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Harvesting Krill

**Ecological Impact, Assessment,
Products & Markets**

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TABLE OF CONTENTS

	Page
Director's Introduction..... <i>Tony Pitcher</i>	1
 Contributed Papers	
Modelling and data requirements for management of the Antarctic krill-based ecosystem..... <i>David Agnew</i>	4
Fishery biology of <i>Euphausia pacifica</i> in the Japanese waters..... <i>Yoshinari Endo</i>	10
The CCAMLR experience <i>Inigo Everson</i>	11
Putting krill into ecosystem models..... <i>Astrid Jarre-Teichmann</i>	14
Acoustic estimation of krill abundance utilizing volume scattering measurements..... <i>Michael C. Macaulay</i>	21
Exploitation and management of Antarctic krill..... <i>Denzil G.M. Miller and David J. Agnew</i>	24
By-catch of juvenile fishes the Antarctic krill fishery..... <i>Carlos A. Moreno</i>	26
Development of the krill fishing industry..... <i>Stephen Nicol</i>	35
Biological information necessary for the management of the Antarctic krill fishery..... <i>Stephen Nicol</i>	42
Using the Ecopath II approach to assess krill biomass and dynamics..... <i>Daniel Pauly</i>	47
Comparisons of repeat acoustic surveys in Jervis Inlet, British Columbia, 1994-1995..... <i>S.J. Romaine et al.</i>	48
Overview of the krill of the Gulf of St. Lawrence..... <i>Yvan Simard</i>	53
The importance of euphausiids to a British Columbian coastal marine ecosystem..... <i>R. W. Tanasichuk</i>	58
The influence of inter-annual variations in sea temperature on the population biology and productivity of euphausiids in Barkley Sound, Canada..... <i>R. W. Tanasichuk</i>	62
 Discussion papers	
Three components leading to an assessment of the potential yield of British Columbia krill stocks: a fishery manager's point of view..... <i>Jim Morrison</i>	65
Summary of workshop discussion (addressing issues raised by Jim Morrison)..... <i>Taja Lee</i>	68
List of participants	77
Workshop agenda	81

DIRECTION'S INTRODUCTION

"Let them eat krill"

Tony J. Pitcher, Fisheries Centre, UBC.

Krill are defined here as the euphausiids, a relatively small (about 85 species world-wide) and uniform taxon of large (10-80 mm adults) pelagic shrimp-like filter-feeding crustaceans. Most species inhabit the upper 400m of the ocean and shed their eggs into the sea, but a few (e.g. *Nyctiphanes*) have evolved parental care of the eggs until hatching into nauplii. Many species exhibit diurnal migration, approaching the surface to feed at night. Krill biomass world-wide is thought to exceed 300 million tonnes and they are particularly abundant in North Atlantic, Antarctic and North Pacific oceans.

In the North Pacific, the large-eyed *Euphausia pacifica* occurs in sub-arctic waters less than 300m deep, is especially plentiful in the Sea of Japan, North Pacific drift and Californian current, and is the species that has been considered for commercial harvest in British Columbia.

Ecological Role of Krill

Krill, whose biomass often rivals that of copepods in the plankton community, comprise a critical link in oceanic food webs between their phytoplankton food and their fish predators, many of which are commercially important fishes. It follows that direct harvesting of such a pivotal component in the food web has an ecological impact that must be evaluated if large-scale fisheries for krill are contemplated.

Most krill species are herbivorous, and in high latitudes krill consume many diatoms, but many krill species can utilise zooplankton as well, and some (e.g.

Megacyctiphanes) are carnivorous. So for most krill species, through the 'cascade' effect, phytoplankton might be expected to increase when krill are harvested by man,

Organisms that feed on krill might decrease in abundance if krill are harvested. These include many species of fish that are themselves the subjects of substantial human fisheries. In the North Pacific, krill form an important component of the diet of herring, salmon, pollack, sardine, mackerel and capelin, all of which support important commercial fisheries. The role of krill as food of squid is thought to have been overestimated.

Hence there is a fear that excessive harvest of krill might lead to:

- algal blooms of unharvested phytoplankton
- negative impacts on krill-dependent predators
- subsequent lower abundance of commercial fish stocks

Krill consumption by fish has been estimated and modelled in the Antarctic and so this workshop would aim to set up analogous models for the BC coastal region. Using the models, the impact of various levels of krill harvest in this region may be forecast.

Assessment, Potential Yield and Management of Krill Fisheries

Abundance is the key input parameter for the evaluation of all harvest impacts and for fishery regulation. The assessment and measurement of krill abundance presents challenges to both existing sonar technology and to mathematical modelling.

Estimating the biomass of krill in the plankton cannot be done with standard fisheries acoustics technology, most of which

has been designed for fish which are larger and have relatively high target strengths. Selection of equipment, selection of frequency, target identification, calibration of gear and measurement error are important topics in acoustic methodology for krill assessment.

Although krill growth appears to be well understood, modelling their population dynamics is subject to considerable uncertainty, especially in recruitment and the effect of social swarming behaviour. The design and analysis of surveys that can provide robust estimates of krill abundance is therefore critical to success.

Estimation of the potential yield of krill stocks leads to problems in demographics and in the estimation of recruitment. Assessment and potential yield evaluations may subsequently be used in developing suitable management measures for krill fisheries. In the Antarctic, CCAMLR researchers in particular have recently made some progress in these two areas.

