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ANTARCTIC KRILL AND ECOSYSTEM MANAGEMENT – FROM SEATTLE TO SIENA

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Abstract

This paper outlines CCAMLR's development of a management approach for the Antarctic krill (*Euphausia superba*) fishery and associated ecosystem component between 1984 and 1995. The approach is shown to be consistent with the objectives of the CAMLR Convention, particularly its Article II. Emphasis is given to the initiation of the CCAMLR Ecosystem Monitoring Program (CEMP) and the deliberations of the Working Group on Krill (WG-Krill). Particular prominence is also attached to the modelling approach developed in order to calculate a precautionary catch limit for the krill fishery in various CCAMLR statistical areas. This paper complements those of Constable (2002 – this volume) and Everson (2002 – this volume), with the three papers documenting developments during CCAMLR's first 20 years of existence.

Résumé

Il s'agit ici du developpement par la CCAMLR d'une approche de la gestion de la pêcherie du krill antarctique (*Euphausia superba*) et des éléments connexes de l'écosystème de 1984 à 1995. Il est démontré que cette approche s'inscrit dans les objectifs de la Convention de la CCAMLR, notamment son Article II. La création du Programme de contrôle de l'écosystème de la CCAMLR (CEMP) est mise en avant, de même que le sont les délibérations du Groupe de travail sur le krill (WG-Krill). La modélisation visant à calculer une limite de capture de précaution pour la pêcherie de krill des diverses zones statistiques de la CCAMLR est une approche qui est également mise en valeur. Ce document vient compléter ceux de Constable (2002 – présent volume) et Everson (2002 – présent volume), qui ensemble constituent la documentation des réalisations de la CCAMLR au cours de ses 20 premières années d'existence.

Резюме

В настоящей работе описано, как с 1984 по 1995 г. АНТКОМ разрабатывал подход к управлению промыслом антарктического криля (*Euphausia superba*) и соответствующими компонентами экосистемы. Показано, что подход соответствует целям Конвенции АНТКОМ, в частности Статьи II. Особое внимание уделено созданию Программы АНТКОМа по мониторингу экосистемы (CEMP) и решениям Рабочей группы по крилю (WG-Krill). Также подчеркивается подход к моделированию, разработанный с целью расчета предохранительного ограничения на вылов криля в различных статистических районах зоны действия Конвенции. Настоящая статья дополняет работы Констебля (2002 г. – в этом томе) и Эверсона (2002 г. – в этом томе); все 3 документа описывают изменения, произошедшие на протяжении первых 20 лет существования АНТКОМа.

Resumen

Este trabajo describe el desarrollo del enfoque de ordenación de la CCRVMA para la pesquería de kril antártico (*Euphausia superba*) basado en el ecosistema entre 1984 y 1995. Se demuestra una congruencia del enfoque de ordenación con los objetivos de la Convención de la CCRVMA, en particular con el artículo II de dicha Convención. Se destaca el comienzo del Programa de Seguimiento del Ecosistema de la CCRVMA (CEMP) y las deliberaciones del grupo de trabajo sobre el kril (WG-Krill). Se resalta en especial la creación de modelos para calcular los límites de captura precautorios para la pesquería de kril en diversas áreas estadísticas de la CCRVMA. Este trabajo complementa los trabajos de Constable (2002 – este volumen) y Everson (2002 – este volumen); estos tres trabajos apoyan con pruebas los avances logrados en los 20 años de vigencia de la CCRVMA.

Keywords: Antarctic krill management, ecosystem approach, CCAMLR

INTRODUCTION

A directed fishery for Antarctic krill (*Euphausia superba*) has existed since the early 1970s, with catches peaking at over 500 000 tonnes in 1982 and a total of 6.1 million tonnes being taken between 1973 and 2001 (Figure 1). The krill fishery's early development paralleled progressive overfishing of finfish stocks in the Southern Ocean as a whole (Kock, 1992). The latter raised serious concerns about the future sustainability of Antarctic marine living resources in general and of krill in particular, given its key position in the Antarctic food chain (Mitchell and Sandbrook, 1980) (Figure 2). Consequently, the Antarctic Treaty Consultative Parties initiated negotiations to provide for the management, conservation and sustainable utilisation of marine living resources found south of the Antarctic Polar Front (the Convention Area – Figure 3) (Edwards and Heap, 1981). These negotiations culminated in the Convention on the Conservation of Antarctic Marine Living Resources ('CAMLR Convention'), which was signed in Canberra in 1980 and entered into force on 7 April 1982.

The CAMLR Convention was unique in that its Article II (Table 1) not only strove to ensure the conservation and rational use of Antarctic marine living resources directly, it also aimed to ensure that irreversible and negative impacts of harvesting did not affect both harvested species and those dependent on them as a source of food or in some other ecologically related way. These provisions laid the foundation for what has since been termed the 'ecosystem approach' and clearly indicated that precaution should be applied to minimise the risk of irreversible changes in the marine ecosystem within the Convention Area arising from harvesting and associated activities (Nicol, 1991). In simple and practical terms, these objectives required that:

(i) harvested populations should be assessed and monitored;

(ii) ecological interactions between harvested and other species, either dependent on, or related to them, should be defined and quantified; and

(iii) levels of depletion should be estimated in order to monitor effectively the restoration of depleted populations.

To give effect to (i) and (iii), the Commission established under the Convention (CCAMLR) set up a scientific working group (Working Group on Fish Stock Assessment – WG-FSA) in 1984 to advise its Scientific Committee (SC-CAMLR) on potential catch levels for harvested species other than krill (Agnew, 1997). Standard fishery management techniques were initially based on the estimation of Maximum Sustainable Yield (MSY) (Beverton and Holt, 1956; Sissenwine, 1978) as a means to set appropriate catch levels. In 1987, the approach was refined to include management measures based on the consequences of a target, or desirable, fishing level (SC-CAMLR, 1987). This led to the introduction of $F_{0.1}$ (see Hilborn and Walters, 1992 for definition) as a management standard for selected finfish species. Over the years, WG-FSA has refined its management procedures and most recently has come to base these on more rigorous appreciations of biological optimal yield aimed at ensuring continued sustainability of harvested stocks (see Constable, 2002 – this volume).

As emphasised by Agnew (1997), (ii) represented a new, and as yet unprecedented, challenge for CCAMLR. In particular, the application of MSY models (such as those parameterised by Holt and Talbot (1978) and Sissenwine (1978)) in the management of krill to account for ecosystem concerns was likely to be unsatisfactory and was recognised as being inordinately difficult. The major reasons are that MSY approaches assume stability in natural systems, consider the exploited stock as coming from a single species and rely on a predictable relationship between stock size/growth and fishing effort. For low trophic level and aggregating species, such as krill, these assumptions are usually inappropriate (May et al., 1979; Gulland, 1983a; Butterworth, 1986, 1988, 1990; Mangel, 1994) as they do not take into specific account that:

- krill are generally lower, and more pivotal, in the trophic structure than fish, and the effects of their removal should not be considered in a single-species context; and

- like some other pelagic species, krill form aggregations, the level of mixing between which may be low (Miller and Hampton, 1989). Spatial and temporal variability in abundance thus may render krill particularly vulnerable to local overfishing, and the effects of harvesting are probably distributed unevenly through the stock. The stock–effort relationship is also unlikely to be simple (Butterworth, 1988; Mangel, 1988).

Furthermore:

- krill stocks rarely exhibit definite spatial boundaries;

- prior to exploitation, krill stocks (i.e. initial stocks) are unlikely to have attained a steady state at the carrying capacity of the environment; and

- the carrying capacity for a low trophic level species such as krill is unlikely to be constant.

With krill's key position in the Antarctic food web (Figure 2), an additional deficiency in the application of MSY arises from the need to account for interactions between exploited stocks and other species. As emphasised earlier, this is crucial to meeting the objectives of Article II of the Convention and is a consideration compounded by krill's low trophic status (de la Mare, 1986b). Thus, krill interactions are not only relevant to species at similar or lower trophic levels (i.e. 'related species'), they also apply to higher levels (i.e. 'dependent species' or krill predators).

CCAMLR soon accepted that it was not appropriate to apply MSY to the krill fishery, since sustainable harvesting in a multi-species context (May et al., 1979; Beddington and May, 1980) was likely to be substantially below MSY and unable to safeguard ecosystem needs (Beddington and Cooke, 1982). It was this concern which influenced CCAMLR's efforts to develop an ecosystem-based management regime for the Antarctic krill fishery and which directed the Commission to focus initially on defining the anticipated scope of its desired management paradigm to account for ecosystem concerns.

This paper attempts to document the early development of CCAMLR's efforts to manage the krill fishery in a manner consistent with the ecosystem considerations prescribed by Article II of the Convention. Some key developments are highlighted to provide a historical and philosophical outline of CCAMLR's early efforts to develop a multi-species management regime between 1985 and 1994. This 'first phase' of development attempted to address the 'new management' ethos and 'conservation ethic' (see Hewitt and Linen Low, 2000) embodied in the Convention. It necessitated consideration not only of sustainability issues, but also of ecosystem concerns, precautionary approaches and integration with non-fisheries interests. Later developments are outlined elsewhere in the papers by Everson (2002 – this volume) and Constable (2002 – this volume).

FOUNDATIONS OF CCAMLR'S ECOSYSTEM MANAGEMENT REGIME

CCAMLR Ecosystem Monitoring Program

Agnew (1997) has provided a concise background to the development of the CCAMLR Ecosystem Monitoring Program (CEMP). Based on studies undertaken by the international BIOMASS Program (Biological Investigations of Marine Antarctic Systems and Stocks) during the late 1970s/early 1980s (El-Sayed, 1994), and in conjunction with later work (e.g. Bengtson, 1984; Lubimova et al., 1985), SC-CAMLR recognised in 1984 that there were several prevailing difficulties which impeded the rapid development of specific CCAMLR management strategies. In particular, it noted that (SC-CAMLR, 1984, paragraph 9.12):

- there is considerable uncertainty about various aspects of the basic structure of the ecosystem (e.g. the relative importance of krill in predator diets);

- the current status of the ecosystem is unclear;

- there is a lack of information on current population trends for a number of species previously reduced by harvesting; and

- it is not possible to predict the effects of a total moratorium of different harvesting strategies on ecosystem dynamics.

These considerations led to the setting up of CEMP in 1985 with the following objective (SC-CAMLR, 1985, paragraph 7.2):

> 'To detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine

living resources. The monitoring system should be designed to distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological.'

