JOINT MEETING OF THE WORKING GROUP ON KRILL AND THE WORKING GROUP FOR THE CCAMLR ECOSYSTEM MONITORING PROGRAM

(Viña del Mar, Chile, 5 and 6 August, 1992)

(Convener's and Rapporteurs' Summary)

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INTRODUCTION

The following report was prepared by the Convener of the Joint Meeting, Mr O. Østvedt (Scientific Committee Chairman) and by the Conveners of the Working Group on Krill (WG-Krill) and the Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP), Mr D.G.M. Miller (South Africa) and Dr J.L. Bengtson (USA) respectively. It provides a summary of the meeting's discussions and agreed conclusions.

MEETING OBJECTIVES

The major objective of the Joint Meeting was to facilitate interaction between WG-Krill and WG-CEMP on matters of common concern.

INFORMATION REVIEW AND EVALUATION

Krill Requirement of Predators

1. Krill Escapement

In the past there has been some confusion concerning the meaning of the term "krill escapement". This appears to have arisen primarily from the use by WG-Krill of the *ad hoc* discount factor **d** in its calculation of krill yield which, by implication, takes some account of the amount of krill needed to escape from the fishery in order to meet predator demands. WG-Krill has noted that such demands would to a large extent be implicitly assumed in the krill natural mortality function **M** also used in the calculation of potential yield. WG-Krill had effectively done away with **d** by refining the estimation procedure. Consequently it was felt that it would be helpful to provide the following explanation of what is specifically meant by "escapement" (based on the definition provided by WG-Krill at its most recent meeting) in the context of accounting for the krill requirements of predators and with a view to improving understanding of information required from WG-CEMP.

A schematic representation of the concepts considered are given in Figure 1. The distribution of krill biomass in the absence of fishing is depicted by the solid curve. Biomass (**B**) is expressed as proportional escapement (**B**/**K**), where **K** is the average biomass in the absence of fishing. Natural fluctuations in recruitment from year to year lead in turn to fluctuations in biomass and hence account for the distribution in **B**/**K** shown, rather than **B** being exactly equal to **K**.

Once fishing occurs, this biomass distribution shifts to the left and its shape may broaden (see dashed curve). The heavier the level of fishing, the greater the shift and the broadening. When considering the effect of fishing on predators, it is not the extent of the shift (related to the average proportional escapement, $\mathbf{B_f/K}$) which is the most important. Rather, it is the lower tail of the distribution, since it is occurrences of especially low biomass that are the most likely to impact on the health of predator populations. It must be noted for the example illustrated, that if the "critical" level below which predators are deleteriously affected is as shown, there is a much greater likelihood of this occurring in the presence of fishing because a much greater fraction of the area under the dashed curve lies below this "critical" level than is the case for the solid (no fishing) curve.

The explanation presented above emphasises the need to consider critical levels of predator performance in relation to escapement of krill from the fishery in the development of operational definitions to address the requirements of Article II.

2. Functional Relationships Between Krill and Predators

Following on from (1) above, an initial approach to improve information on functional relationships between krill availability (i.e., abundance plus distribution) and predator performance was developed. This is attached as Appendix 1. It was emphasised that the assumptions underlying the approach are by necessity simplistic and an important component of the modelling exercise would be to test their validity.

Action: Initiation of modelling in accordance with suggestions contained in Appendix 1.

3. Krill Biomass Versus Availability

In considering krill biomass (abundance) and availability (abundance plus distribution) in relation to interactions with predators, krill availability is likely to be the more important. This distinction needs to be taken into account in the development of models relating krill yield to functional relationships between krill and its predators (see also (2) above and Appendix 1). In the interests of simplicity, however, the development of models of functional relationships between predators and krill should focus initially on krill abundance in relation to predator consumption alone. Models addressing the problem of krill availability specifically would constitute a subsequent refinement to the initial approach.

Action: Existing data should be analysed as an initial step in addressing the problem of krill abundance versus availability
Predator-prey surveys should be implemented.
The problem should be considered in subsequent refinements of the modelling approach identified in (2) above.

4. Refining Functional Relationships

It was agreed that the natural variability in predator performance and krill availability, caused by fluctuating environmental conditions, offered "natural experiments" within CEMP. Viewing these natural experiments in a predictive context could assist in understanding inter- and intra-annual patterns in interactions among predators, prey, and environmental conditions. Ways to evaluate the impact of natural experiments should be considered.