Harvesting Technology for Krill

The Russian, Norwegian and Japanese have harvested Antarctic krill since the 1960s, trawling on the large social swarms that gather. Cost effective harvesting of krill in other waters appears not to have been extensively investigated, although recent innovations have been made in British Columbia.

Processing and Products from Krill

The processing of organisms high in oils and pigments presents both technical difficulties and economic opportunities to serve new and emerging markets.

Markets for Krill

Unconventional processing of krill products

is developing unexpected new markets. For example, krill pigments that may be used in the aquaculture feed industry fetch much higher prices and profits than using krill for fishmeal or using krill tails for human consumption, as has been done in Russia and Japan.

The BC Krill Industry

The krill harvesting industry in BC has already invested a considerable amount of work in three areas:

- harvesting technology
- acoustic assessment technology
- product technology

The small krill harvest quotas currently allowed in BC have not been subjected to independent review. This workshop brings together the BC industry, government and independent fishery scientists to address this problem.

New Fishery Guidelines

Essential features of the development of a new fishery are summarized in Figure 1.

The Workshop

The workshop aims to provide a rational basis for krill exploitation by evaluating ecological parameters and impacts, assessment methodology, krill products and markets.

The workshop was held on 14-16 November, 1995. It brought together international experts on krill from South Africa, the United Kingdom, Australia, Chile, Japan, Germany and the USA together with concerned representatives from BC fishing industry, BC government, local researchers and scientific staff from the UBC Fisheries Centre. Clients for the workshop are BC fishing industry. The workshop was co-sponsored by Sustainable Oceans Resource

Society of B.C. and participating companies; B.C. Ministry of Agriculture, Fisheries and Food; and Spark Oceans Initiative, Science Council of B.C.

Apart from this FC research report, an important output is a multi-author book in the *Chapman & Hall Fish & Fisheries Series*, with the suggested title: *Harvesting Krill: ecological impacts, assessment, products and markets*, edited by I. Everson and T.J. Pitcher. It is hoped that the book will be published in 1997.

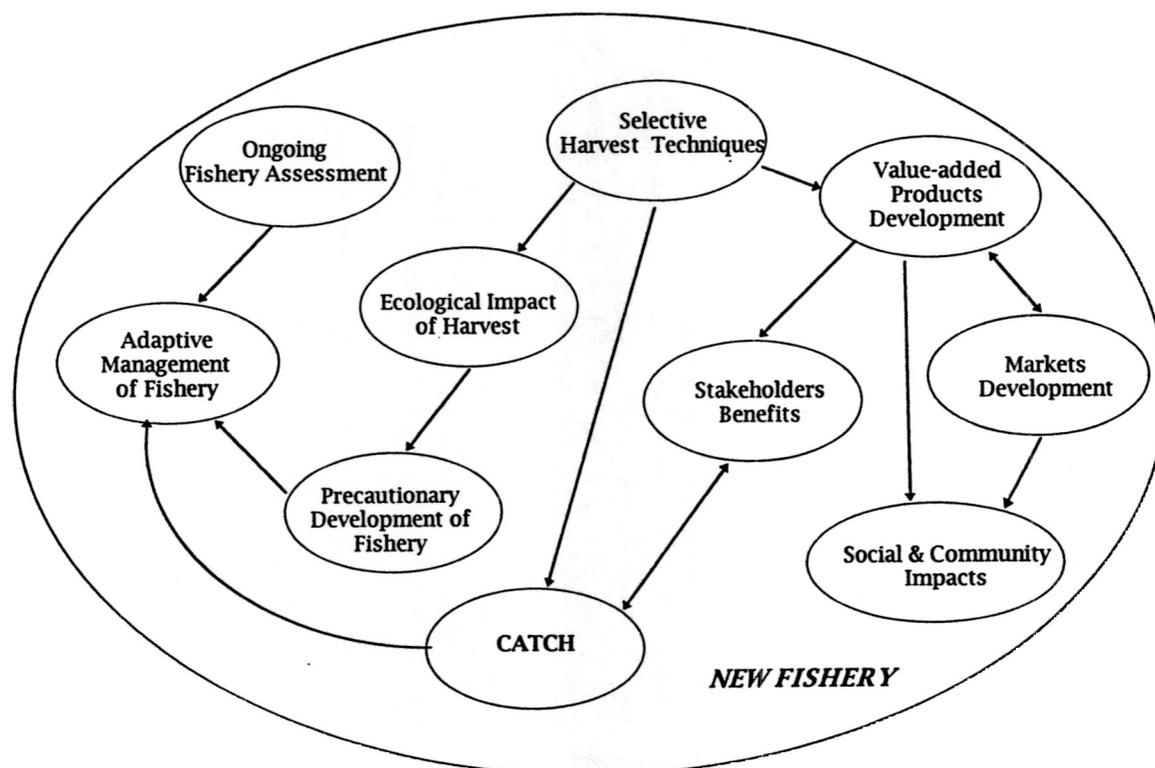


Figure 1. Diagram summarising essential features of the development of a new fishery.

**MODELLING AND DATA
REQUIREMENTS FOR
MANAGEMENT OF THE
ANTARCTIC KRILL-BASED
ECOSYSTEM**

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Scope

The development of CCAMLR's management of Antarctic krill (*Euphausia superba*), and the krill-based ecosystem has been described in some detail by Miller & Agnew, Everson and Nicol (a) in this volume. This paper explains some of the models used, and the data (see also Nicol (b) this volume) that CCAMLR has required to develop and implement these models.