In striving to meet this objective, it was recognised (SC-CAMLR, 1985, paragraph 7.3) that monitoring of the Antarctic marine ecosystem comprised:

'(a) the monitoring of parameters of selected indicator species (those likely to exhibit quantifiably significant changes in monitored parameters) of seals, seabird and whales; and

(b) the monitoring of harvested species (krill, fish and squid) and other species reflecting change, as an aid to understanding the nature and cause of any observed change.'

Working Group for the CCAMLR Ecosystem Monitoring Program

To address such considerations (SC-CAMLR, 1985, paragraph 7.14), a specialist Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP) was set up with the terms of reference as shown in Table 2. WG-CEMP soon gathered momentum, and at a series of meetings between 1985 and 1992 (Table 3) elaborated and refined a scheme to assimilate early research on various key elements of the Antarctic marine ecosystem and to develop a suite of monitored species, sites and parameters (see Figure 4 and Agnew (1997) for details). These initiatives aimed to provide a series of benchmarks against which changes in predator performance could be evaluated as a function of krill availability and/or environmental variability.

WG-CEMP's early progress represented the first developmental phase of CCAMLR's ecosystem-based management approach. In a limited way, the process also considered how CEMP results might be taken into account in formulating management decisions (CCAMLR, 1989; Croxall, 1989; Agnew, 1997).

MANAGEMENT OF THE KRILL FISHERY

Working Group on Krill

Concomitant with CEMP's development, SC-CAMLR foresaw the need to consider and monitor the effects of krill fishing on krill stocks directly. Such monitoring was seen to include consideration of spatial or temporal overlaps between fishing activities and those of other ecosystem components (particularly land-based predators). The Working Group on Krill (WG-Krill) was formed in 1988 to develop a CCAMLR krill management regime further, and terms of reference were developed (Table 4). The latter clearly emphasised the krill-centric nature of the group's work.

The development of a direct krill management approach was affected by two key factors. Firstly, it was considered that intensive and area-restricted krill fishing is not only likely to affect the targeted krill stock(s) directly, but also the species' predators depending on the extent, as well as location, of fishing (Table 5). Hand-in-hand with the reservations concerning the single-species approaches to management highlighted earlier, the second consideration was that, in the interests of precaution, there was still sufficient urgency attached to the need to manage krill exploitation in its own right. This was agreed by WG-Krill despite conflicting views on the urgency attached to, and other considerations associated with, the need for krill management measures specifically (Table 6).

There was substantial agreement within WG-Krill that general principles for marine living resources management (Gulland, 1977, 1983b) were applicable to krill (Miller, 1991), namely:

(i) the collection/compilation of essential data;

(ii) the analysis of such data to determine the status of target stocks; and

(iii) ongoing action to attain management objectives, including evaluation of analysed data and implementation of appropriate action.

WG-Krill recognised that to implement these principles, consideration should be given to:

(a) krill stock collapses which are more likely to affect other components of the ecosystem than species at higher trophic levels;

(b) those ecosystem components at higher trophic levels which might be affected by harvested krill stock collapses and are more likely to be important to other interest groups/stakeholders (such as tourism, industry, conservation groups and other fishing sectors); and

(c) much more research being required to understand potential ecosystem effects than is required purely to establish the dynamics of krill, given the very nature of the system. This is likely to generate greater lags between harvesting and the development of management solutions.

Consequently, and particularly in response to (c), it was agreed that a precautionary approach to krill fisheries management would be applied, especially given the limited data available on the potential yield of krill stocks being targeted by exploitation and from the fishery itself (Butterworth, 1986). In other words, krill exploitation should only be allowed to commence and develop within the bounds of reasonable precaution as a result of limitations in essential krill fishery and associated ecosystem data. It must be emphasised that WG-Krill's approach preceded later thinking encapsulated by the statement on the precautionary approach arising from the FAO's Lysekil meeting (Anon., 1995), with the approach constituting:

> 'The application of prudent foresight, taking into account the uncertainties in fisheries systems and the need to take action with incomplete knowledge'.

Development of the Approach to Krill Management

WG-Krill's early discussions were intricate and complex (see Miller and Agnew (2000) for details). Compromises were sought on a number of the conundrums vexing fisheries managers globally. These required that due account be taken of uncertainty so as to serve conflicting interests, particularly those requiring some 'burden of proof' to balance intuitively contradictory considerations where:

- catch levels are maintained and/or progressively increased until there is certainty that they are no longer sustainable; or

- no catches are permissable until there is certainty that over-exploitation will not occur and harvesting will be essentially risk free.

WG-Krill sought an intermediate position between these two extremes to account for shorter-term interests of current (or potential) resource users and longer-term interests aimed at maintaining future options (primarily economic). To ensure coherence in its management approach, WG-Krill recognised that any compromise would need to be within a prescribed framework of management action and measurable conservation goals.

Following work by Butterworth amongst others (Butterworth, 1986, 1990), conservation principles were agreed for the krill fishery (Table 7). These provided the 'operational definitions' considered necessary to formulate an objective krill management regime. Taken a step further, they provided the basis for criteria agreed by WG-Krill in 1990 which attempted to set clear objective statements for practical and realistic management action so as to address both single and multi-species concerns (see Miller and Agnew (2000) for full explanation).

WG-Krill's approach was endorsed by a special working group (Working Group for the Development of Management Procedures – WG-DAC) which was tasked at a political level by CCAMLR with formalising a strategy for the development of a precautionary management regime consistent with the objectives of Article II (Table 8). This was an unprecedented step for any international fisheries commission and led to WG-DAC outlining the key management principles summarised in Table 9. Implicitly, WG-DAC endorsed the various practical steps agreed by WG-Krill to be taken in the formulation of krill management procedures (Table 10), which were both ecosystem-based and precautionary in nature.

Krill Management Approach in Practice

Model Development

In giving effect to the steps outlined in Table 10, WG-Krill was required to balance consistency in krill catch levels over time with specific uncertainties (especially krill demand of predators) so that, on available information at least, the possibility of violating the objectives of Article II was reduced (cf. Butterworth et al., 1994). The details of this process were quite elaborate and can be found in Miller and Agnew (2000).

WG-Krill's initial task was to identify management areas where management action could be initiated. However, delineation of krill stock boundaries has proved extremely difficult since the extent to which krill are resident in, or move between, various areas is largely unknown and likely to be quite variable (Miller and Hampton, 1989). For practical reasons, WG-Krill focused its efforts on areas where the krill fishery is historically located (i.e. Subareas 48.1, 48.2, 48.3, and to a lesser degree Subarea 58.4). Such areas, particularly Subareas 48.1 and 48.3, contain sites where large colonies of land-based krill predators breed or are located (Bengtson, 1984; Croxall et al., 1988; Croxall, 1989). Consequently, all elements of the management paradigm (fishery, krill and land-based predators) overlap in space and/or time to varying degrees.

The second task was to develop methods to estimate appropriate levels of krill harvesting (i.e. yield). Finally, the effects of harvesting on dependent predators needed to be considered at various levels, necessitating various models being developed to estimate potential yield in a manner taking explicit account of potential changes likely to be associated with harvesting activities.

At the outset, WG-Krill recognised that a substantial amount of data is required before traditional feedback assessments might be applied to krill. Given the size of most management areas for the species and difficulties inherent in determining its age (Siegel and Nicol, 2000), it was recognised that traditional annual assessments of krill are unlikely to be possible (Butterworth, 1986). WG-Krill thus concentrated on developing calculations of long-term yield based on the approach of Beddington and Cooke (1983), as initially modified by Butterworth et al. (1991, 1994).

Termed the Krill Yield Model (KYM), the approach used estimates of krill recruitment variability, growth and natural mortality (*M*) in a stochastic simulation to determine the effects of various levels of harvesting on the target krill population. For each level of harvesting, the parameter γ in the equation $Y = \gamma B_0$ (Table 11) is calculated and the stock is tracked over a 20-year period (where Y = yield and B_0 = unexploited biomass). Because the model is run many times, the distribution of various management properties can be determined and the probability of various outcomes of both management and fisheries-associated actions are calculable. WG-Krill developed a simple decision rule to select an appropriate level of krill yield, whereby:

> 'γ is selected such that the probability of the spawning stock size falling below 20% of its average value prior to exploitation, over a 20-year period of harvesting, should be equal to 10%'.

This approach required an estimate of pre-exploitation biomass from acoustic survey information. In its first application (SC-CAMLR, 1991), acoustic estimates of krill biomass from the 1981 FIBEX (First International BIOMASS Experiment) survey (BIOMASS, 1986) were used to estimate B_0 in Statistical Area 48. The FIBEX estimate was favoured since it covered Area 48 as a whole and there was little necessity for adjustment to account for krill flux (i.e. movement). A year after initiating the above, CCAMLR adopted its first krill Conservation Measure (32/X) in 1991 (Table 12) using results from the yield model (γ was estimated as 0.1 and the FIBEX B_0 estimate for Area 48 was 15 million tonnes).

Conservation Measure 32/X incorporated two 'limits' on the uncontrolled expansion of krill fishing. Firstly, the precautionary krill catch limit of 1.5 million tonnes for Area 48 was seen as being sufficiently above prevailing historic catch levels to allow for reasonable growth of the fishery, but low enough to minimise the possibility of a detrimental impact on krill stocks (i.e. some allowance was made for uncertainty in parameter estimates used in the KYM) (SC-CAMLR, 1991). Secondly, the 'catch trigger' (620 000 tonnes) for Subareas 48.1, 48.2 and 48.3 was slightly higher than the largest annual krill catch to date. This trigger was perceived to be the level at which rapid expansion of catch is most likely, thereby necessitating subdivision of catch by Subarea (i.e. paragraph 3 of Conservation Measure 32/X) to avoid possible unacceptable concentration of catch within the foraging areas of vulnerable predators (SC-CAMLR, 1991).

Initially the KYM used a fixed *M*. However, there is considerable uncertainty concerning a suitable level for this parameter. In later models uncertainty was ascribed to a uniform distribution between 0.6 and 1.0. Other parameters, such as variable age-at-recruitment, seasonal growth and catch history, as well as age-at-first-capture, were added to the model. Prior distributions for a number of parameters were refined, particularly recruitment variability along with the relationship between this and likely variability in *M* (de la Mare, 1994a, 1994b). Some of the parameters put into the KYM, and its later variant the Generalised Yield Model (GYM), are detailed in Table 13 and the model's form is illustrated in Figure 5.

