Setting a precautionary catch limit for Antarctic krill

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Setting a Precautionary Catch Limit for Antarctic Krill

Roger P. Hewitt
Jon L. Watkins
Mikio Naganobu
Pavel Tshernyshkov
Andrew S. Brierley
David A. Demer
Svetlana Kasatkina
Yoshimi Takao
Cathy Goss
Alexander Malyshko
Mark A. Brandon
So Kawaguchi
Volker Siegel
Philip N. Trathan
Jennifer H. Emery
Inigo Everson
Denzil G.M. Miller

1NOAA/Southwest Fisheries Science Center • La Jolla, California USA
2British Antarctic Survey • Cambridge UK
3National Research Institute of Far Seas Fisheries • Shimizu Japan
4AtlantNIRO • Kaliningrad Russia
5Gatty Marine Laboratory, University of St. Andrews • Fife Scotland
6National Research Institute of Fisheries Engineering • Ibaraki Japan
7The Open University • Milton Keynes UK
8Institut für Seefischerei • Hamburg Germany
9Marine and Coastal Management • Roggebaai South Africa

Abstract

A revised precautionary catch limit for Antarctic krill (Euphausia superba) in the Scotia Sea of 4 million tons was recently adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The limit was based on a total biomass of 44.3 million tons, as estimated from an acoustic and net survey of krill across the Scotia Sea sector of the Southern Ocean, and a harvest rate of 9.1%, as determined from an analysis of the risks of exceeding defined conservation criteria. We caution, however, that before the fishery can expand to the 4-million-ton level it will be necessary to establish mechanisms to avoid concentration of fishing effort, particularly in proximity to colonies of land-breeding krill predators, and to consider the effects of krill immigrating into the region from multiple sources.

The Antarctic Circumpolar Current (ACC) concentrates and accelerates as it passes through Drake Passage transporting massive quantities of water from the Bellingshausen Sea (southeast Pacific) to the Scotia Sea (southwest Atlantic) sectors of the Southern Ocean. High concentrations of Antarctic krill (Euphausia superba) and krill predators are located in this region (Marr, 1963; Laws, 1985) as well as an international fishery targeting krill (Agnew and Nicol, 1996). The fishery is regulated under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), part of the Antarctic Treaty system (Box 1). Article II of Convention mandates that fisheries be managed such that: a) the size of harvested populations is sufficient to ensure stable recruitment; b) ecological relationships between harvested and dependent populations are maintained; and c) changes to the marine ecosystem that cannot be reversed over two or three decades are prevented. In order to meet this charge CCAMLR adopted a precautionary approach whereby the provi-
Sions of Article II were more specifically defined and risks were quantitatively assessed (Butterworth et al., 1992; Constable et al., 2000).

The approach is to set the proportion of the unexploited biomass that can be harvested under specific management criteria (Box 2). Risks are evaluated by comparing statistical distributions of population biomasses generated from simulated population trajectories, with and without fishing mortality. Uncertainty is accommodated by using values of abundance, recruitment, growth and mortality drawn from appropriate statistical distributions. The first criterion is to protect the viability of the harvested population and for Antarctic krill is defined such that the probability that the population biomass falls to less than 20% of its unexploited median level should be less than 10%. The second criterion is to protect the viability of krill predator populations and is defined such that the median population level should be at least 75% of the unexploited median population level. The third criterion is to evaluate these risks using population trajectories that extend at least 20 years. The value of the harvest rate, expressed as a proportion of the unexploited biomass that meets these criteria is accepted as the most precautionary. This value together with an estimate of the unexploited population biomass is used to set the precautionary catch limit for krill. Initially, an estimate of krill biomass was generated from acoustic data collected during the first international BIOMASS experiment (FIBEX) in 1981 (Trathan et al., 1992), the only large-scale acoustic survey in this region prior to 2000.