Underlying philosophies: precautionary and ecosystem approaches and dealing with uncertainty

CCAMLR has considered two underlying philosophies in its approach to managing Antarctic resource exploitation, both of which arise from its Article II (see Everson and Miller & Agnew this volume). These are the precautionary approach and the ecosystem approach. The precautionary approach, which is essentially a set of guidelines for responsible exploitation includes, especially, a re-adjustment of the concept of the burden of proof. One of its central concepts is that fisheries should develop in a controlled fashion in concordance with the information available to manage them, and that the consequences of development should be demonstrated prior to that development. Although this approach

has been the subject of much international discussion recently (in particular see the report of the FAO/Government of Sweden meeting in Lysekil and the FAO Code of Conduct) CCAMLR has been using these concepts in its management since the mid-1980s.

The ecosystem approach and strategies for dealing with uncertainty arise naturally out of this philosophy. Among the consequences which should be considered as fisheries develop is the effects these fisheries have on dependent and related species. This will depend on ecosystem complexity and interactions, and its consideration is termed the ecosystem approach. Similarly uncertainty must be taken into account in developing management advice within a precautionary approach.

Importantly these ideas should not be taken to imply that fisheries cannot start until all information to predict the dynamics of a system has been gathered, nor should it be taken to imply that lack of information is a reason to impose management systems which are independent of scientific advice. On the contrary, models for management should be constructed to incorporate all uncertainties, and efforts should always be made to decrease these uncertainties within the constraints (practical, economic, biological) of the system. Management advice developed using such models is truly precautionary, and in general will tend to be more conservative (in terms of the TAC and effects on the stock and dependent species) as uncertainty increases.

Conceptual Framework

CCAMLR has developed a conceptual framework of the Antarctic ecosystem within

which it is developing a management system which takes the approaches outlined above into account (Figure 1: see SC-CAMLR 1995 for explanation). The components of this framework have been selected as the most important ecosystem components for management of the system. It is not an attempt to model the whole antarctic ecosystem, neither is it a framework for an ecopath approach (see Jarre-Teichmann this volume).

Within this framework several models of individual components and interactions have already been developed. CCAMLR's intention is to further develop these models and to integrate different models as required for specific management objectives.

Krill yield model

The krill yield model is the model that is being used currently to set precautionary limits for the krill fishery. It developed from the approaches developed by Beddington and Cooke (1983), and involves stochastic projections of a population which is subjected to a constant fishing yield. Uncertainty in any model parameters, such as selectivity, natural mortality, production and recruitment are taken into account in the modelling and stochastic process. The yield is expressed as a ratio of unexploited biomass determined from a survey, which itself can be associated with various levels of uncertainty, in the equation $yield = g B_0$, where B_0 is the pre-exploitation biomass survey and g is the ratio calculated by the model.

The essential features of the model are that a range of g are chosen, a projection model with a number of stochastic parameters is run for 1000 simulations with catches equal

to this yield, and statistics are calculated using the projected distributions of spawning stock biomass for the probability that the spawning stock biomass (B_{sp}) drops below a certain proportion (d_{crit}) of its unexploited median level (K_{sp}), and the median level of B_{sp} after a 20 year period of fishing.

A schematic diagram of the model is given in Figure 2 (see Butterworth et al 1994 and SC-CAMLR 1994 for a full description).

An appropriate long-term yield for the fishery may then be chosen by applying a number of clearly defined decision rules to the outputs of the model. In the CCAMLR system, the first decision rule has been to choose g_1 such that the probability of spawning stock biomass dropping below 20% (d_{crit}) of its median level in the absence of fishing is 10%. This decision rule acts to safeguard the stock against overexploitation. The second decision rule has been to choose a g_2 such that the median spawning stock biomass after 20 years is 75% of its median level in the absence of fishing. This second rule acts to protect predators against situations where their prey suffer unacceptable declines. The final decision rule has been to choose the most conservative of these two g as the final g that should be applied to an estimate of B_0 to calculate a precautionary catch limit for krill.

Central to this model is variability in recruitment. In its first formulation (Butterworth et al 1994) the model used bounded variables for M (from $U[.4,1.0]$) and recruitment variance (from a log-normal distribution). However, later developments described by de la Mare (1994) and incorporated into the yield model by Agnew (1994) included the sampling of recruitment

from distributions whose mean and variance were consistent with recruitment estimated from trawl survey data, and calculations of M which were also consistent with these data. These developments effectively reduced the uncertainty associated with estimation of recruitment and natural mortality by basing it upon empirical data, and demonstrate well the process of review and modification demanded of the precautionary approach.

Application of the yield model

Results for Antarctic krill have produced estimates of g_1 and g_2 of 0.149 and 0.116 respectively, although the model is currently subject to revision in some areas of the Antarctic. As an example of the use of these g values, for the southern Indian Ocean (Division 58.4.2) where B_0 has been estimated as 3.9 Million tonnes, the calculated yield would be 450 000 tonnes.

The approach provides a framework for determining an estimate of yield that is calculated taking uncertainty in model parameters into account. Any number of parameters may be added to such a model, and uncertainty in any of them, to any degree, may be incorporated. The approach is ultimately extremely flexible, because the model itself may be modified, different parameters introduced, variances adjusted, and even autocorrelation and trends introduced as more information becomes available.