Most recently an age-structured krill population model has been constructed for the Antarctic Peninsula (e.g. Constable, 2002 – this volume). This confirmed that krill recruitment, growth and *M* estimates used in the GYM are internally consistent and are capable of reproducing population trends similar to those observed in surveys (Murphy et al., 1999). The effects of serial correlation in krill recruitment have also been investigated, especially following observations of linkages between recruitment and sea-ice cover (Loeb et al., 1997), and cyclicity in sea-ice dynamics (Murphy et al., 1995). Finally, B_0 values were recalculated for various statistical subareas (Trathan, et al., 1992, 1995) using a revised acoustic target strength for krill (after Everson et al., 1990; Foote et al., 1990; Greene et al., 1990). Subsequently, CCAMLR agreed to re-survey krill B_0 in Area 48 during the austral summer of 1999/2000 (CCAMLR, 1998a), which resulted in changes to Conservation Measure 32/X (Table 12).

The development of the KYM/GYM necessitated elaboration of two additional management principles. Firstly, WG-Krill was required to consider the possible allocation of the Area 48 precautionary catch limit adopted in 1990 (1.5 million tonnes) (Conservation Measure 32/X) to subareas within Area 48. Various methods were identified (e.g. based on historic catch levels, predator needs and the proportionate combinations of results from the KYM). WG-Krill persistently acknowledged the need to define krill 'management regions' to replace more *pro-rata* designations based on statistical areas/subareas (CCAMLR, 1992). The demarcation of such regions was recognised as essential to account for equivocal evidence of the potential effects of localised krill fishing on land-based predators (Agnew, 1992b; Sushin and Myskov, 1992; Kerry et al., 1992). In 1992, Conservation Measure 46/Xl was adopted as an interim allocation of catches by statistical subarea within Area 48 for the 1992/93 and 1993/94 seasons (CCAMLR, 1992). This measure was subsequently allowed to lapse and its replacement was left to await the results of attempts to refine alternative subarea allocations based on krill, fishery, predator and environmental considerations (e.g. as initially outlined by Watters and Hewitt, 1992) (see also Everson, 2002 – this volume; Constable, 2002 – this volume).

The second, far-reaching development elaborated a decision rule to address predator requirements (CCAMLR, 1994). Early versions of the KYM made some allowance for predator needs and a 'discount factor' (λ) was applied to reduce the krill yield proportionately. The difficulty was that there was no way of determining an appropriate level of λ, and it was argued that krill-predator needs would be taken into account implicitly in the estimation of krill M in any event. To address the issue, WG-Krill and WG-CEMP, at a joint meeting in 1992, agreed that the population projections from the KYM could be used to elaborate an additional, three-part decision rule (Table 14) to augment that safeguarding against critical reductions in stock biomass identified above (SC-CAMLR, 1992). Together, both decision rules were designed to act in concert, as well as conservatively, to ensure that krill spawning stock as well as predator (ecosystem) needs are not compromised. By adopting such rules, CCAMLR, through WG-Krill's work, and with the involvement of WG-CEMP, finally came to achieve an explicit formulation of the operational criteria originally identified for krill management (Table 7). Comparable rules have since been applied to species other than krill (e.g. Patagonian toothfish, *Dissostichus eleginoides*) (SC-CAMLR, 1998).

In 1994, CCAMLR accepted the revised yield model, final FIBEX B_0 estimates, and the three-part decision rule, thereby completing the most important phase in the development of a krill management procedure within four years (1991–1994). The value of γ now accepted for krill, using the three-part decision rule (Table 14), is 0.116. Catch limits for Divisions 58.4.1 and 58.4.2 (e.g. as per Conservation Measure 106/XV – Table 12) were recently set using this γ value and estimates of B_0 from Australian acoustic surveys (Pauly et al., 1996).

Although the decision rules (Table 14) took explicit account of the needs of predators, only arbitrary levels of krill escapement were set to meet such needs. These were commensurate with the rules and WG-Krill recognised that available CEMP data on predator performance and krill variability might facilitate explicit modelling of the functional relationship(s) between predator and krill populations. Consequently, more objective definitions of the levels of escapement necessary to meet predator needs were seen as essential (Butterworth and Thomson, 1994, 1995).

The approach initially utilised preliminary information on the population dynamics of a variety of predator species to identify better functional relationships between juvenile and adult predator survival rates using krill abundance (Butterworth and Thomson, 1994; Thomson, 1998). From the 'one-way' interaction model developed (i.e. where fluctuations in krill abundance have an impact on predator populations, but not vice versa), variability in annual krill recruitment was shown to render predator populations less resilient to krill harvesting than deterministic evaluations would suggest (Butterworth and Thomson, 1995). These initial results focused subsequent discussion on interpreting adult survival rate estimates for some of the predator populations used in the model (SC-CAMLR, 1993).

Further model development (Butterworth and Thomson, 1995) introduced the concept of krill 'availability' to provide a random component in the relationship between biomass and availability (i.e. with biomass as a function of spatial as well as temporal variability). For the black-browed albatross and Antarctic fur seal in particular, an almost unrealistically poor resilience was observed in relation to krill fishing, and by implication to changes in krill availability (even without taking into account variability in krill recruitment) (Butterworth and Thomson, 1994). CCAMLR continues to try and ascertain whether the modelling technique is inappropriate or whether there are inherent negative biases in available estimates of predator survival rates from field data (SC-CAMLR, 1995, 1997).

Despite the tantalising perspectives highlighted from these developments, WG-Krill and WG-CEMP stressed that it is extremely difficult to develop site-specific models of krill–predator interactions, mainly because the major reason for this is that there are quantitative considerations attached to the specific temporal or spatial relationship between krill on one hand and predators on the other. Murphy et al. (1988) clearly indicated the temporal and spatial scales linking various components of the ecosystem. Miller (1999) later showed how such linkages could be extended to include the fishery (Figure 6). As emphasised by Everson (2002 – this volume), the issue is one of variation in 'krill availability'. In other words, site-restricted predators are only likely to be able to feed on krill available nearby, while other predators may forage farther afield. WG-Krill therefore encouraged the development of fine-scale krill-predator models as early as 1989 (SC-CAMLR, 1992), and despite some progress (Mangel and Switzer, 1998) the matters remains a top priority for consideration.

In the absence of more quantitative assessments of predator responses to changes in krill availability (with the exception of Murphy, 1995), and to different levels of krill escapement in particular, SC-CAMLR accepted a target level of escapement of 0.75 as an initial value on which to base management recommendations (SC-CAMLR, 1994). It was acknowledged that this value may be revised as the available models are further refined.

Tracking Indices in Krill Biomass

Realising that age-based assessments of krill were unlikely to be possible initially, WG-Krill also considered the use of catch-per-unit-of-effort (CPUE) indices to monitor trends in krill population biomass and in biomass dynamic models. In 1986, simulation studies of the Soviet and Japanese krill fisheries were commissioned to investigate the possibility of using CPUE as an index of krill biomass (SC-CAMLR, 1986, 1987). These studies (SC-CAMLR, 1988; Butterworth, 1988; Mangel, 1988) concluded that certain catch-dependent indices, particularly those containing some element of fishery search-time, could be used to assess krill abundance. The CPUE simulation studies supported Shimadzu's (1985) and Everson's (1988) earlier conclusions that catch-per-fishing time (i.e. CPH) provides the most useful index of local krill abundance. They also indicated that various catch and effort data might be utilised to derive a Composite Index of Krill Abundance (SC-CAMLR, 1988).

A subsequent experiment to investigate the properties of a Composite Index showed that the frequency distributions of commercial catch-per-fishing-time and krill density from acoustic surveys exhibited similar forms, although non-random movement (i.e. searching behaviour) by a fishing vessel could obscure such comparisons (SC-CAMLR, 1994). A further difficulty in using search-time is that fishing operations are more likely to be limited by catch processing efficiency than krill availability. The conclusion of this work was that CPUE, even including search-time, is not a very good estimator of krill biomass, and to date there have been no further attempts to utilise it. Nevertheless, CCAMLR has continued to encourage the development of approaches to use CPUE data to monitor fishing activities in relation to krill biomass, at least at a very local level. More specifically, it has confirmed the need to collect information on fishing vessel activities at random times in an effort to quantify search-time (SC-CAMLR, 1993).

Estimating Krill Potential Yield from Predator Consumption

As early as 1990, the use of predator consumption rates to bound estimates of B_0 and, consequently, krill potential yield (SC-CAMLR, 1990; Agnew, 1992a) was considered. These ideas were refined by Everson and de la Mare (1996), amongst others, to provide a method for estimating B_0 from predator consumption rates around South Georgia with:

$$B_0 = PT(M^2 + V(M))/M^3 \qquad (1)$$

where P is the annual krill consumption by land-based predators, M is the annual krill mortality rate, T is the krill retention time within predator foraging area(s), and $V(M)$ is the variance of the M estimate.

Such ideas contributed greatly to the debate initiated by the joint WG-Krill/WG-CEMP meeting in Viña del Mar, Chile, in 1992 on the need to develop ecosystem assessments as a means to obtain some indication of 'ecosystem health', taking into account more widespread conditions affecting variability in the 'availability' of krill to predators and fisheries alike. These discussions served as the precursor to the merging of WG-CEMP and WG-Krill into a single Working Group for Ecosystem Monitoring and Management (WG-EMM) in 1994 (see section on WG-EMM below).

Implications of Links between Krill and Environmental Parameters

Flux

WG-Krill recognised that the application of its suggested management approach is crucially dependent on the movement (flux) of krill between various localities. Subsequently, developments in 1993 focused on assessing the effect(s) of krill flux (either passively as a result of water movement or actively through migration) in estimating yield, primarily as a consequence of potential impacts on B_0 values (SC-CAMLR, 1993).

A CCAMLR-sponsored Workshop on Evaluating Krill Flux Factors in 1994 used data from satellite-tracked drifters to investigate the passive transport of krill by prevailing easterly currents through the Scotia Arc (SC-CAMLR, 1994). Results indicated water transport times between the Antarctic Peninsula and South Georgia of about six months (Ichii and Naganobu, 1996). As originally postulated by Marr (1962), the effects of this circulatory system could link krill populations around the South Shetlands, South Orkneys and South Georgia. Despite general support for the workshop's conclusions, from subsequent results of the CCAMLR Workshop on Area 48 (SC-CAMLR, 1998) the extent to which krill are exchanged between areas (through passive transport around the Antarctic Continent) or stay resident in highly productive areas (i.e. the South Shetland Islands) remains unresolved.

Uncertainty attached to krill flux holds considerable significance for any management approach, especially the setting of precautionary limits for subareas within Area 48 (i.e. the 'management areas' alluded to above). If flux is important, the krill stock available in any one area could be substantially greater, or less, than that estimated by a single survey of limited duration. If krill are essentially resident in one area, then stock size will be equivalent to that observed during a limited-time survey. Assuming that there is no flux results in a conservative estimate of yield (SC-CAMLR, 1994) – the approach which has been adopted by CCAMLR to date. However, this does imply that, should flux be important, there is no fishing in upstream areas. Obviously, heavy fishing in upstream areas could remove all krill from downstream if flux was important, but would have no effect if the contrary was true. Consideration of krill flux therefore remains on CCAMLR's management agenda (Constable et al., 2000).