Our motivations for conducting a new acoustic survey were threefold. The first was the recognition of several technical improvements

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### Box 1

**What is CCAMLR?**

The Convention for the Conservation of Antarctic Marine Living Resources was negotiated by the Antarctic Treaty Consultative Parties in the late 1970s and entered into force in 1982 with a permanent Secretariat located in Hobart, Tasmania, Australia. It is widely acknowledged that the Convention was the first international fisheries agreement to mandate an ecosystem approach to resource management, and that its Commission (CCAMLR) was the first to formally incorporate uncertainty into the formulation of management advice, the first to implement conservation measures designed to reduce catastrophic by-catches of seabirds, and the first to effectively address illegal, unregulated and unreported (IUU) fishing of Patagonian toothfish (widely marketed in North America as Chilean seabass) through a catch documentation scheme. The meetings of Scientific Committee of CAMLR and its Working Groups are the venues where such initiatives are developed and tested, where management advice is formulated, and where full participation by member nations is highly valued. Conservation measures are adopted by CCAMLR by consensus, but implemented and enforced by Members. Currently there are 24 Members of the Commission (Argentina, Australia, Belgium, Brazil, Chile, European Community, France, Germany, India, Italy, Japan, Korea, Namibia, New Zealand, Norway, Poland, Russia, South Africa, Spain, Sweden, Ukraine, UK, USA and Uruguay) with another seven nations (Bulgaria, Canada, Finland, Greece, Netherlands, Peru and Vanuatu) acceding to the tenets of the Convention.
Evaluating the risk of exceeding defined conservation criteria.

In principle, CCAMLR has adopted a feedback approach to management of the krill fishery, by which management measures are adjusted in response to ecosystem monitoring. However, such a management scheme remains to be fully developed. In the interim, a complementary approach, which defined and implemented provisions of Article II of the Convention in reference to the Scotia Sea krill stock, was adopted in order to set a precautionary catch limit. Once specific management objectives and the criteria for achieving them were agreed to in the policy arena the analysis of risk and provision of advice could be accomplished with less ambiguity.

The frequency distributions of simulated population sizes (left) illustrate the approach for Antarctic krill and are reproduced from a recent paper by Constable et al. (2000).

The first is the frequency distribution of unexploited population biomass obtained from an age structured population model that incorporates variability for growth, mortality and initial population biomass. The black dotted line indicates the median of the distribution.

The second is the frequency distribution of lowest population biomasses achieved during each of the 20-year trajectories under a specific harvest rate. The red area represents the probability of biomass declining below 20% of the unexploited median biomass over a 20-year harvesting period. This probability is currently set at 10% or less with the intent of protecting future recruitment.

The third is the frequency distribution of population biomasses at the end of a 20-year under a specific harvest rate. The current criterion is that the median of this distribution (blue dotted line) is equal to at least 75% of the median of the unexploited population biomasses with the intent of protecting the availability of prey to krill predators.

For krill in the Scotia Sea, the harvest rate meeting these criteria was 9.1%. The criteria are somewhat arbitrary and may be adjusted as more information becomes available regarding the relationships between krill population biomass, recruitment and predator response. The approach, however, allows for the incorporation of natural variability in population parameters and uncertainty in their estimation in the evaluation of risk associated with various harvest rates.

Box 2

Biomass relative to median unexploited biomass

Oceanography • Vol. 15 • No. 3/2002

28
Figure 1. Island groups and bathymetry of the Scotia Sea (shading indicates 500 m, 1000 m, and 3000 m isobaths). (a) Survey strata outlined in black relative to historical fishing activity (red squares) and major ocean frontal zones (blue lines; from north to south, the Sub-Antarctic Front, the Polar Front, the Southern ACC Front, and the southern ACC Boundary). (b) Survey transects color coded, where green indicates those transects occupied by the Japanese R/V Kaiyo Maru, yellow indicates the Russian R/V Atlantida, blue indicates the British RRS James Clark Ross, and red indicates the US chartered R/V Yuzhmorgeologiya. Arrows indicate direction of major currents.

Harvest statistics for Antarctic krill are maintained by the CCAMLR Secretariat, P.O. Box 213, North Hobart 7002, Tasmania, Australia. Email: ccamlr@ccamlr.org; website: www.ccamlr.org

Oceanography • Vol. 15 • No. 3/2002
Delineating acoustic return from krill.