The decision rules are also subject to modification to suit local conditions. The incorporation of rules based on P/B ratios, for situations depending more heavily upon within-season production than the Antarctic system for which the present system was

developed, is relatively simple. Similarly, adjustment of the "risk levels", that is the 10% probability of stock depletion or the limit of 75% depletion of the final stock, is also a matter for adjustment to suit individual situations. The choice of such levels is arbitrary, and depends on the individual comfort levels of managers confronted with various community concerns, but those values quoted above have been found to be acceptable in the Antarctic krill situation.

Most importantly, the approach offers a framework for the precautionary development of a fishery, because as uncertainty decreases so estimated yields increase. Under such a framework, a precautionary fishery could be allowed with a very conservative catch limit, based on a model with maximum uncertainty. As information from both the fishery and fishery-independent research becomes more comprehensive, uncertainty will decrease and, up to a point, catch limits will increase. The model should not be used as an excuse to do no research, but rather should be used in situations where there is little information so that some scientifically based management can be implemented immediately, while efforts to refine the model, and even to develop other, more responsive (feedback) approaches, proceed. Fisheries developing under such a regime should always be controlled by conservative catch limits and should avoid boom and bust situations which are damaging to stocks, ecosystems and industry.

Other models

A number of other models have been developed under the conceptual model outlined in Figure 1. One of the earliest to

be investigated was the overlap between predator foraging areas and the fishery, which has been the subject of much discussion in CCAMLR, because this overlap offers potential for competition between these two resource users. The krill fishery is generally concentrated in quite specific areas over the shelf break, and these areas may be within foraging distance (generally about 100km) of penguin and seal colonies on the Antarctic mainland and offshore islands. These predators are dependent upon gathering large quantities of krill to feed offspring during the breeding period (January to March). Models developed by Agnew (1992), Ichii et al (1994) and Agnew & Phegan (1994) have explored the relationship between predator foraging areas and krill fishery distribution, and while the precise functional relationship which would define their interaction remains elusive, present evidence is that the overlap problem is decreasing.

Time and space does not allow a description of the other models, but full discussions may be found in the papers listed in the references section.

Data requirements

Data requirements for the modelling of krill yield are fairly minimal, and centre around an estimate of unexploited biomass, and estimate of recruitment proportion and variability, and krill growth - see Nicol (b) (this volume) for further information. Refinement of the yield model necessarily depends on a better understanding of the system or additional data. Other modelling demands more data, such as predator abundance, distribution, foraging characteristics, breeding biology and survivorship. Easily obtained fisheries data

which have proved extremely valuable to CCAMLR are fine scale (at least 1/20 latitude by 10 longitude by 10 days periods) catch and effort data and representative length frequencies from the fishery.

One very important component, especially in a developing fishery, is the provision that scientific observers are on vessels for the accurate collection of basic biological and environmental data, and also to obtain data on bycatch of juvenile fish (see Moreno this volume) and other incidental mortality in the fishery.

Conclusion

CCAMLR has specified a framework within which it is developing a number of models of various parts of the Antarctic exploited ecosystem. The objective of all the modelling is towards rational management of Antarctic marine living resources within the contexts of a precautionary approach and an ecosystem approach to management.

The first acceptance of such approaches was in 1991, when CCAMLR adopted a conservation measure setting a precautionary catch limit for krill which was calculated using the krill yield model outlined in this paper. The model incorporates uncertainty in a number of parameters, and decision rules are applied to its outputs which choose a level of fishing which both conserves the krill stock and protects predator requirements for krill. This approach has been accepted by CCAMLR, in its consensus decision making process, as an appropriate method for controlling the development of krill fisheries.

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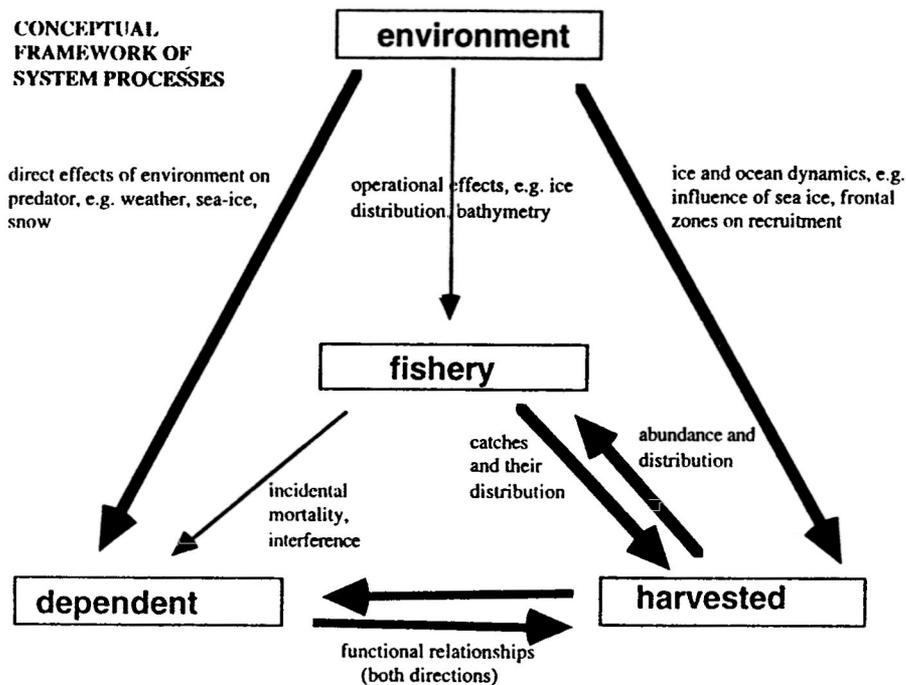