In contiguous areas, such as Subareas 48.1, 48.2 and 48.3, flux-modified catch limits might necessitate further division of catch between subsidiary areas within an overall areal catch in order to take into account possible fluxes (i.e. movement) of krill biomass into such areas from a single upstream source (i.e. Subarea 48.1). Thus, the total yield estimate for Area 48 would remain the same, but the catch limits for individual subareas would change. Balanced against the current perception that not taking flux into account remains conservative, CCAMLR is increasingly aware that in the case where krill flux rates are not constant between areas, a simple *pro-rata* allocation of some total precautionary catch for Area 48 to subareas could lead to inappropriately high local catches in some smaller areas (SC-CAMLR, 1992 onwards).

Sea-Ice

After water circulation, the environmental factor most likely to influence krill distribution and abundance is sea-ice (Mackintosh, 1972, 1973). In its final discussions, WG-Krill began to consider the possibility that variability in krill recruitment is linked to cycles in the extent of sea-ice in the Antarctic Peninsula region. Kawaguchi and Satake (1994), Siegel and Loeb (1995) and Loeb et al. (1997) all reported that winters with substantial sea-ice are followed by summers of high krill recruitment, as shown by high proportions of juvenile krill (i.e. animals spawned the previous summer) taken in both commercial and research net hauls. Observations of this kind may be attributable to winter sea-ice offering an important feeding/nursery ground and refugium for both adult and larval/juvenile krill (following suggestions by Hamner et al., 1989 and Daly, 1990). They also intimate that krill recruitment is largely independent of spawning stock size in the region. However, Siegel and Loeb (1995) have suggested that prolonged winter sea-ice cover leads to early krill maturation and spawning with subsequent enhanced recruitment to the next season's ice. Consecutive years of heavy sea-ice cover therefore act in concert to increase krill recruitment (Loeb et al., 1997), while the absence of sea-ice may influence the dominance of either krill or salps at different times (Loeb et al., 1997).

The above have contributed to later investigations of possible associations between sea-ice and krill CPUE (see Sushin and Myskov, 1992; Fedulov et al., 1996; Miller and Agnew, 2000 for details). The existence of any linkage between sea-ice and the performance of the krill fishery in the forthcoming year offers an intriguing possibility for predicting catch rates based on a relatively simple environmental index (i.e. sea-ice cover). The matter remains under serious consideration by WG-EMM.

Working Group for Ecosystem Monitoring and Management

In developing precautionary catch limits for krill, CCAMLR (through WG-DAC) identified a number of other approaches (e.g. reactive management, predictive management, open/closed areas, indirect methods, pulse fishing and feedback management) on which management of the krill fishery might be based (SC-CAMLR, 1991–1993). The scope of these approaches and the associated dialogue served to emphasise a need to evaluate objectively the effects of any introduced management measures on both the krill resource and fishers alike. CCAMLR has accepted that while adequate protection should be afforded to krill-dependent predators at critical times and in specific areas, such protection should not exert unnecessary or unreasonable restrictions on the fishery (SC-CAMLR, 1993). Building on the experiences of WG-CEMP and WG-Krill, SC-CAMLR felt the need to bring together all those interested in krill fishing and associated ecosystem considerations to maximise the efficient use of available expertise and/or resources. To achieve this, and as already indicated, WG-Krill and WG-CEMP were amalgamated into a single group (WG-EMM) in Cape Town, South Africa, in 1994. The terms of reference are provided in Table 15. Subsequent instructions by SC-CAMLR (Table 16) mandated WG-EMM's agenda together with the associated actions necessary to further the initiatives of the previous two working groups. Specific priorities were identified (Table 17) and a strategy for future action was outlined (Table 18). Please refer to the paper by Constable (2002 – this volume) for details of WG-EMM's later initiatives.

DISCUSSION

Figure 7 provides a *post-hoc* summary of the various steps taken by CCAMLR in its early development of a krill management approach. A key issue remaining in 1994 when WG-EMM came into being was how ecosystem (i.e. multi-species) considerations might be more formally subsumed into management decisions. While some areas of progress have been outlined here, the topic is one which continues to warrant priority attention and development. CCAMLR has recognised this essential need, and recent work by WG-EMM has striven to find a way whereby ecosystem concerns may be incorporated into management measures (e.g. see discussion by Constable et al., 2000). Everson (2000) has since provided an outline of such a decision process as a template for future action (Figure 8).

To address the various shortcomings highlighted by this paper, much information (e.g. on search-time by fishing vessels) is still required above that currently forthcoming from the krill fishery. Only with such information will it be possible to assess objectively the potential utility of regularly monitoring selected indices or fisheries' factors (e.g. length-frequency composition of catches) crucial to developing realistic management procedures. As identified by WG-Krill, the placement of suitably qualified observers aboard krill fishing vessels would go a long way to improving the flow of data necessary to effectively monitor the fishery (e.g. SC-CAMLR, 1989, 1990a; CCAMLR, 1991), to assess its impact on available stocks and to evaluate the effects of future management action. Following similar work in other fora (e.g. de la Mare, 1986a), various CCAMLR initiatives to date (e.g. Ichii et al., 1992, 1994a, 1994b; Mujica et al., 1992; Vagin et al., 1992) are to be encouraged and their results are awaited with interest. At a minimum, some relevant key areas for further consideration by WG-EMM are outlined in Table 17. Other specific topics to be addressed include:

<u>Krill stocks</u>

Define management areas/associated krill stocks:

- formulate interim precautionary measures (limits on catch/entry), especially for areas apart from those used as part of the CCAMLR statistical area reporting system; and

- elaborate management objectives and operational definitions.

Develop candidate management procedures and simulation trials for management objectives under different scenarios:

- continue to elaborate management procedures into adaptive or feedback management.

Continue to refine advice as uncertainty changes.

Ecosystem considerations

Model functional relationships between krill and key predators:

- refine identification of key ecosystem components linked to krill; and

- develop management approaches for fishery and predators.

Continue development of decision rules to incorporate ecosystem concerns into krill management.

Progress on these topics after 1994 is reflected in the papers by Agnew and Nicol (1996), Agnew (1997), Constable et al. (2000), Miller and Agnew (2000), Constable (2002 – this volume) and Everson (2002 – this volume), amongst others.

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The paper is dedicated to the memory of a dear colleague, Mudini Makhethakhetha.

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Table 1: CAMLR Convention Article II (CCAMLR, 1999a).

1. The objective of this Convention is the conservation of Antarctic marine living resources.
2. For the purposes of this Convention, the term 'conservation' includes rational use.
3. 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 resources and the restoration of depleted populations to the levels defined in subparagraph (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 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.

Table 2: WG-CEMP terms of reference (SC-CAMLR, 1985, paragraph 7.14).

Plan, recommend, coordinate and ensure the continuity of a multi-nation CEMP within the Convention Area.
Identify and recommend research including theoretical investigations to facilitate design and evaluation of the recommended ecosystem monitoring program.
Develop and recommend methods for the collection, storage and analysis of data including data formats for submission to CCAMLR.
Facilitate analysis of data, their interpretation, and identify management implications.
Report progress to each meeting of SC-CAMLR meeting with recommendations for further work.

Table 3: Key events associated with CCAMLR's development of a krill management approach (1982–1995).

Year	Event
1982	Convention entry into force
1984	Ad hoc WG-CEMP formed
1985	Ad hoc WG-CEMP Meeting (Seattle, USA) WG-CEMP established
1986	1st WG-CEMP Meeting (Hamburg, Germany)
1987	2nd WG-CEMP Meeting (Dammarie-les-Lys, France) Ad hoc WG-Krill formed
1988	WG-Krill formed Krill CPUE Simulation Study
1989	3rd WG-CEMP Meeting (Mar del Plata, Argentina) 1st WG-Krill Meeting (La Jolla, USA) Krill CPUE Simulation Study Workshop (La Jolla, USA)
1990	4th WG-CEMP Meeting (Stockholm, Sweden) 2nd WG-Krill Meeting (St Petersburg, Soviet Union)
1991	5th WG-CEMP Meeting (Santa Cruz de Tenerife, Spain) 3rd WG-Krill Meeting (Yalta, Soviet Union)
1992	6th WG-CEMP Meeting (Viña del Mar, Chile) 4th WG-Krill Meeting (Punta Arenas, Chile) 1st Meeting WG-CEMP and WG-Krill (Viña del Mar, Chile)
1993	7th WG-CEMP Meeting (Seoul, Republic of Korea) 5th WG-CEMP Meeting (Tokyo, Japan)
1994	8th WG-CEMP Meeting (Cape Town, South Africa) 6th WG-Krill Meeting (Cape Town, South Africa) 2nd Meeting WG-CEMP and WG-Krill (Cape Town, South Africa)
1995	1st Meeting WG-EMM (Siena, Italy)

Table 4: WG-Krill's terms of reference (SC-CAMLR, 1988, paragraph 2.26).

Review and evaluate methods and techniques for estimating krill abundance, taking note of effects of patchiness and the influences of physical environment.

Review and evaluate information concerning the size, distribution and composition of commercial krill catches, including likely future trends in catches.

Liaise with WG-CEMP for assessing any impact of changes in krill abundance and distribution on dependent and related species.

Evaluate the impact on krill stocks and fisheries of current and future patterns of harvesting, including changes caused by management action, in order that SC-CAMLR may formulate appropriate scientific advice on krill to the Commission.

Report to SC-CAMLR on information, and data, required from commercial krill fisheries.

Table 5: Effects of intensive and area-restricted krill fishing (after Everson, 1981).

Target	Single Krill Stock	Several Krill Stocks (Defined by Area)
	On Krill Stock	
(i) Growth	Small	Probably small
(ii) Mortality	No change (male) Small (female)	May change (male) Large (female)
(iii) Biomass	Small	Significant reduction (post fishing)
	On Krill Predators	
(i) Species close to fishing area (e.g. breeding seabirds)		
(a) heavy fishing prior to critical seasonal period	Significant in fished area – minimal elsewhere	Significant – increase with time then level off
(b) intensive fishing during and after critical period	Small	Significant in subsequent years
(ii) Species not tied to fishing area (e.g. whales)		
(a) intensive fishing before predator normally present in area	Small overall	Reduced density (i.e. feeding elsewhere)
(b) intensive fishing during and after predator present in area	No/slight reduction in density	Slight short-term reduction Major long-term reduction

Table 6: Views on the urgency associated with the development of management measures for the krill fishery by CCAMLR (from Croxall et al., 1992).