It was also agreed that large variability in predator performance and environmental stochasticity complicate the task of differentiating between changes caused by natural phenomena and those attributable to fishing. For example, the physical environment (e.g., sea-ice) affects predators directly as well as indirectly through their prey. Although some form of experimental harvesting regime may constitute the only way whereby functional relationships between krill, predators, environment and fishery could be determined, such a regime would have to be carried out over a number of years to take full account of the high levels of variability alluded to above. Such experiments may form part of a more general approach to the question of separating natural from fishery induced changes. There may, however, be other methods for refining functional relationships which do not require elaborate experimental designs.

If such experiments are to be conducted, their design must be carefully evaluated in advance. This would require some form of modelling approach which should attempt to evaluate the statistical precision necessary to quantify the detection of harvest induced changes in addition to provide some assessment of associated practical considerations.

Conclusions: The role of experimental harvesting regimes to establish functional links between krill, predators, environment and fishery should be thoroughly examined.

Action: Detailed descriptions of possible experimental harvesting regimes should be provided and their efficacy evaluated.

Strategic modelling should be developed to evaluate the statistical performance and cost-effectiveness of possible experimental harvesting regimes and in refining estimates of functional relationships between krill availability and predator performance.

Potential Overlap of Krill Fishing and Predators

5. Considering Predator Demands in Subarea Allocation of Catch Limits

In developing an approach to the possible future allocation of the precautionary catch limit of 1.5 million tonnes of krill to areas within Statistical Area 48, one option considered by WG-Krill focused on the need to take explicit account of predator demands. Doubts not only surround the possibility of obtaining gross estimates of the krill demand for important predators in various parts of Statistical Area 48, the inclusion of land-based predators alone in such estimates was questioned. Similarly, although localised situations could be used, their relationship to whole statistical subareas may be difficult to evaluate. Consequently, WG-CEMP was requested to give careful consideration to the matter as a whole with a view to evaluating the overall applicability of incorporating information on predator demands into the allocation of krill catch limits within statistical subareas.

Action: Some crude estimates of the krill demands of predators by Subarea should be provided.

The feasibility of utilising such information in the allocation of precautionary catch limits should be investigated.

6. Timing and Location of Fishery

The value of haul-by-haul data in determining the location of krill fishing activities was emphasised, particularly with respect to identifying areas of overlap between the fishery and land-based predators. Reports from the Chilean and Russian fisheries were welcomed. The submission of such data to CCAMLR, where possible, was encouraged. Problems experienced by some fishing countries in supplying such data were noted.

Action: The submission of haul-by-haul data from the krill fishery from all areas fished should be encouraged.

7. Dialogue on Operational Characteristics of the Krill Fishery

The ongoing dialogue between fishermen, fishing operators and scientists involved with issues pertaining to the krill fishery was found to be extremely useful in improving current understanding of the fishery's dynamics and its operational characteristics. This enhanced understanding is likely to facilitate consideration of various approaches to management in the future and would ensure that such approaches take explicit account of the needs of both the commercial fishery and predator requirements.

8. Krill "Surplus"

The continued use of the term "krill surplus" is not encouraged since it refers specifically to the dated concept that krill formerly eaten by baleen whales are now available to the rest of the system, including the fishery. Current thinking on ecosystem dynamics suggests that this concept is simplistic and, given other priorities in the work of WG-CEMP in particular, it was felt that it would be inappropriate to assign a high priority to undertaking further analyses of essentially historic krill-whale interactions. It was noted, however, that individual scientists may find some utility in using historic estimates of krill by whales in a simple accounting exercise to evaluate the possible reconciliation of such gross limits of krill production with more recent estimates of krill abundance.

Action: Individual scientists should undertake simple accounting exercises to compare historic whale consumption figures with recent estimates of krill abundance.

Development of Approaches for Feedback Management

9. CEMP Experimental Approach

Although the experimental approach has been integral in the development of CEMP, it was agreed that it would be useful to formulate a more formal statement of how this approach might be implemented in practice. The establishment of some form of experimental fishing regime (see (4) above), with both treatment and control areas was thought to offer a useful way to demonstrate cause/effect relationships between potential fisheries impacts and predator performance. Even though it is expected that it would be some time before experimental harvesting regimes can be implemented, some consideration should be given to ensuring that CEMP is conducted in such a way as not to preclude the possibility of initiating specific experiments in the future. Furthermore, as the movement of krill between various areas is likely to be a factor in the design of any experiments that may be undertaken, the advice of WG-Krill should be sought in identifying potential treatment and control areas. The initiation of monitoring to establish suitable baselines in such areas requires consideration.