Figure 1 Conceptual framework of system processes

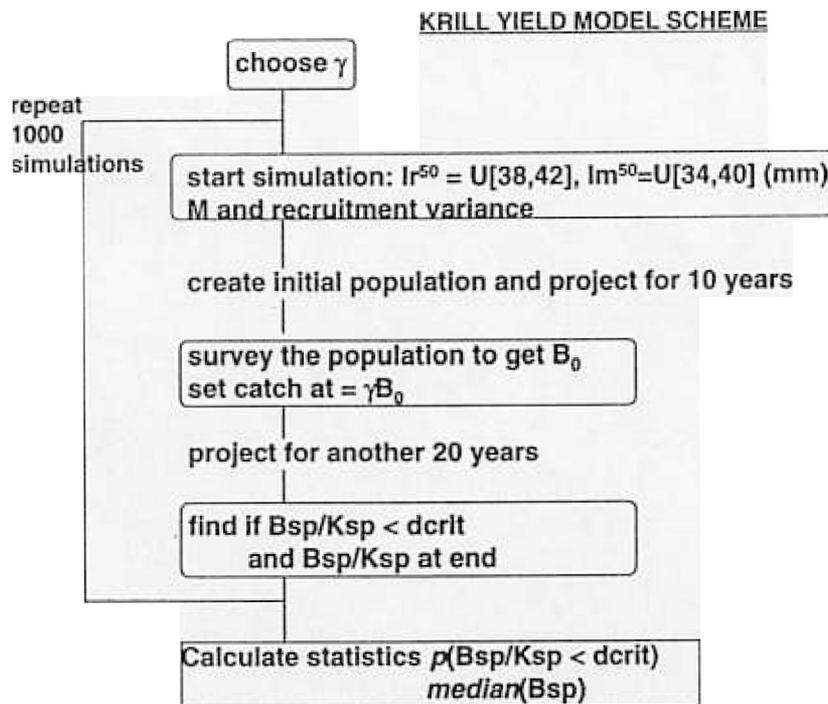


Figure 2. Krill yield model scheme

FISHERY BIOLOGY OF EUPHAUSIA PACIFICA IN THE JAPANESE WATERS

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The fishery on *Euphausia pacifica* or tsunonashi-okiami in Japanese vernacular name commenced in mid 1940s in the Sanriku waters, the sea area off northeastern Japan. The average annual catch is about 60,000 tons in the last 10 years. The fishing condition is highly dependent on the strength of the cold Oyashio Current. Attempts were made to predict the fishing conditions and the first fishing day of the year based on the southernmost latitude of the Oyashio Current in winter. There is some possibility that long-term trend in the fishing conditions can be predicted based on the wind field over the North Pacific Ocean upon which southward shift of the Oyashio Current seems to depend.

E. pacifica is considered as a key species in the Sanriku waters and many endemic and migrant predators including pelagic and demersal fishes, marine mammals, sea birds and possibly benthic organisms such as opihuroids depend on the species as food.

Among demersal fishes, walleye pollack is most important in the Sanriku waters. A study examined the occurrence of *E. pacifica* in the stomachs of various size groups of walleye pollack, Pacific cod and Pacific herring and estimated the amount of krill consumed by these demersal fishes. The estimated values were 540,000, 8,500 and 1,300 tons for walleye pollack, Pacific cod and Pacific herring, respectively. A total of

550,000 tons of *E. pacifica* were consumed each year off Miyagi and Fukushima Prefectures. As about 52% of the demersal fish landings for the whole fishing grounds of krill is landed at the Ishinomaki Fish Market, about 1,000,000 tons of *E. pacifica* may be consumed by demersal fishes in the whole area.

Pelagic fishes such as sardines, Japanese chub mackerel and Japanese flying squid migrate in large numbers into the sea area in May-January. The quantitative estimates of krill consumed by these pelagic fishes are needed.

In early summer, sooty shearwater, slender-billed shearwater and pale-footed shearwater visit the Sanriku waters in large flocks during their northward migration. Slender-billed shearwater seems to be an important krill feeder because the species feed mainly on a euphausiid, *Nyctiphanes australis* in their breeding area of Tasmanian waters. In the fishing season of *E. pacifica*, a large number of auklets may feed on them, which seems to come to the sea area from the Okhotsk Sea to overwinter.

E. pacifica males with empty ejaculatory duct(s) are easily found in the commercial catch. Females with an attached spermatophore, however, are rare. Two possible reasons can be pointed out on the scarcity of females with an attached spermatophore. The first one is that copulated females leave the swarm and stay in the midwater deeper than 15 m in the daytime and therefore cannot be collected by bow mounted trawl. The second one is detachment of attached spermatophores from thelycum when molting, which was supported by the observation of successive occurrence of small number (15%) of females with an attached spermatophore but

carapace not swollen in late March-early April, large number of females with an attached spermatophore and swollen carapace in early April, and finally females without spermatophore but swollen carapace in mid April off Ibaraki Prefecture.