Conflicting views on the need for precaution:

catch levels can be maintained (or even increased) until there is certainty that they are no longer sustainable; or

no catches are permissable until there is certainty that over-exploitation will not occur and harvesting will be essentially risk free.

Specific CCAMLR views:

krill catches are small in relation to the available stock(s);

there is no intention to increase krill catches dramatically in foreseeable future;

krill management should be based on 'best scientific information available' and hence on scientifically formulated assessments. Such assessments are currently limited since data are inadequate, particularly on:

(i) krill abundance, distribution and flux;

(ii) functional relationships between krill and predators; and

historical catch levels do not offer a scientific basis for managing the fishery.

Table 7: General concepts agreed by WG-Krill for operational definition of Article II objectives (after Butterworth, 1990; SC-CAMLR, 1990, paragraph 2.19; Miller, 1991).

(a) Aim to keep the krill biomass at a level higher than might be the case if only single-species harvesting considerations were of concern.

(b) Given that krill dynamics have a stochastic component, focus on the lowest biomass that might occur over a future period, rather than the mean biomass at the end of that period as in a single-species context.

(c) Ensure that any reduction of food to predators due to krill harvesting is not such that land-breeding predators with restricted foraging ranges are disproportionately affected in comparison with pelagic predators.

(d) Examine what level of krill escapement is sufficient to reasonably meet the requirements of krill predators (see especially WG-CEMP/WG-Krill deliberations – SC-CAMLR, 1990, Annex 6).

Table 8: Philosophical considerations underpinning CCAMLR management procedures as developed by WG-DAC subject to Article II of the Convention (CCAMLR, 1989, paragraphs 65 to 75; CCAMLR, 1990, paragraphs 8.1 to 8.14; CCAMLR, 1991, paragraphs 6.13 to 6.23).

1. The term 'conservation' includes rational use. 'Rational use' is subject to different interpretations, *inter alia*:
   (i) harvesting of resources is on sustainable basis;
   (ii) harvesting on a sustainable basis means harvesting activities are conducted to ensure that the highest possible long-term yield can be taken from a resource, subject to the general principles of conservation to be met; and
   (iii) the cost efficiency of harvesting activities and their management should be given due weight.
2. Harvesting and/or associated activities should be conducted according to accepted conservation principles.
3. As a general principle, the ecosystem(s) should be maintained in a state where:
   (i) present and future options are preserved. Requires prevention of decrease in size of any harvested population to levels below which stable recruitment and maintenance of ecological relationships between harvested, dependent and related populations are ensured;
   (ii) risk(s) of irreversible change or long-term adverse effects of harvesting and/or associated activities should be minimised; and
   (iii) wherever applicable, both consumptive and non-consumptive resource use should be given due weight and should be maximised on a continuing basis.
4. Management decisions should take account of uncertainty associated with imperfect knowledge and should be 'precautionary' (i.e. conservative) in the absence of complete knowledge.
5. Measures conserving resources should be formulated and applied to avoid wasteful use of other resources.
6. Planned and actual use of resources should be preceded, and accompanied, by surveys to assess resource potential, the monitoring of resource status and associated analysis of ancillary data.

Table 9: Steps endorsed by WG-DAC for the formulation of krill management procedures (after de la Mare, 1990).

(i) Refine conservation objectives and formulate subsidiary objectives or goals in operationally achievable terms.

(ii) Choose candidate management strategies to be implemented.

(iii) Identify/initiate interim conservation measures to ensure conservation objectives are met while management procedures under development in longer term.

(iv) Examine candidate management procedures, including simulation trials and other analyses. Identify data requirements for procedures, and any refinements or additions necessary to meet conservation objectives.

(v) Review progress, include selecting most suitable candidate management procedures for intensive analysis and refining conservation objectives/management procedures if necessary.

(vi) Intensively analyse final candidates for management procedures. Similar to (iv), but with particular attention on balancing benefits for fishery as well as for the management authority.

(vii) Conduct next major review of progress. If suitable procedures identified then proceed to formal adoption of decision rules and conservation measures, otherwise further refine objectives and management procedures (i.e. repeat steps (vi) and (vii)).

Table 10: Practical considerations associated with managing CCAMLR krill fisheries (after Butterworth, 1990; Miller, 1991).

(i)	A basis for assessing the status of krill stock(s) concerned ('ESTIMATOR').
(ii)	An algorithm specifying appropriate regulatory procedures subject to (i) ('CATCH CONTROL LAW' (Total Allowable Catch – TAC)).
(iii)	A basis for simulating and testing performance of management procedures (i.e. components of (i) and (ii)).
(iv)	Operational definition of conservation objectives to provide criteria against which management performance procedures may be assessed ('MEASURABLE PROPERTIES').

Table 11: Variations of the KYM (SC-CAMLR, 1990–1994). Later modified into the GYM (Constable and de la Mare, 1996).

Formula	Key Features
$Y = 0.5MB_0$	Gulland (1971) formulation – 0.5 too high because of uncertainties in estimation of M and recruitment (R).
$Y = \lambda MB_0$	Butterworth et al. (1992, 1994) – used for first krill precautionary catch limits.
$Y = \gamma B_0$	Constable and de La Mare (1996) – refinement of above with λ and M into single constant γ which is calculated and the stock tracked stochastically over 20-year period. Appropriate yield level selected by three-part, conservatively applied, decision rule to designate value of γ (see Table 13).

Table 12: CCAMLR conservation measures for krill prior to 1995 (from Miller and Agnew, 2000).

CONSERVATION MEASURE 32/X[1]

The total catch of *Euphausia superba* in Statistical Area 48 shall be limited to 1.5 million tonnes in any fishing season. A fishing season begins on 1 July and finishes on 30 June of the following year.

This limit shall be kept under review by the Commission, taking into account the advice of the Scientific Committee.

Precautionary catch limits to be agreed by the Commission on the basis of the advice of the Scientific Committee shall be applied to subareas, or on such other basis as the Scientific Committee may advise, if the total catch in Subareas 48.1, 48.2 and 48.3 in any fishing season exceeds 620 000 tonnes.

For the purposes of implementing this conservation measure, the catches shall be reported to the Commission on a monthly basis.

CONSERVATION MEASURE 45/XI–45/XIV[2]

The total catch of *Euphausia superba* in Statistical Division 58.4.2 shall be limited to 390 000 (450 000) tonnes in any fishing season. A fishing season begins on 1 July and finishes on 30 June of the following year.

This limit shall be kept under review by the Commission, taking into account the advice of the Scientific Committee.

For the purposes of implementing this conservation measure, the catches shall be reported to the Commission on a monthly basis.

CONSERVATION MEASURE 46/XI[3]

If the total catch of *Euphausia superba* in Statistical Subareas 48.1, 48.2 and 48.3 in any fishing season exceeds 620 000 tonnes, then catches in the following statistical subareas shall not exceed the precautionary catch limit prescribed below:

Antarctic Peninsula	Subarea 48.1	420 000 tonnes
South Orkney Islands	Subarea 48.2	735 000 tonnes
South Georgia	Subarea 48.3	360 000 tonnes
South Sandwich Islands	Subarea 48.4	75 000 tonnes
Weddell Sea	Subarea 48.5	75 000 tonnes
Bouvet Island Region	Subarea 48.6	300 000 tonnes

CONSERVATION MEASURE 106/XV–106/XIX[4]

The total catch of *Euphausia superba* in Statistical Division 58.4.1 shall be limited to 750 000 (450 000) tonnes in any fishing season. A fishing season begins on 1 July and finishes on 30 June of the following year.

(The total catch shall be further subdivided into two subdivisions with Division 58.4.1 as follows: west of 115°E, 227 000 tonnes; and east of 115°E, 163 000 tonnes.)

This limit shall be kept under review by the Commission, taking into account the advice of the Scientific Committee.

For the purposes of implementing this conservation measure, the catches shall be reported to the Commission on a monthly basis.

[1] Revised as Conservation Measure 32/XIX in 2000 – changes made to Area 48 limit (to 4.0 million tonnes) and catch subdivided into subareas on basis of survey results of 2000
[2] Revised as Conservation Measure 45/XIV in 1995 – ( ) changes made
[3] Lapsed in 1994
[4] Revised as Conservation Measure 109/XIX in 2000 – ( ) changes made

Table 13: Critical parameters in the development of an operational management procedure for the krill fishery in Subareas 48.1, 48.2 and 48.3 (from Miller, 1991).

Parameter	Actions for Further Assessment
Stock identity	Determine krill immigration and emigration from area.[1]
Natural mortality *(M)*	Verify current range of available values.
Age-at-maturity	Determine krill chronological and biological age and improve assessment thereof.
Nature of fishery	Collate additional information on seasonal and regional patterns of fishing and on operational characteristics of fishery.
Stock–recruitment relationship	Improve information on krill recruitment relationship in particular area(s). Information to include time of spawning, fecundity per recruit, average survival from one development stage to next and time of recruitment to fishery.
Median recruitment	Estimate surplus productivity. Improve knowledge on distribution of krill abundance both locally and globally. Also improve estimates of krill abundance by area.
Mass-at-age	Improve estimation of growth and alternative growth functions – take implicit account of possible seasonal/ regional fluctuation(s).
Functional relationships	Model functional relationships between krill and predators to improve estimation of escapement.[2]

[1] Knowledge of krill flux in specific areas is key to estimating biomass and potential yield by area (SC-CAMLR, 1990, 1994)

[2] Current escapement of 0.75 is between 0.5 (applicable in single-species context) and 1.0 (no fishing)

Table 14: Three-part decision rule to select value of γ (proportionality coefficient) used by CCAMLR in setting precautionary catch limits for the Antarctic krill fishery (SC-CAMLR, 1994).

(i) γ (γ_1) is chosen so that probability of spawning biomass dropping below 20% of pre-exploitation median level over a 20-year harvesting period is 10%;

(ii) γ (γ_2) is chosen so that median krill escapement over a 20-year period is 75%; and

(iii) the lower of γ_1 and γ_2 is selected as the level of γ for the calculation of krill yield.

Table 15: WG-EMM's terms of reference (SC-CAMLR, 1994, paragraph 7.41).

(i) Assess status of krill.

(ii) Assess status and trends of dependent and related populations including identification of information required to evaluate predator/prey/fisheries interactions and their relationships to environmental features.

(iii) Assess environmental and trends which may influence abundance and distribution of harvested, dependent, related and/or depleted populations.

(iv) Identify, recommend and coordinate research necessary to obtain information on predator/prey/fisheries interactions, particularly those involving harvested, dependent, related and/or depleted populations.

(v) Liaise with WG-FSA on stock assessment related matters.