Echosounders have been used since the 1940s to locate fish and qualitatively assess their abundance. Since the 1960s, however, their practical value as a quantitative tool for stock assessment has increased dramatically with the availability of digital electronics, cheap computing power and the Global Positioning System (GPS). The current survey took advantage of some of these developments:

On each survey vessel samples of volume backscattering strength at 38 and 120 kHz were collected; vertical resolution was 0.71 m from transducer to 500 m depth and horizontal resolution was approximately 10 m (ping interval was 2 sec while steaming at 10 knots). These data were corrected for losses due to spherical spreading and absorption of sound energy and adjusted for the effects of temperature on acoustic wavelength and equivalent two-way beam angle. The reconstructed echograms were filtered to include only the transect periods between stations and to exclude echoes due to surface turbulence and the bottom (first two panels).

Echograms were then resampled by averaging volume backscattering strength over 5 m (vertical) by 500 m (horizontal) bins. Time-varied echograms of pure noise were generated and subtracted from the resampled echograms. In this example the primary sound reflectors are aggregations of Antarctic krill and myctophid fish (second two panels).

Backscattering was attributed to krill when the difference between mean volume backscattering at 120 kHz and 38 kHz was greater than 2 dB but less than 16 dB (Watkins and Brierley, 2000). This was accomplished by subtracting the 38 kHz noise-free resampled echogram from the 120 kHz noise-free resampled echogram. Portions of the 120 kHz noise-free resampled echogram were then masked to exclude regions where the difference between the mean volume backscattering strength at 120 kHz and that at 38 kHz was less than 2 dB or greater than 16 dB (lower of third set of panels).

In the final steps the masked noise-free resampled 120 kHz echograms were vertically integrated 500 m depth and averaged over 1 nautical mile horizontal distance (upper of third set of panels). Integrated volume backscattering area was converted to area krill density by applying a factor equal to the quotient of the weight of an individual krill and its backscattering cross-sectional area summed over the length frequency distribution (Hewitt and Demer, 1993). Conversion factors were calculated for each length frequency cluster and applied to the appropriate segments of each transect. Area krill density values were under-weighted by the degree to which the survey vessel deviated from the intended transect direction.\(^3\)

\(^3\)Copies of the CCAMLR 2000 Survey core data sets are maintained by the CCAMLR Secretariat. Rules of access to CCAMLR data are available from the CCAMLR website. Any scientist from a member country can request access to the data through that country's representative to the Scientific Committee. A collection of papers describing various aspects of the survey is expected to be published in a special issue of Deep Sea Research II.
Table 1

