Southwest Atlantic sector since 1976, while the densities of salps have increased over the same period. The results of this study are alarming and need to be investigated further.

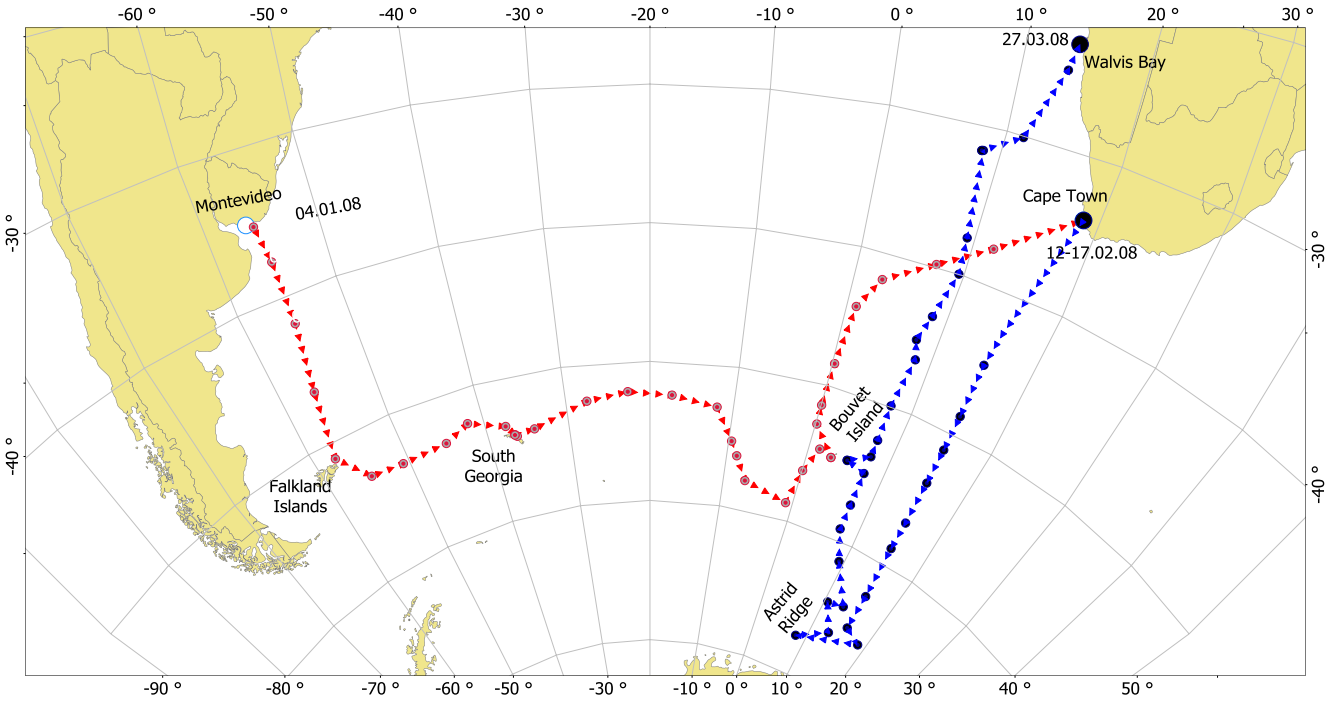
From 2011 to 2015, Norwegian krill fishing companies will allocate five survey days annually free of charge for krill research in the target area of the South Orkneys. This ship time forms the basis of a Norwegian–Chinese krill project (NorChiK), which is investigating krill abundance and overlap with krill predators. The survey hopes to gain more knowledge regarding the accuracy of area-based trigger levels.

An array of Norwegian and international scientists took part in the AKES survey.

▲ *A trawl net filled with krill. Photo: Leif Nøttestad.*

The Norwegian investigations are now an important complement to the US–Antarctic Marine Living Resources Program (US–AMLR) off the Antarctic Peninsula and the British Antarctic Survey's (BAS) investigations off South Georgia. IMR is responsible for the science together with the Yellow Sea Fisheries Research Institute, Qingdao, China, and two surveys have been successfully carried out to date. Together, these regional efforts from different CCAMLR member nations effectively cover the regions with highest krill concentrations and the most extensive fisheries. However, the flux and connectivity between the regions, as well as the dynamics in other areas important for young krill, are still poorly understood. To address this, BAS and IMR are currently planning to transfer the knowledge gained from the regional surveys into a broader understanding of the ecosystem dynamics. In this context, Norway has started looking at funding possibilities for a new survey to the Southern Ocean with RV "G.O. Sars" in the 2014/2015 season. In the meantime, the ongoing work of collecting and analysing acoustic data from commercial vessels during normal fishing operations continues to provide valuable information at low costs. The ultimate aim of these joint international efforts is to facilitate an improved management system due to increased information and a better understanding of the ecosystem.