Action: CEMP's experimental approach should be formalised in practical terms.
The development of strategic models should be encouraged in order to evaluate the statistical performance and cost-effectiveness of possible experimental harvesting regimes designed to distinguish between natural variation in predator performance and effects due to fishing.

10. Feedback Mechanisms for Management Advice

Indices of various measures of predator performance are being calculated annually by CEMP. It was agreed that it would be helpful for CEMP to consider criteria that might be used to specify levels of change or the magnitude of trends to be used in the initiation of management measures (see also discussion under (1) above). There is also a need to develop an appropriate mechanism to include information forthcoming from CEMP in the formulation of management advice on the krill fishery. It was noted that measures could be proposed regardless of whether changes in predator performance could reasonably be attributed to the fishery or whether such measures were deemed necessary to avoid having the fishery exacerbate a situation induced by factors independent of the fishery (e.g., by natural environmental fluctuations).

WG-CEMP was also requested to consider the feasibility of using a dynamic allocation scheme to allocate krill catch limits in various areas. Such allocation would be based on various measures of predator performance within such areas. The scheme would contrast with more static approaches, such as outlined in (5) above, where catches would be limited on the basis of the prey requirements of predators in each statistical subarea. Dynamic allocation of catch levels is likely only to be possible *post hoc* rather than anticipatory.

Action: The possible use and predictive applicability of employing dynamic allocation of krill catch levels based on predator performance should be investigated.
Simulation approaches should be developed to investigate the performance of and the decision rules underlying the incorporation of CEMP information into the formulation of management advice.

11. Precautionary Management Measures

It was noted that although attempts should be made to undertake the best scientific evaluations possible at this time, the information necessary to make such evaluations varies from a total lack of relevant data to data exhibiting considerable inherent variability. This range of information renders it necessary at times to formulate management advice based on a limited understanding of the status of, and interactions between various ecosystem components. In addition, in certain instances when the necessary data are available the decision rules necessary for their inclusion into management advice are lacking. It was therefore agreed that WG-CEMP should consider a precautionary approach to management along with an accompanying mixture of measures which could be applied in zones where, or for critical times when, there is significant overlap between the fishery and land-based predators (particularly during foraging). Such consideration should take account of:

(i) the needs of the fishery;
(ii) historical catch levels;
(iii) potential impacts of fishing on predators;
(iv) potential control/experimental sites for an experimental fishing regime;
(v) uncertainty in knowledge concerning functional relationships between predators, prey, and the environment; and

(vi) minimising the possibility that adverse impacts on the ecosystem occur.

Action: Additional measures to minimise potentially deleterious effects of fishing confined within the foraging ranges of vulnerable land-based predators should be formulated and evaluated.

Information Required from WG-Krill

12. Fishery Data

The continued submission of haul-by-haul data from areas within 100 km of land-based predator sites was again encouraged. Similarly, continued dialogue within WG-Krill was encouraged (see (7)). The need for fine-scale reporting of catches from subareas other than those already identified in Statistical Area 48 and the CEMP ISRs was recognised. There is also a need for demographic information (length, sex ratio, maturity stage, etc.) on krill caught in the fishery, particularly close to land-based predator sites (i.e., especially within the ISRs)

Action: Encourage submission of haul-by-haul data from the fishery within at least 100 km of land-based predator sites.
Encourage the deployment of scientific observers aboard fishing vessels to expedite the above.
The fine-scale reporting of fisheries data from statistical areas other than Statistical Area 48 should implemented.

13. Fishery Independent Data

Estimates of krill abundance and distribution in the ISRs should be encouraged and produced on an ongoing basis. In this connection, some time may be required to implement the predator-prey surveys as recommended by WG-Krill's *ad hoc* Subgroup on Survey Design. The importance of krill movement in estimates of abundance and particularly krill availability was reiterated.

Action: Continued updating of krill abundance estimates in the ISRs.
Krill abundance surveys to be carried out to cover complete ISRs.

Predator-prey surveys to be implemented using the recommended procedures.