(vi) Develop further, coordinate the implementation of, and ensure continuity in CEMP.

(vii) Taking into account assessments and research carried out under terms of reference (i) to (v) above, develop management advice on status of Antarctic marine ecosystem and for management of krill fisheries in full accordance with Convention Article II.

Table 16: SC-CAMLR guidance to WG-EMM (SC-CAMLR, 1994, paragraphs 7.41 and 7.42).

WG-EMM Terms of Reference

Develop assessment methods, including survey methods, for predators/prey, and standard methods to monitor dependent/related species and environmental conditions.

Continue to utilise best available technology and to develop standard methods for collection, recording, reporting and analysis of biological, environmental, fishery and other pertinent data.

Develop models for predator/prey populations, their direct interaction with each other, and their potential interactions with fisheries and environment.

Coordinate relevant research activities.

Develop and evaluate approaches to manage krill fisheries, taking account of current and future harvesting patterns.

Priority Activities

Further work on krill flux in Area 48, especially in relation to predators, to consider both temporal and spatial variation.

Investigate options for management decision rules (including those implicit next below) to calculate appropriate krill harvesting levels, distribution and timing.

Further work on functional relationships between predators and prey, especially further determination of parameters for, and formulation of, relevant models.

Further evaluate significance of localised interactions between krill harvesting and krill-dependent predators, including identification of suitable future research and management measures.

Review links between prey, predators and environmental data in CEMP.

Table 17: Specific priorities to be addressed by WG-EMM, identified in 1994/95 (SC-CAMLR, 1994, 1995).

Refine krill precautionary catch limits.
Develop functionally based krill precautionary catch limits, taking account of spatial/temporal overlaps.
Refine indices of predator performance, environment and fishery, including combination thereof.
Develop strategic and dynamic models of predator–fisheries–krill interactions.
Develop decision rules to be used for incorporation of indices and interactions into management.
Take and monitor management action – monitor/review outcomes and refine action if necessary.

Table 18: Key strategic considerations to be addressed by WG-EMM as identified by SC-CAMLR in 1995 (SC-CAMLR, 1995).

Synthesis of WG-EMM Functions
Provide advice on ecosystem assessment combining information from dependent and harvested species and environment.
Use ecosystem assessment to provide management advice.
Ecosystem Assessment
Analyse status of key biotic components of ecosystem.
Predict likely consequences of alternative management actions on further status of these components.

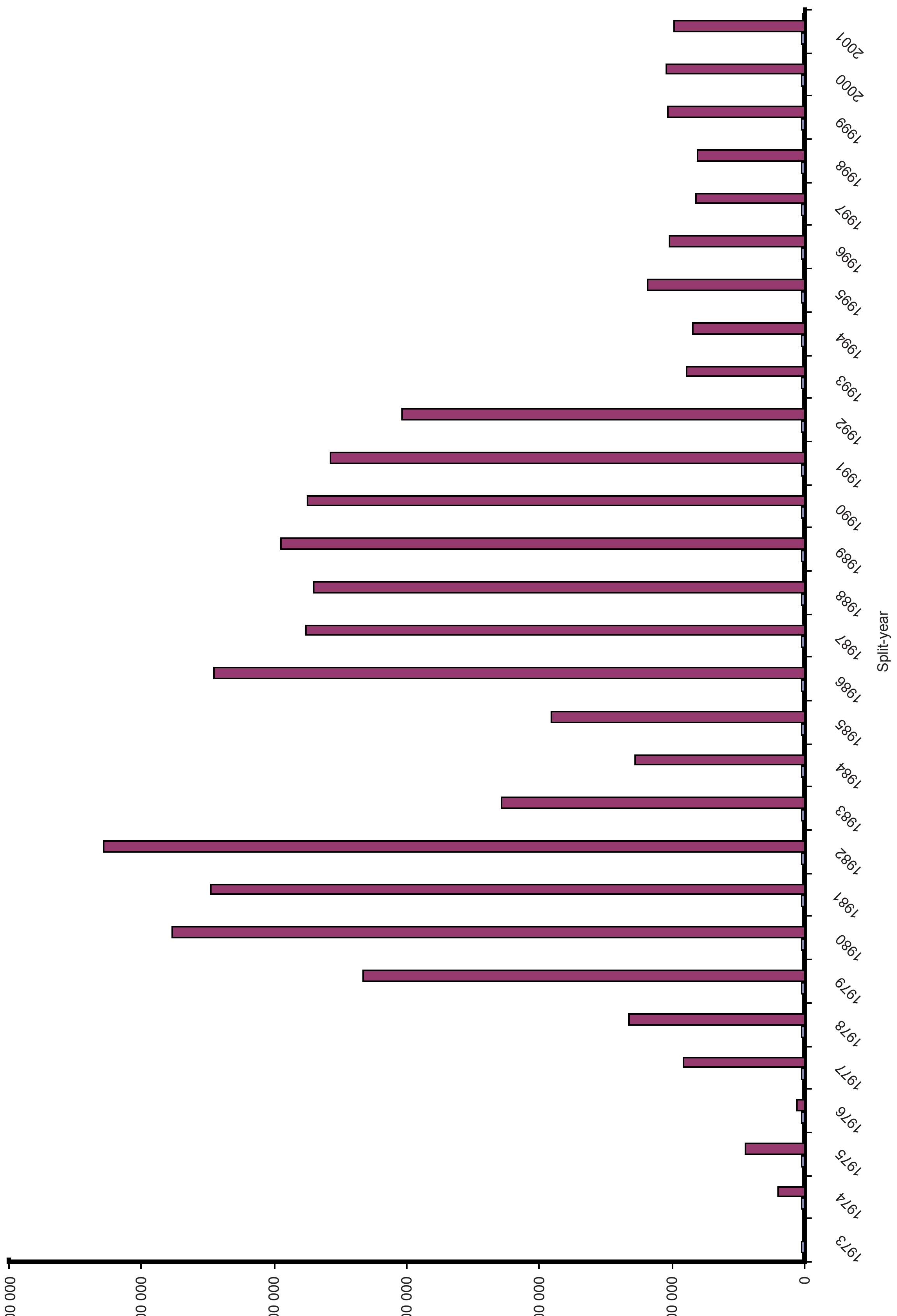


Figure 1: Krill catches (1972/73 to 2000/2001) (CCAMLR, 1990b, 1990c, 1998b, 1999, 2000, 2001, 2002). Catches are by split-year – a split-year being the 12-month period from 1 July in one year to 30 June in the next.

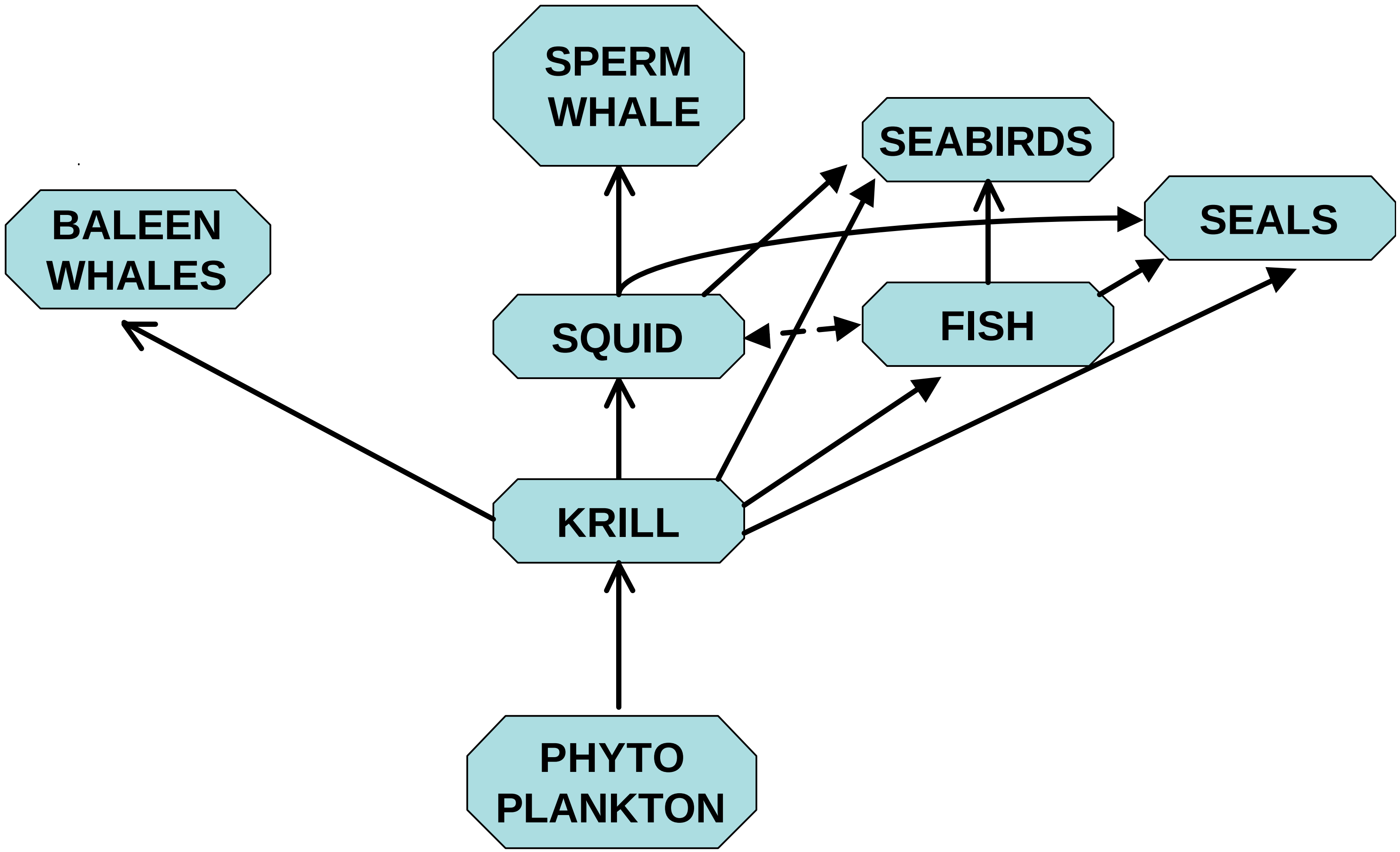


Figure 2: A simplified representation of the Antarctic marine food chain indicating krill's central position.