▼ *The route taken by the RV "G. O. Sars" with the first leg marked in red and the second leg marked in blue.*



RESEARCH VESSEL "G.O. SARS":

- Built 2003.
- Length 77.5 m, beam 18.6 m.
- 4096 tonnes.
- Cruising speed 10 knots, top speed 17 knots.
- Very quiet.
- Advanced acoustical instruments (echo sounders, sonars, current meter).
- Large and well equipped trawl deck.
- Large hangar amidships for storing and operating various pieces of sampling equipment and instruments.
- Special laboratories for analysing samples: oceanography, plankton and fish.
- Echo sounder that penetrates 150 m into the sea bottom, and core sampling equipment.
- Equipment for seismic research.

◀ *"G. O. Sars" berthed at Grytviken, South Georgia. Photo: Kjartan Maestad.*

Literature cited and further reading

Atkinson, A., Siegel, V., Pakhomov, E., and Rothery, P. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature, 432: 100–103.

Calise, L., and Skaret, G. 2011. Sensitivity investigation of the SDWBA Antarctic krill target strength model to fatness, material contrasts and orientation. CCAMLR Science, 18: 97–122.

Conti, S. G., and Demer, D. A. 2006. Improved parameterisation of the SDWBA for estimating krill target strength. ICES Journal of Marine Science, 63: 928–935.

Iversen, S. A., Myklevole, S., Maestad, K., and Nøttestad, L. (eds) 2010. Cruising for Krill In the Southern Ocean with G.O Sars. Bergen. ISBN 978-82-7128-572-2.

Krafft, B. A., Melle, W., Knutsen, T., Bagøien, E., Broms, C., Ellersten, B., and Siegel, V. 2010. Distribution and demography of Antarctic krill in the Southeast Atlantic sector of the Southern Ocean during austral summer 2008. Polar Biology, 33: 957–968.

Krafft, B. A., Skaret, G., Knutsen, T., Melle, W., Klevjer, T. A., and Søiland, H. Antarctic krill swarm characteristics in the Southeast Atlantic sector of the Southern Ocean. In revision for Marine Ecology Progress Series.

Lee, C. I., Pakhomov, E., Atkinson, A., and Siegel, V. 2010. Long-Term Relationships between the Marine Environment, Krill and Salps in the Southern Ocean. Journal of Marine Biology, Article ID 410129.

Watters, G., Hill, S., Hinke J., and Trathan, P. 2009. The risks of not deciding to allocate the precautionary krill catch limit among SSMUs and allowing uncontrolled expansion of the krill fishery up to the trigger level. CCAMLR WGEMM 09/12.

Wiebe, P. H., Chu, D., Kaartvedt, S., Hundt, A., Melle, W., Ona, E., and Batta-Lona, P. 2009. Acoustic properties of Salpa thompsoni. ICES Journal of Marine Science, 67: 583–593.

Svein A. Iversen has worked at the Institute of Marine Research (IMR) in Bergen since 1973, mainly on the biology, migration, and population dynamics of pelagic fish such as mackerel, horse mackerel, herring, and sprat in European waters and Japanese anchovy in the Yellow Sea and East China Sea. He has been a member of various ICES working groups since 1982, mainly those dealing with mackerel and horse mackerel. He was the Norwegian representative to the scientific committee of the Commission for the Conservation of Antarctic Marine Living Resources in 2003–2011 and is currently leading the project Antarctic Krill and Ecosystem Study (AKES) at IMR.

Georg Skaret is a research scientist at the Institute of Marine Research (IMR). In 2007, he received his PhD from the University of Bergen working on behavioural ecology of pelagic fish. He has been working at the IMR since 2008, with a focus on Antarctic krill in the Southern Ocean. In particular, his work is related to acoustic properties applied during biomass estimation and during ecological and behavioural studies. He has participated in several CCAMLR scientific workshops focusing on krill and ecosystem assessment.