Coordination of WG-Krill and WG-CEMP Activities

14. Enhanced Coordination

It was agreed that the Joint Meeting of WG-Krill and WG-CEMP had been a useful forum for promoting a dialogue on issues of common interest. In particular, very fruitful discussions had arisen as a result of personal contact between those with knowledge of predator biology, krill biology and the fishery. The meeting also provided an opportunity for modellers to be included in such discussions on, particularly on the costs of developing of, the most fruitful approaches to addressing deficiencies in knowledge on interactions between predators, krill and the fishery. This deployment of a wide range of scientific skills in one place was seen as being particularly beneficial to the ongoing work of both WG-Krill and WG-CEMP.

Action: Possible future opportunities to continue a close dialogue between the two Working Groups should be provided

15. Coordinating the Formulation of Management Advice

As the work of WG-Krill and WG-CEMP has progressed, areas of overlap between the two groups in relation to the formulation of management advice to the Scientific Committee have been increasingly identified.

In particular, the modelling approach outlined in Appendix 1 was seen as an important first step in a process to augment current understanding of interactions between predators, the environment, krill and the fishery. The need for further modelling both as part of, and outside CEMP was highlighted. Such modelling would improve knowledge on functional relationships (see (2)) as well as provide some basis for decision rules to account for the incorporation of information from CEMP into the formulation of management advice.

Action: Both WG-Krill and WG-CEMP should continue to consider the most effective ways of coordinating their management advice.

16. Liaison Between Working Group Conveners

To facilitate communication between the Scientific Committee's three working groups, it is important that the Conveners of the respective groups should be in contact with each other.

Action: The Conveners of the Working Group on Fish Stock Assessment (WG-FSA), WG-Krill and WG-CEMP will meet immediately prior to the 1992 annual meeting (SC-CAMLR-X, paragraph 12.4).

