Appendix 1: Precautionary catch limits and Krill's Yield Model (KYM)

In 1981, the First International BIOMASS Experiment (FIBEX) was undertaken, the largest survey conducted in the Antarctic marine environment. During FIBEX, various sectors of the Antarctic were surveyed by a large fleet using acoustic techniques to determine krill biomass. The results of FIBEX were used by CCAMLR to estimate the krill pre-exploitation biomass (B_0), which was needed to estimate initial krill yield and apply precautionary catch limits.

In 2000, CCAMLR sponsored another large survey of krill biomass in the Antarctic (the "2000 Synoptic Survey"). This survey took advantage of the use of new technologies to determine krill abundance and distribution. The 2000 Synoptic Survey covered most of the Scotia Sea, including the continental shelf, oceanic regions, the major frontal zones associated with the Antarctic Circumpolar Current, and the principal fishing areas. The total krill biomass from the study area was estimated in 44.3 million tonnes. In addition, during the 2000 Synoptic Survey, oceanographic data on relevant environmental features were collected.

In order to provide precautionary limits for krill catches, CCAMLR designed a "Krill Yield Model" (KYM). The KYM was developed after the second meeting of the CCAMLR Working Group on Krill (WG-Krill) in 1990, as a response to concerns raised about the level of krill exploitation in Subarea 48.3.

Given the size of most management areas for krill and the difficulties inherent to determining krill age it is doubtful whether traditional annual assessments of krill will ever be achievable. Traditional analysis such as yield-per-recruit do not take into account either uncertainty in the biological parameters or random fluctuations in recruitment.

Therefore, to determine precautionary catch limits, CCAMLR concentrated on using stochastic projection methods (using computer simulations) and developed calculations on long-term yield catch limits (over a period of 20 years). In this approach, estimates of krill recruitment variability, growth, and natural mortality are used in stochastic simulations[1] to determine the effects of various levels of harvesting on the population.[2]

For each level of harvesting, the parameter _ (proportionality coefficient)[3] in the equation $Y = \_ B_0$ is calculated and the stock is tracked over a 20 year period (where Y = yield and B_0 = pre-exploitation biomass). The stochastic model is run a large number of times and the distribution of various management quantities are determined, and the probability of

[1] For this simulations a Monte Carlo integration is used.

[2] Miller, D.G.M. and Agnew, D (2000) Management of Krill Fisheries in the Southern Ocean. In: *Krill: Biology, Ecology and Fisheries* – (I. Everson, ed.) Fish and Aquatic Resources, Series 6. Blackwell Science, Oxford: 300-337.

[3] The value of _ depends on the biological parameters of the stock under consideration.

various outcomes of both management and fisheries-associated actions can be calculated. To give an estimate of the potential annual sustainable yield for a particular area, the single estimate of biomass obtained from a survey for a specific area before harvesting begins is used in the equation. It is important to note that with new information or improved technologies, the estimated annual krill yield will be revised and not retained for the total projected period (in this case 20 years). The 20 years period allows to set catch limits over a number of years, which is administratively more efficient than setting annual limits, a strategy that had failed for managing finfish stocks in CCAMLR.[4]

In setting precautionary limits, CCAMLR is required to take into account the needs of krill predators. In early application of the KYM, the effect of krill harvesting on dependent predators was discussed and a "discount" factor was introduced in order to reduce yield calculations in a proportionate manner. Currently, detailed modelling of the impact that the krill fishery might have on such predators, in order to provide reliable quantitative results, is still under development. Thus, for the moment, CCAMLR is following an ad hoc approach to set precautionary catch limits.[5]

Following that ad hoc approach, in 1994, the Scientific Committee used a three-part decision rule to determine precautionary catch limits of the Antarctic krill fishery.

This decision rule is as follows:

(i) _ (_1) is chosen so that the probability of spawning biomass dropping below 20% of pre-exploitation median level over a 20-year harvesting period is 10%;

(ii) _ (_2) is chosen so that the median krill escapement over a 20-year period is 75% and

(iii) the lower of _1 and _2 is selected as the level of _ for the calculation of krill yield.

The first two criteria of the decision rule (i) and (ii) are related to the objectives 3(a) – "the recruitment criterion" – and 3(b) – "the predator criterion" – in Article II of CCAMLR, respectively.[6] In (i) the krill fishery is considered in a 'single-species'

[4] Constable, A.J., de la Mare, W.K., Agnew, D.J., Everson, I., and Miller, D. (2000). Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). *ICES Journal of Marine Science*, 57: 778-791.

[5] *Supra* note 2.

6 Article II, paragraph 3 of CCAMLR: "any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation: (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment; (b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and (c) prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the

context, whereas (ii) includes the need for krill of dependent predators. On the other hand, the length of time over which the risk is evaluated (20 years) relates to 3(c) of Article II. In this manner, the objectives of the Convention are specified in scientifically and measurable terms. The values used in (i) and (ii) are arbitrary and will be revised from time to time. [7]

The recruitment criterion (i) will need to be revised taking into account any information that becomes available on the relationship between stock and recruitment. The predator criterion (ii) will vary depending on better information on the functional relationship between abundance of prey and recruitment in predator populations. The current escapement value in (ii) of 75% is an initial value on which to base management recommendations. This value lies between the customary 50% level applicable in a single species conventional fisheries context (without taking into account predators) and the 100% level associated with no fishing activities (i.e. providing complete protection for predators).

As defined in the decision rule, the final stage in the application of the results from the yield model to provide a precautionary catch limit is to select the lower of the two values of _. By doing this, CCAMLR aims at protecting the stock by taking due account of uncertainty.

The KYM will be continually refined as more data become available to reduce the uncertainty in estimates of some of the input parameters and as more is learnt about the relationships between these inputs. These factors could affect estimates of the value of _ that are appropriate to avoid recruitment overfishing. Possibly more important, however, will be the refinement of the functional relationships between abundance of krill and recruitment in predator populations. This will provide a sounder basis for the selection of a target krill escapement value that would address the concerns related to Article II (i.e. would provide more scientifically defensible method than the ad hoc approach underlying the present selection of 75%).[8]

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direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources".

[7] *Supra* note 4.

[8] Id.