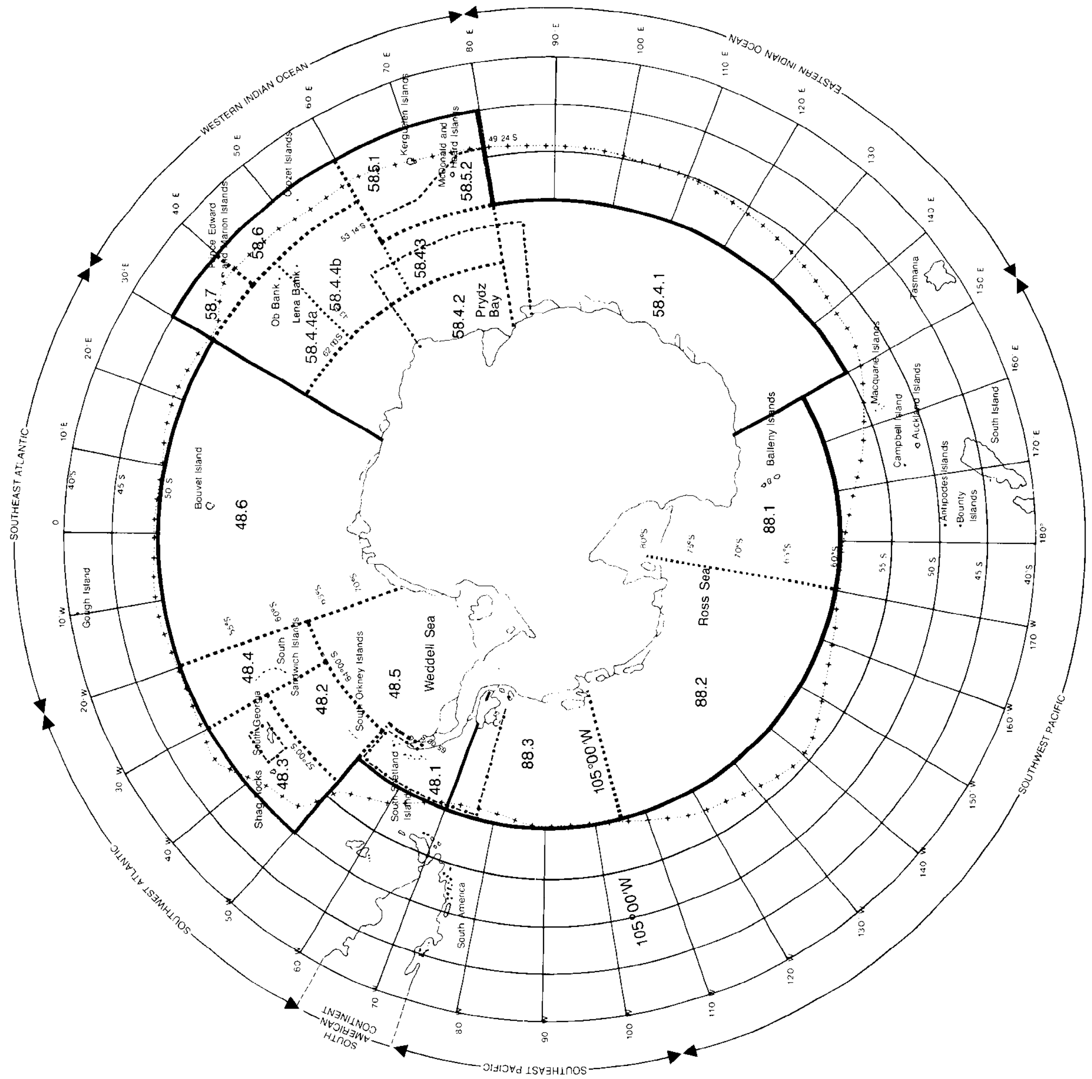
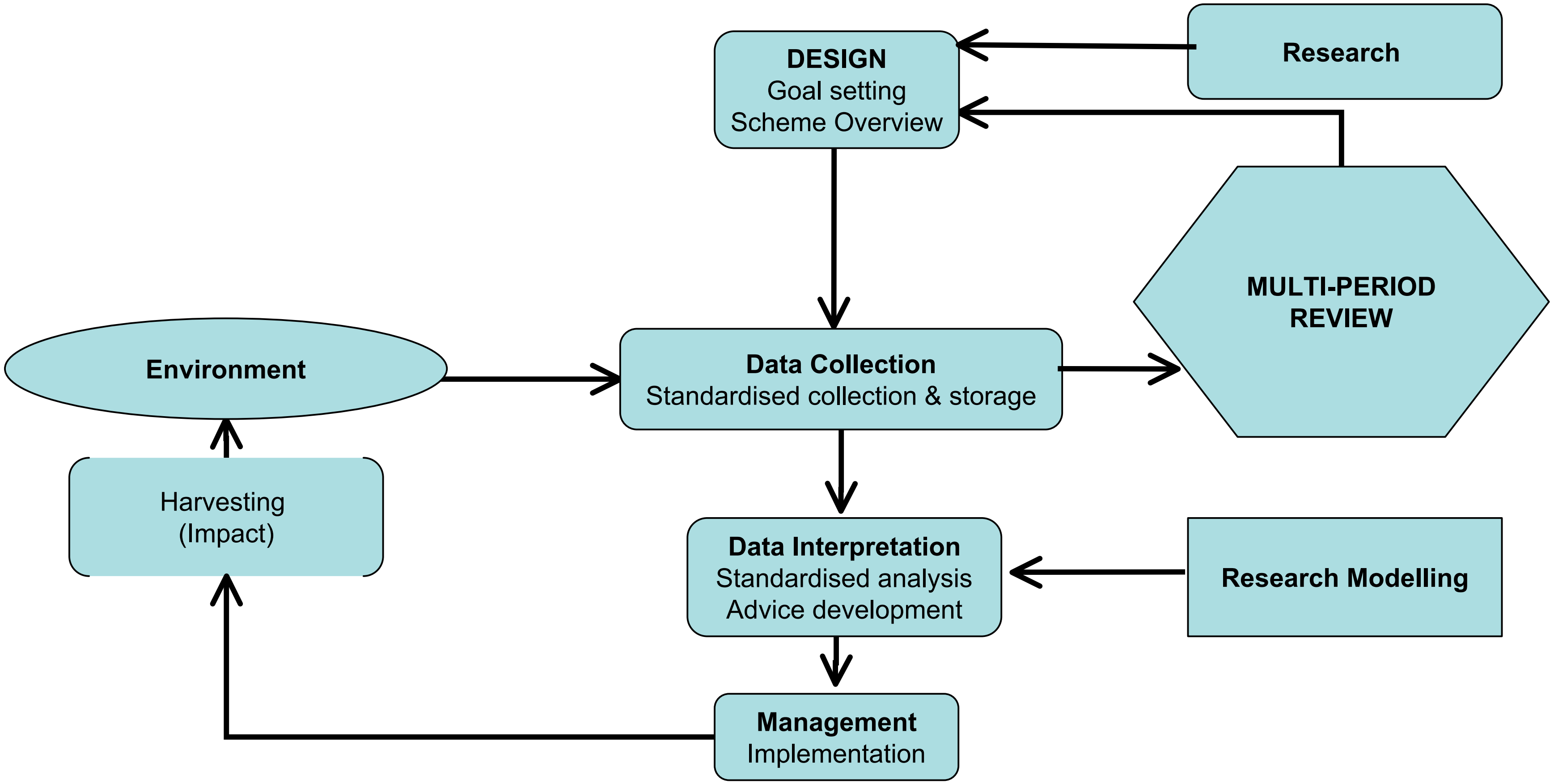


Figure 3: The CAMLR Convention Area (also showing various statistical areas, subareas and divisions used by CCAMLR for the reporting of fisheries catch data) (CCAMLR, 1999a).



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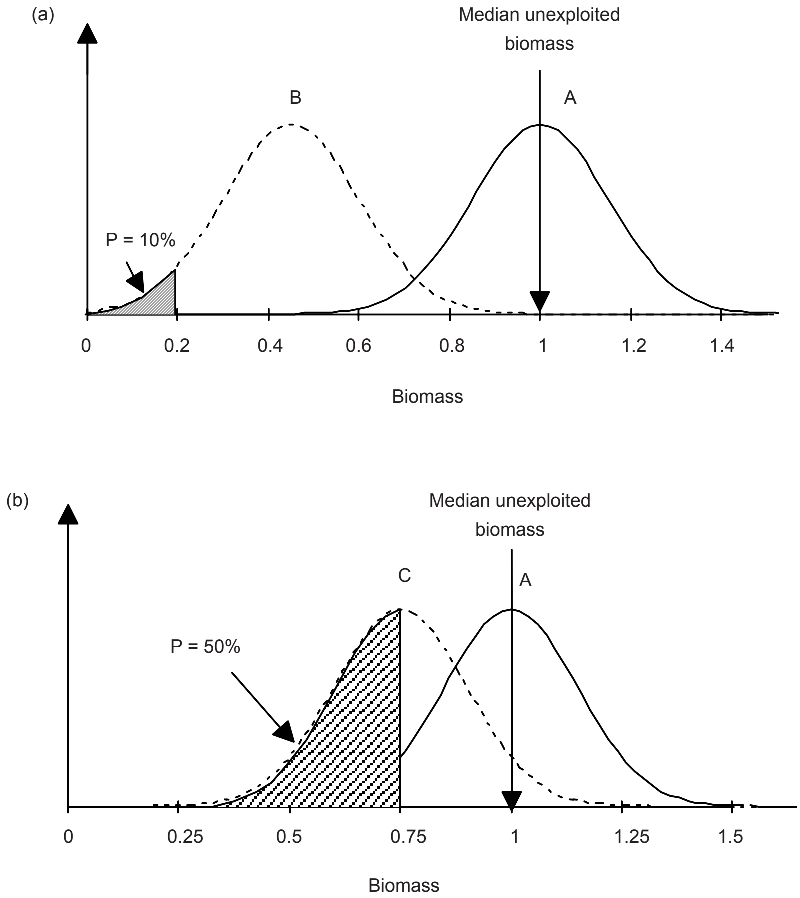