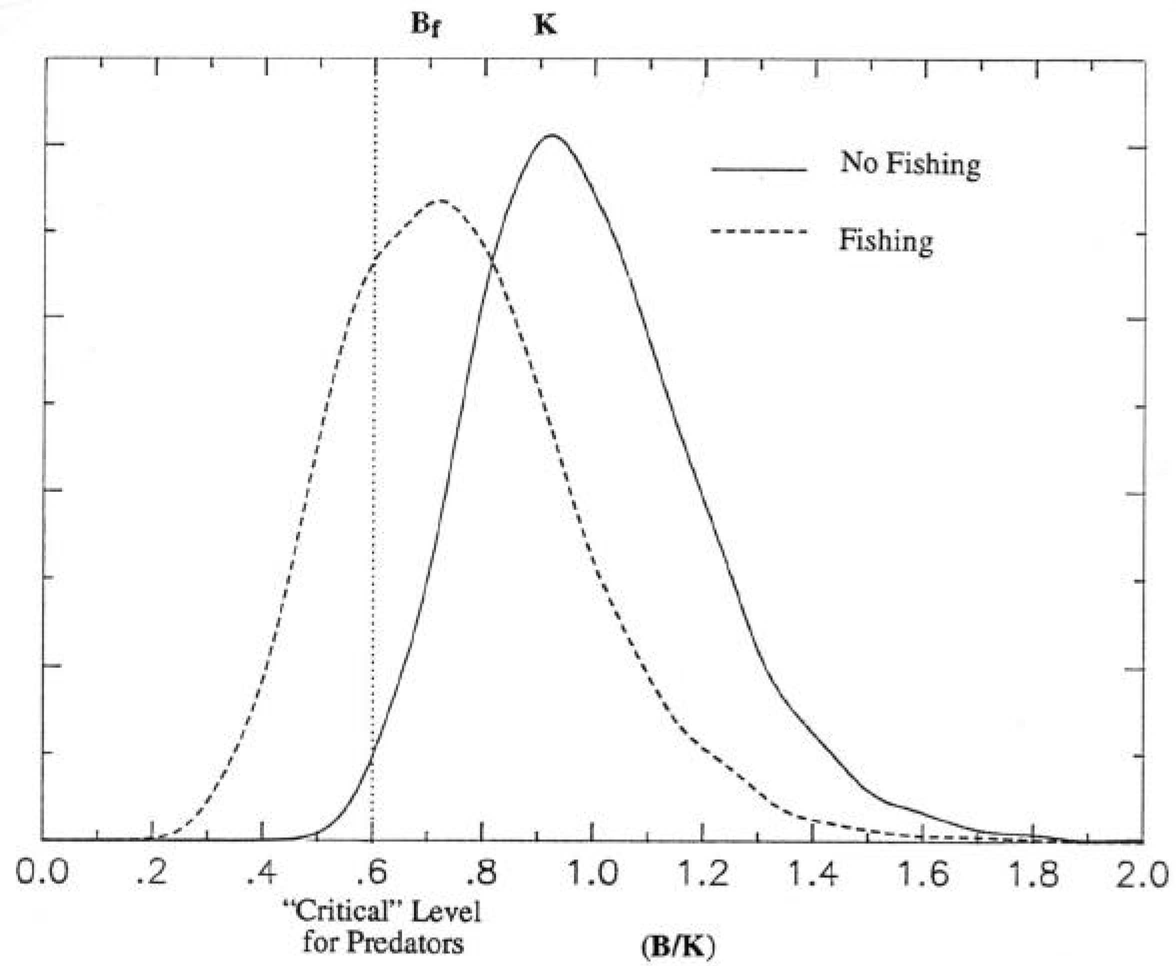

Figure 1: Effect of fishing on the frequency distribution of **B/K.**

AN INITIAL ANALYSIS OF THE EXTENT TO WHICH DIFFERENT LEVELS OF FISHING ON KRILL MAY AFFECT PREDATOR POPULATIONS

SCHEMATIC REPRESENTATION

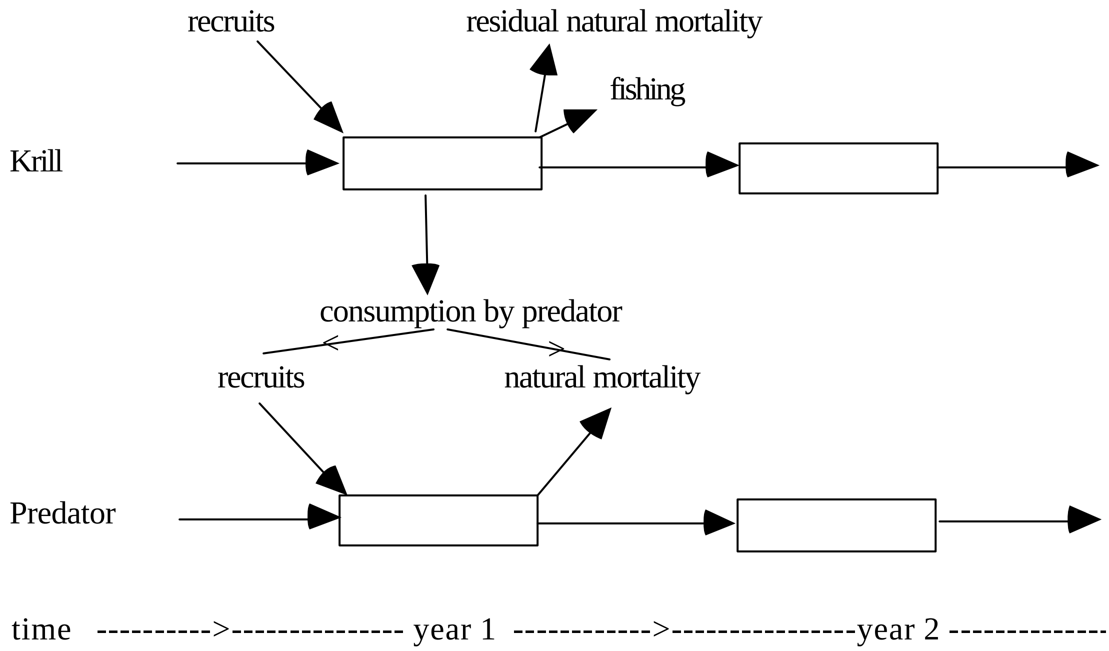

Figure 1

FACTORS TO BE TAKEN INTO ACCOUNT

The diagram in Figure 1 above indicates the inputs and outputs ("births" and "deaths") to be taken into account in modelling the demography of the krill and predator populations and their interaction. The details given below are intended as a broad description (rather than a full specification) of the minimum number of factors which need to be taken into account in the first step in this process. This first step is intended primarily as a learning exercise, following which greater realism can be incorporated into the model.

The Krill Component

The model for the krill population should be a similar but possibly slightly simplified version of that used to explore potential yield possibilities in WG-Krill-92/4. Key elements are that recruitment must include a stochastic component, and that the model must be age-structured. Integration over prior distributions for parameters whose values are uncertain can be ignored for the moment.

Fishing mortality could be modelled as a fixed annual catch. In WG-Krill-92/4, the krill natural mortality rate **M** was considered to be fixed in time. This will now be partitioned into two components: the one, the residual natural mortality (**M**') arising from predators other than the species considered, is to be treated as fixed in time; the other, arising from consumption of krill by the predator under consideration, will vary in time depending on the size of both the predator and the krill population.