Eggs and larvae of the species occur throughout the year but most of them occur in April-July. The life span of *E. pacifica* in the Sanriku waters is estimated to be one and a half years, which is similar to that in the Strait of Georgia, shorter than that in the Okhotsk Sea and off Kamchatka-south of Aleutians but longer than that off Oregon and southern California. Growth cessation in summer is not so long as reported in the Japan Sea.

In the coastal waters of Ibaraki Prefecture, the southernmost distributional range of the species, swarms descend to cooler mid water as the surface water temperature increases. Since this finding, mid water swarms as well as benthopelagic and surface swarms have been targeted. Surface swarms were formed in the years when cold water (5-7C) prevailed from the surface to the bottom, whereas benthopelagic swarms were formed when the water column was stratified with warm water >10C at the surface and thick cold water (6-9C) at the deeper layers. The benthopelagic population proved to occur throughout the year on the sea floor at 280m depth. Observations by submersibles showed that the dense bed of ophiuroids co-occurred with benthopelagic *E. pacifica* and ophiuroids were waving their arms as if they were trying to catch them. Distributional range, biomass, diurnal and seasonal migration of benthopelagic krill must be clarified to understand the structure of marine food webs of the Sanriku waters and management of krill fishery.

THE CCAMLR EXPERIENCE

Inigo Everson, British Antarctic Survey, Cambridge, UK.

Increased pressure on conventional fishery resources during the 1960's caused several fishing nations to look further afield in their search for harvestable resources. As a direct result, the former Soviet Union sent exploratory fishing vessels to the Southern Ocean in search of krill and fish. Intensive fishing on *Notothenia rossii* around South Georgia for about three years around 1970 resulted in reported catches of over half a million tonnes with the result that the stock collapsed. At the same time that this fishery was active the technology to catch and process krill were being developed.

Experience in other parts of the world where major fisheries, such as the Peruvian Anchovy, had collapsed raised concerns amongst scientists concerned with Southern Ocean resources. The main reason for this concern was that, since krill is at the hub of the Southern Ocean food web, overfishing could have a major impact, not just on krill itself but also on dependent species such as whales, seals, birds, fish and squid. As a direct result the Scientific Committee for Antarctic Research (SCAR) set up a programme, Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS), focused on krill in the context of the structure and dynamic functioning of the Southern Ocean ecosystem. A major research initiative of BIOMASS was FIBEX, a large scale multiship survey of the standing stock of krill in part of the Southwest Atlantic and Indian Ocean sectors.

The same concerns which were behind the BIOMASS programme were also raised within the Antarctic Treaty system. After

lengthy discussions between the Treaty parties agreement was reached on the Convention for the Conservation of Antarctic Marine Living Resources which came into force in 1982 as the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR is unique among regulatory bodies since the Convention requires it to take an ecosystem approach to management. This means that the effects of exploitation of a given stock or species are considered not in isolation, but also in relation to the system as a whole, and in particular to species dependent on that stock. These critical and innovative features are enshrined in Article II of the Convention. The scientific advice comes CCAMLR from the Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR).

Bearing in mind the agreed aims of the Convention, there are two primary considerations which need to be taken into account when assessing the impact of krill harvesting. The first one is the traditional single species approach whereby the resource is managed so as to ensure it remains healthy in perpetuity. The second is to ensure that harvesting on krill does not adversely affect dependent species, the so called ecosystem approach.

In order to develop advice for management of the krill fishery SC-CAMLR requires ecological data on distribution and annual production. Information on the large scale distribution of krill indicates that it is likely to be found anywhere south of the Antarctic Polar Frontal Zone (APFZ). However within this range its distribution is extremely patchy. Combining this patchy distribution with the enormous area, 36 million square kilometres, of the Southern Ocean, much of it covered by sea ice, means that standing

stock is difficult to determine. Indeed the problems are so huge that there has never been a Southern Ocean survey to estimate standing stock, the nearest was the FIBEX survey which covered about a quarter of the area. Estimation of potential yield has therefore been undertaken only for these limited areas covered by FIBEX and not for the Southern Ocean as a whole. Fortunately the FIBEX survey covered the area in which over 90% of the krill catch has been taken.

Standing stock (B_0) can be used to estimate potential yield using the equation $Y = \lambda M B_0$ where B_0 is a discount factor, typically less than 0.5, and M is the coefficient of natural mortality. This basic equation was modified to take account of the requirements of predators and in addition stochastic components incorporated to allow for variability in standing stock, recruitment, mortality and predator demand. All these have been incorporated into a single factor, γ , which is computed such that the median standing stock should not fall below 75% of its pre-exploitation level and also that there should be less than a 10% probability that the standing stock should fall below 20% of its pre-exploitation level in any one season. This approach has been used as the basis for setting precautionary catch limits in Area 48 (Atlantic Sector) and 58.4.1. (***) Indian Ocean sector).

While the precautionary approach outlined above is adequate for considerations on a large scale, it fails to take account of the differing spatial and temporal scales on which the krill and the dependent species function. The extent of this particular difficulty can be seen by considering the situation in the case of land-based predators such as penguins. During the breeding season, adult birds which are feeding chicks

are restricted to an area perhaps within 100 kilometres range of their breeding site and also require to provision their chicks on a daily basis. The available area might only be, in the case of the Atlantic sector, less than one per cent of the total area. Conservation measures therefore need to minimise the chance that all commercial fishing will take place in that same area at the critical period of the breeding season. This particular problem, although foreseen several years ago, is one now being actively addressed by CCAMLR.