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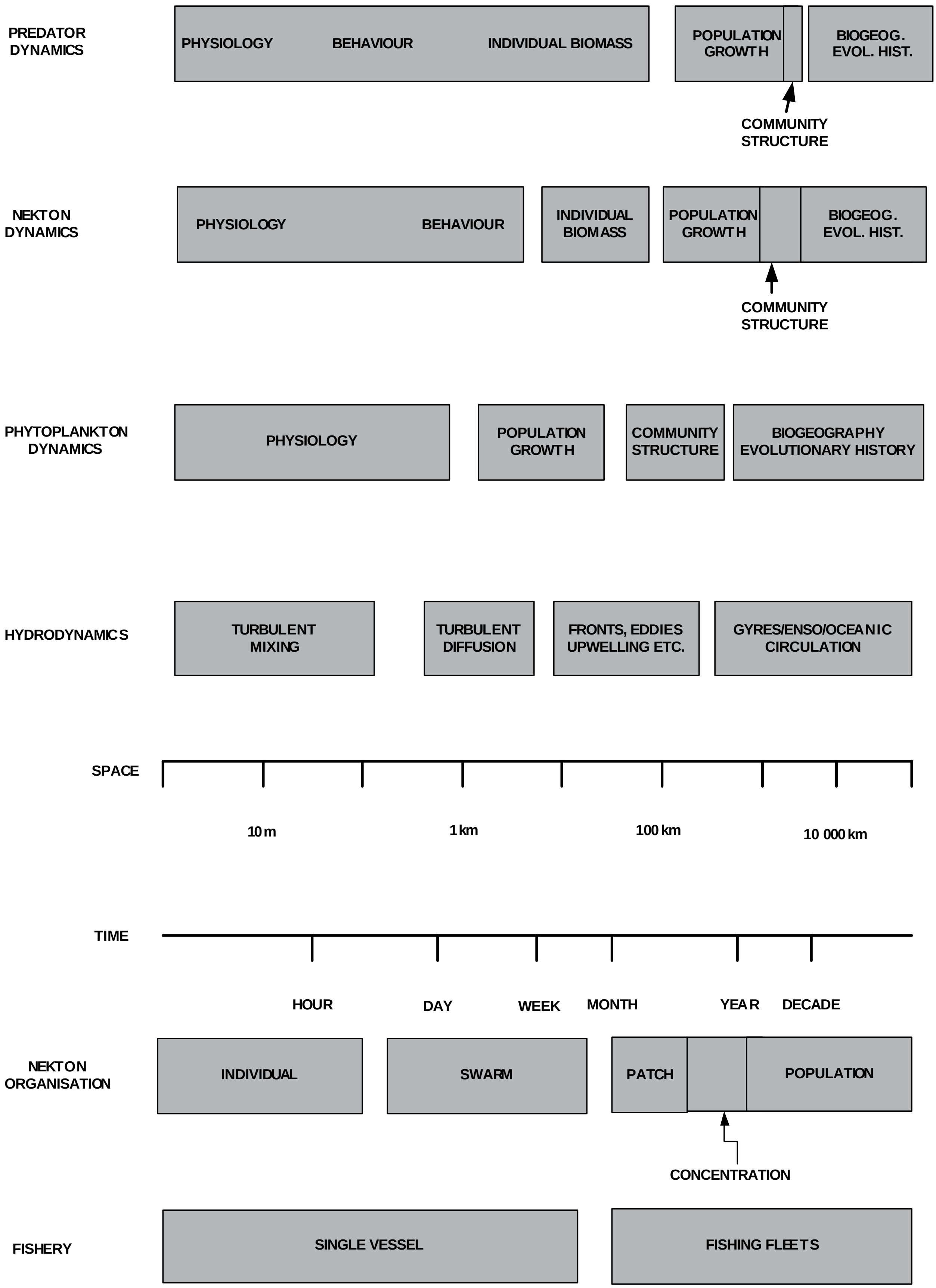

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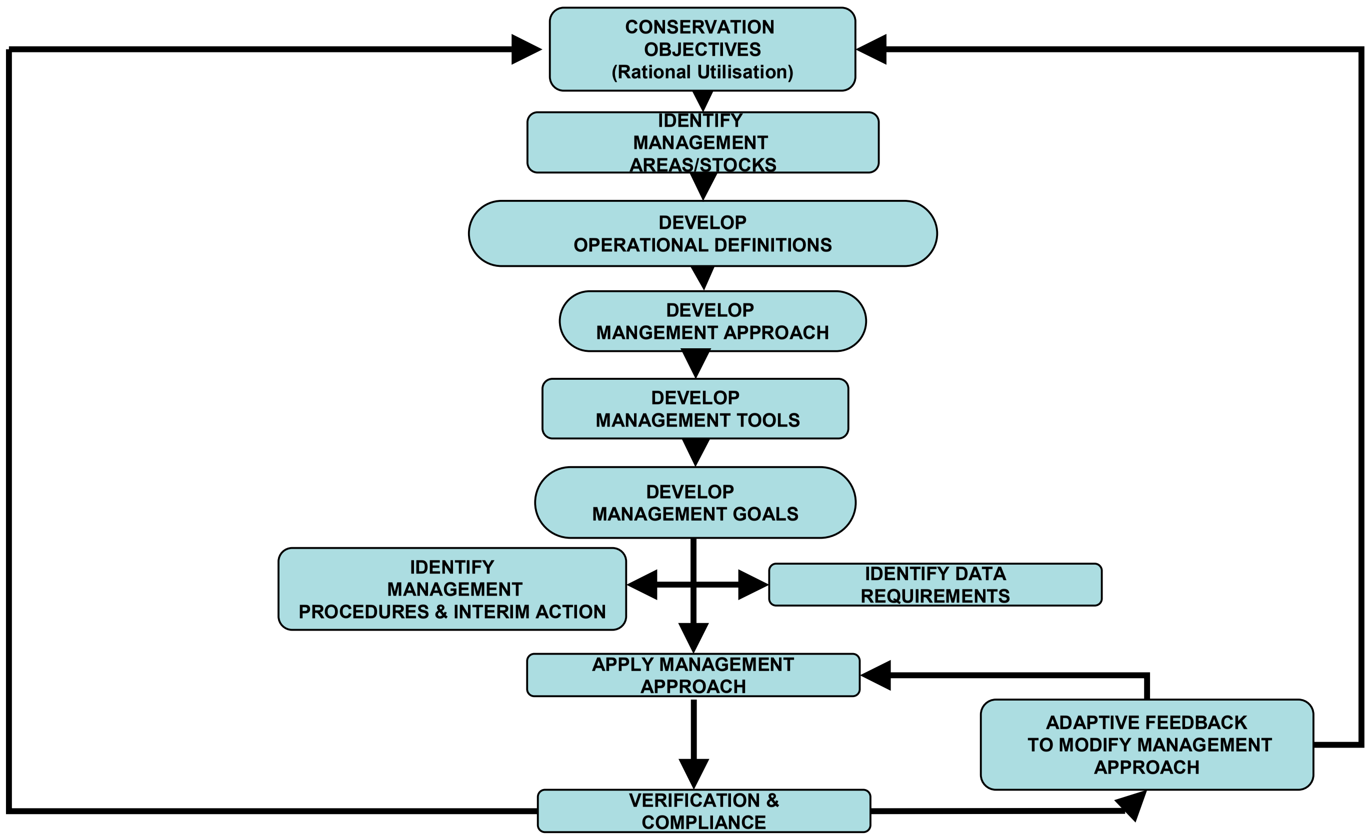
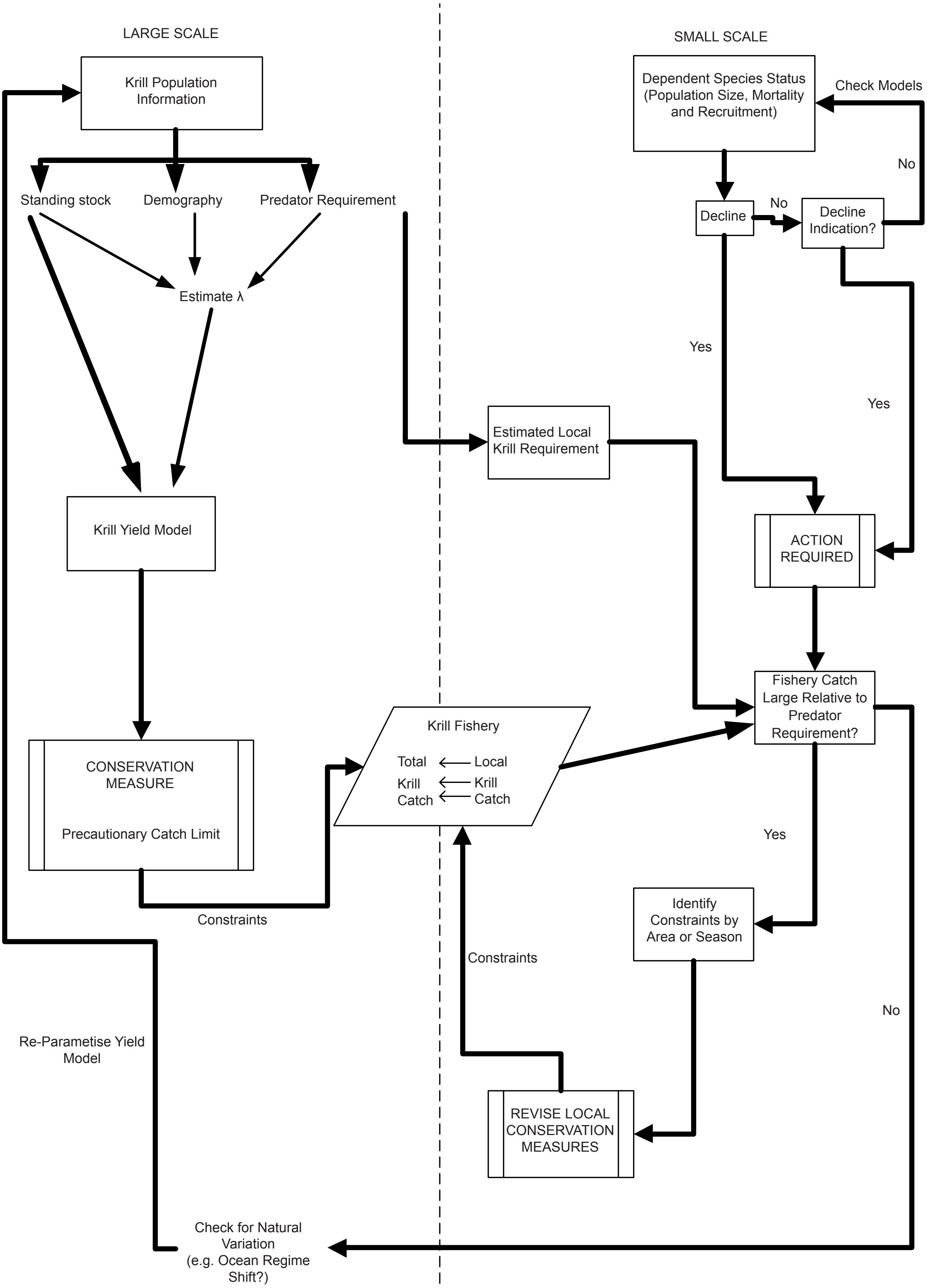


Figure 7: A *post-hoc* summary of CCAMLR's development of a management approach for the krill fishery, ±1987–1994.



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