Krill density and biomass estimates by strata.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Mean krill density (g/m²)</th>
<th>Area Surveyed (10³ km²)</th>
<th>Biomass (10³ tons)</th>
<th>Coefficient of Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Antarctic Peninsula</td>
<td>11.2</td>
<td>473.3</td>
<td>5320</td>
<td>19.3</td>
</tr>
<tr>
<td>2. Scotia Sea</td>
<td>24.5</td>
<td>1109.8</td>
<td>27235</td>
<td>15.3</td>
</tr>
<tr>
<td>3. East Scotia Sea</td>
<td>11.3</td>
<td>321.8</td>
<td>3642</td>
<td>42.5</td>
</tr>
<tr>
<td>4. South Shetland Islands</td>
<td>37.7</td>
<td>48.6</td>
<td>1836</td>
<td>26.2</td>
</tr>
<tr>
<td>5. South Orkney Islands</td>
<td>150.4</td>
<td>24.4</td>
<td>3670</td>
<td>55.5</td>
</tr>
<tr>
<td>6. South Georgia</td>
<td>39.3</td>
<td>25.0</td>
<td>982</td>
<td>30.8</td>
</tr>
<tr>
<td>7. Sandwich Islands</td>
<td>25.8</td>
<td>62.3</td>
<td>1604</td>
<td>26.4</td>
</tr>
<tr>
<td>All Strata</td>
<td>21.4</td>
<td>2065.2</td>
<td>44289</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Figure 2. Composite krill length-frequency distributions and the geographic distribution of stations for each cluster as defined by Volker Siegel (pers. comm.). Note the broad band of small, 1–2 year old krill extending into the eastern portion of the Scotia Sea from the Weddell Sea, while larger, 3–6 year old krill were encountered in other portions of the surveyed area. Krill were sampled on each survey vessel using a Rectangular Midwater Trawl (Baker et al., 1973) with an 8 m² mouth opening and 4.5 mm mesh. The net was retrieved from 200 m depth at a constant rate of 0.3 m sec⁻¹ while the ship was moving forward at 2.5 ± 0.5 knots. A flow meter and a real-time time depth recorder were attached to determine the volume of water filtered and the net trajectory. Sub-samples of at least 100 krill were taken from each catch for length measurements and maturity stage identification (Makarov and Denys, 1981); all krill were examined from catches of less than 100 specimens. A cluster analysis was conducted by computing a similarity matrix, based on the relative frequency of each krill length class at each station, and subsequently fusing clusters using the Euclidean distance coefficient as measure of similarity. Only stations with a minimum of 20 measured specimens were considered; 66 out of 135 stations were included in the similarity matrix. Station-specific length frequency distributions were weighted by catch and the volume of water filtered before compiling the composite length-frequency distributions shown here.
north to the eastern end of South Georgia; very large
krill (4–6 years old, 52 mm modal length) were
mapped in the western Scotia Sea and Drakes Passage;
a third cluster of large krill (3–5 years old, 48 mm
modal length, but also including several samples of
intermediate size krill) was mapped in the inshore
waters adjacent to the Antarctic Peninsula and extend-
ed across the northeastern part of the survey area
(Figure 2).

The estimate of krill biomass in the Scotia Sea,
together with a harvest rate of 9.1%, was used to estab-
lish a potential yield of 4 million tons (CAMLR-XIX,
2000). The population model underlying the simula-
tions assumes a freely distributed krill population,
homogeneously distributed predation pressure and
randomly determined recruitment. The effects of
uncertainty with regard to input parameters are
included, but spatial and temporal trends in krill
demographics, predator demand and fishing pressure
are not (Hewitt and Linen Low, 2000). Several mem-
ers of CCAMLR are conducting research studies and
long-term monitoring in order to provide some of this
information (Agnew, 1997), but until a more spatially
explicit management scheme is in place the region-
wide model will remain the primary tool for setting
population-wide harvest rates.

Before the fishery can expand to the 4-million-ton
level, however, it will be necessary to establish mecha-
nisms to avoid concentration of fishing effort near
colonies of land-breeding krill predators. The Scientific
Committee of CAMLR is currently investigating how
such mechanisms may be rationalized by the estab-
lishment of small-scale management units. These data
also suggest that krill resident in the Scotia Sea may
come from more than one source, further complicating
management considerations.

The precautionary approach to the management of
the krill fishery adopted by CCAMLR provides a
method by which uncertainty in parameter estimates
can be explicitly included in the estimate of harvest
rate. The framework is flexible and can accommodate
restatement of management objectives and reformula-
tion of the criteria used to ensure that the objectives are
met. Moreover, the approach allows separation of the
political process of setting management objectives and
criteria from the technical process of running the pop-
ulation simulations and determining the harvest rate.
This approach was developed over several years by
Doug Butterworth, Bill de la Mare, Andrew Constable
and their colleagues and is now referred to as the
Generalized Yield Model (GYM). Use of the GYM to
manage the krill fishery, however, was adopted by
CCAMLR as an interim measure to its preferred
approach: a feedback scheme whereby management
measures are adjusted in response to ecosystem moni-
toring (Constable et al., 2000). The full development of
this approach will require: 1) enhancement of
CCAMLR's existing ecosystem monitoring program; 2)
further development of models linking krill, their
predators, environmental influences and the fishery; and 3) high-resolution, real-time information regarding
the behavior of fishing vessels.

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