In order to understand these interactions and develop advice for management, it is necessary to obtain information on the distribution of predators, their diet, food requirements and the spatial and temporal scales over which these operate. These considerations were behind the establishment of the CCAMLR Ecosystem Monitoring Programme (CEMP). In considering the potential impacts of harvesting on dependent species CCAMLR took a pragmatic approach to the problem by concentrating on a small number of species and clearly identified parameters. With nearly a decade of information available for some of these CEMP parameters SC-CAMLR is now looking to incorporate this information into its advice to the Commission for management of the krill fishery.

During the course of little more than a decade, CCAMLR has taken the most advanced conservation management convention forward and developed precautionary conservation measures for the krill fishery in advance of the large scale development of the fishery. The management approaches have taken into account uncertainty in the data in developing a precautionary approach to management. These facts are even more remarkable since

they have taken place in a forum operating by consensus in which members primarily interested in harvesting krill are in a minority. The atmosphere within CCAMLR is positive and constructive and it is to be hoped that this will continue so that current approaches can be refined and sustainable management for krill be sustained and initiated for other fisheries which might develop in the Southern Ocean.

PUTTING KRILL INTO ECOSYSTEM MODELS

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Abstract

More than two decades of intensive ecological research in the Antarctic have refined the over-simplistic view of "the Antarctic ecosystem" towards identification and investigation of a number of different subsystems. Within the pack-ice zone of the Weddell Sea (Atlantic sector of the Antarctic Ocean), a summer pelagic system breaks up into ice-bound and deep-living systems in winter. Furthermore, an export system at the borders of the Weddell gyre can be distinguished from a retention system at its center in summer. Continued studies allow for simple energy-flow budgets to be constructed of some of these subsystems, in which the varying role of krill can be analyzed. Such a model is presented for the ecosystem on the eastern Weddell Sea shelf. Although the benthic components dominate this ecosystem by biomass, the major part of the flows takes place in the pelagic, and these flows are analysed with focus on krill. The results are subsequently compared with a preliminary trophic flow model of a temperate shelf ecosystem off the southern coast of British Columbia. Krill appear to be generally well-used, being of more importance as food for homoiotherms in the Antarctic, and to fish off British Columbia. In view of efforts towards changing the exploitation of krill in any of these ecosystems, the role of krill in the food web needs to be quantified better than to date.

Introduction

Intensive ecological research in Antarctica under the umbrella of the Scientific Committee of Antarctic Research have substantially increased our knowledge on structure and processes in the Antarctic Ocean (see, e.g., Laws 1985 for an overview). Community studies of phyto- and zooplankton (Hart 1942, Voronina 1966, 1971) allowed to distinguish three zones, the ice-free zone, the seasonal pack-ice zone, and the quasi-permanent pack-ice zone, each with their own characteristic food-web (Hempel 1985). The simple food chain "diatoms-krill-consumers" was shown to be oversimplistic both from the lower and from the upper trophic levels (e.g., Hewes et al. 1985, Clarke 1985). Within the pack-ice zone of the Weddell Sea (Atlantic sector of the Antarctic Ocean), a summer pelagic system breaks up into ice-bound and deep-living systems in winter. Furthermore, an export system at the borders of the Weddell gyre can be distinguished from a retention system at its center in summer (Schalk et al. 1993). While sharing their importance with copepods and gelatinous zooplankton in the retention system, krill are a key element in the pelagic export system during summer, and a part of the ice-bound system in winter. Increased knowledge of the various components of these ecosystems has allowed to assemble energy flow budgets of some subsystems, e.g., of the eastern Weddell Sea shelf as part of the summer export system (Jarre-Teichmann et al. in press).

After a brief introduction to the modeling approach used, the role of krill in this high Antarctic ecosystem will be compared to its importance in a temperate shelf ecosystem, based on a preliminary trophic flow budget of the shelf off British Columbia.

An approach for constructing ecosystem models

Among the many approaches used for assessing interactions between species in an ecosystem, trophic flow budgets have proved useful as they allow to combine a major part of the knowledge, i.e., that on population dynamics and trophic interactions, of the many components of an ecosystem into a single, coherent whole. Being straightforward to construct, they are useful to identify major flows in an ecosystem and/or identify gaps in one's understanding of species interactions (Silvert 1981). Furthermore, they can serve as an illustrative tool during the construction process of dynamic models (e.g., Jarre-Teichmann 1992). Assuming average ("steady-state") conditions over an appropriate period of time, trophic interactions between the components of an ecosystem (species or species groups) can be described by a set of linear equations, wherein the production of each component equals its predation by other components in the system (predation mortality), its export from the system (fishing mortality and/or other exports, e.g., emigration), and other losses (baseline mortality), i.e.,

Production by (i) = All predation on (i) + nonpredatory biomass losses of (i) + fishery catches of (i) + other exports of (i)..... (1)

The terms in this equation may be replaced by

Production by (i) = $B_i * P/B_i$
 Predatory losses of (i) = M_2
 $= \sum_j (B_j * Q/B_j * DC_{j,i})$
 Other losses of (i) = $(1 - EE_i) * B_i * P/B_i$

and this leads, for any component in the system, to

$$B_i * P/B_i * EE_i - \sum_j (B_j * Q/B_j * DC_{j,i}) - Ex_i = 0 \quad (2)$$

where

- i indicates a component (stock, species, species group) of the model
- j any of its predators,
- B_i its biomass,
- P/B_i the production of a component per unit biomass (= total mortality under steady-state conditions),
- Q/B_i the consumption of a component per unit biomass,
- $DC_{j,i}$ the average fraction of i in the diet of j (in terms of weight),
- EE_i its ecotrophic efficiency (the fraction of the total production consumed by predators or exported from the system),
- Ex_i its export from the system (e.g., by emigration, or advection, or fishery catch).