The Predator Component

Both the "inputs" and the "outputs" in the model of the predator population (which must also be age-structured) can be considered as survival rates. The relation of the "adult" survival rate to natural deaths is straightforward, but the "juvenile" survival rate should be seen to include the effects of pregnancy rate as well as the higher than average mortality rate early in life.

The key concern is the nature of the functional relationships between these survival rates and krill abundance, which should have the general form indicated in Figure 2, i.e. these rates saturate at high levels of krill abundance (the per capita consumption rate of krill by the predators would also saturate at these levels).

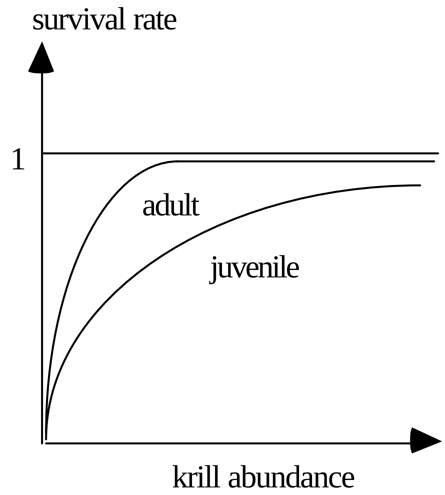

Figure 2

As an initial approach, it may be simplest to specify these relationships as indicated in Figure 3, where **K** is the average krill abundance (i.e., biomass) in the absence of fishing, and a is the fraction of **K** below which the lesser abundance of krill starts to impact on the predators. Two values of a need to be specified: a_J (for the juvenile survival rate) and a_A for the adult survival rate. Because recruitment is likely to be affected before adult mortality as the krill biomass declines, typically $a_A < a_J$. Values of a_J and a_A can be inferred from the distribution of krill biomass in the absence of fishing. For example, given the observed relative frequency of "bad" and "good" years for recruitment, a_J could be chosen so that the ratio of the areas above and below a_J **K** which lie beneath this distribution curve match the observed relative frequency. (Note that although Figure 3 is drawn in a manner which indicates that $\alpha = 1$, circumstances for certain predators may be such as lead to a value of $\alpha > 1$.)

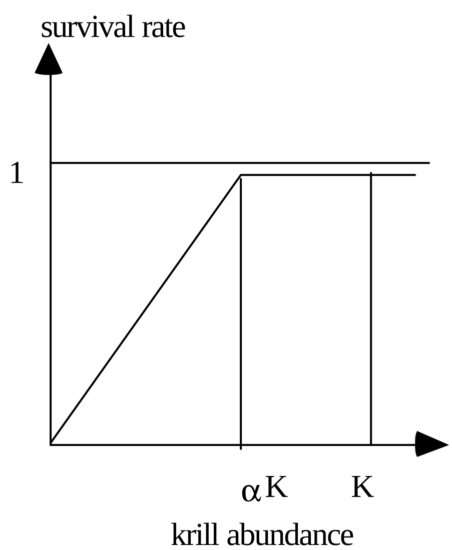

Figure 3

Responses in both adult and juvenile survival rates are seen as necessary components of an initial model. At a later stage, the effect of a stochastic component in these functional response relationships could be investigated; this could provide a means to take account of the fact that land-based predators react to local krill availability, which may not be synonymous with krill abundance in a larger area. Another subsequent refinement of the model might be consideration of breeding space limitations as well as food availability as a limiting factor for the predator population.

INFORMATION REQUESTED FROM WG-CEMP

Rather than attempt to consider some abstract "average predator", models should be developed for two or three choices of an actual predator species. These species should be selected so that their adult survival rates span a reasonably wide range, and information on breeding success and adult mortality variations is available over a reasonable period of time.

The information required for each predator species chosen is as follows:

(i) adult average annual survival rate (i.e. the largest survival rate value in the Figure 3 plot for adults);

(ii) age-at-first breeding;

(iii) categorisation of years with observations across a spectrum from bad to good from the viewpoint of the predator; thus, for example, if three categories are chosen, these might correspond to:

"good" - both breeding success and adult survival good
"poor" - breeding success poor, but adult survival unaffected
"bad" - both breeding success and adult survival poor.

In addition, with future model elaboration to allow for seasonal effects in mind, information on the breeding season for each of the predators selected should be provided.