The energy balance of each component is given by

$$\text{Consumption} = \text{Production} + \text{Respiration} + \text{Non-assimilated food} \quad (3)$$

where the total consumption is composed of consumption within the system and consumption of imports (i.e., feeding "outside the system"), and the production is either consumed by predators, exported from the system, or accounted as a contribution to detritus. This structure defines the necessary parameters for the model. These are, for each component, an estimate of its

- biomass,
- production per unit biomass,
- total food consumption per unit biomass,
- assimilation efficiency,
- diet composition,
- exports from the system,

ecotrophic efficiency.

For each component, one of above parameters B, P/B, Q/B, or EE may be unknown. It is estimated when solving the system, along with the respiration of that component. If an acceptable result for each of the unknowns is achieved from the inputs, the model is regarded as balanced and may further be analyzed. The ECOPATH II software (Christensen & Pauly 1992) was used for balancing and for the analysis of the models.

A model of an Antarctic ecosystem: the eastern Weddell Sea shelf

A 20 box trophic flow model was constructed which summarizes much of the available information on the eastern Weddell Sea shelf (Jarre-Teichmann et al. in press) (Fig. 1).

Euphausia crystallorophias is the most important species on the Weddell Sea shelf. Benthopelagic aggregations of the Antarctic krill *E. superba* have been observed on the deeper shelf of the eastern Weddell Sea, but this species is of more importance in the oceanic area (Boysen-Ennen et al. 1991, Gutt and Siegel 1994). In accordance with Siegel (1987), the total mortality of krill on the eastern Weddell Sea shelf was estimated at 1.0 year⁻¹, although the mortality of *E. crystallorophias* may be higher as it is smaller. Clarke and Morris (1983) estimated daily ration of adult male krill at 5.1% body mass, which led to a gross efficiency of 5.4%. The diet composition of krill was assumed to consist of 85% phytoplankton, 5% zooplankton, and 10% detritus.

Although the various benthic groups dominated the biomass in the system, the

planktonic groups were more important with respect to production: the planktonic groups accounted for only about 15% of the biomass, but for about 95% of the production. Euphausiids alone contributed some 4% to the total system throughput. The predation on euphausiids by whales was not further detailed by Jarre-Teichmann et al. (in press), but Miller et al (1985) scrutinized the predation mortality of krill. In their study, whales contributed about 53% to total krill mortality, seals 32%, squid and fish 8%, penguins 4% and flying birds 3%. The potential demand of predators was about twice as high as the production of krill based on the biomass given in Miller et al. (1985) and the productivity estimated by Siegel (1987,1992), indicating that krill are well-used as a food resource in the Antarctic ecosystem.

A preliminary model of the shelf ecosystem off southern British Columbia

During a workshop at UBC's Fisheries Centre immediately preceding the present one, two preliminary trophic flow models were constructed, one representing the central region of the Alaska Gyre, and the other one the shelf off British Columbia (Pauly and Christensen, in prep.). For the shelf model, 39 groups were selected by the participants (Table 1). The model has to date only been very roughly balanced. Improvements of the set of input parameters are presently ongoing. The structure of the food web on the shelf off British Columbia differs from that on the Weddell Sea shelf - beyond a higher throughput which is to be expected based on the temperature and primary productivity - in that the boxes appear to be better interconnected, and the feeding interactions are more widely spread among the trophic levels. One remarkable aspect of the modeling process was the

appreciation of the important role of krill (*Thysanoessa spinifera* and *Euphausia pacifica*) in the food web. The high demand from krill predators (Table 2) could, however, not be met by the available estimates of krill biomass (between 1.1 g wet mass m^{-2} (Romaine et al. this Workshop), and 3.8 g wet mass m^{-2} (R. Brodeur, pers. comm.)) and its productivity, i.e., 1.6 to 3.7 year⁻¹ (R. Tanasichuk, this Workshop). If krill constitute about 50% of the diet of herring (R. Tanasichuk pers. comm., minimum estimate) they are the dominant predators of krill, followed by hake. All other predator groups are relatively unimportant, contributing not more than 1% to the total predation on krill. If krill is important to top predators such as whales and birds, as in the Antarctic, the interactions will be indirect to a much larger extent. On the other hand, their importance in the diet of hake, herring and ocean perch suggests that changes in the availability of krill, such as, e.g., those caused by an intensive fishery, are likely to affect these fish groups.

It is not quite clear yet which misconception led to the imbalance - by more than one order of magnitude - between krill production and herring and hake food demand on the shelf off southern British Columbia. Consequently, there is not point in further analysis of the flow network at this point in time. It can, however, be inferred that the krill resource appears to be fully used within the ecosystem, leaving little scope for an extended fishery. Even without aiming at a complete understanding of the functioning of the food web, it appears crucial to analyze, probably on a seasonal basis, whether krill represent a bottleneck for the development of some life stages of these species, and, in turn, which may be the (direct and indirect) consequences of lower abundance of krill to

even higher trophic levels in the food web, such as birds and whales.

Acknowledgments

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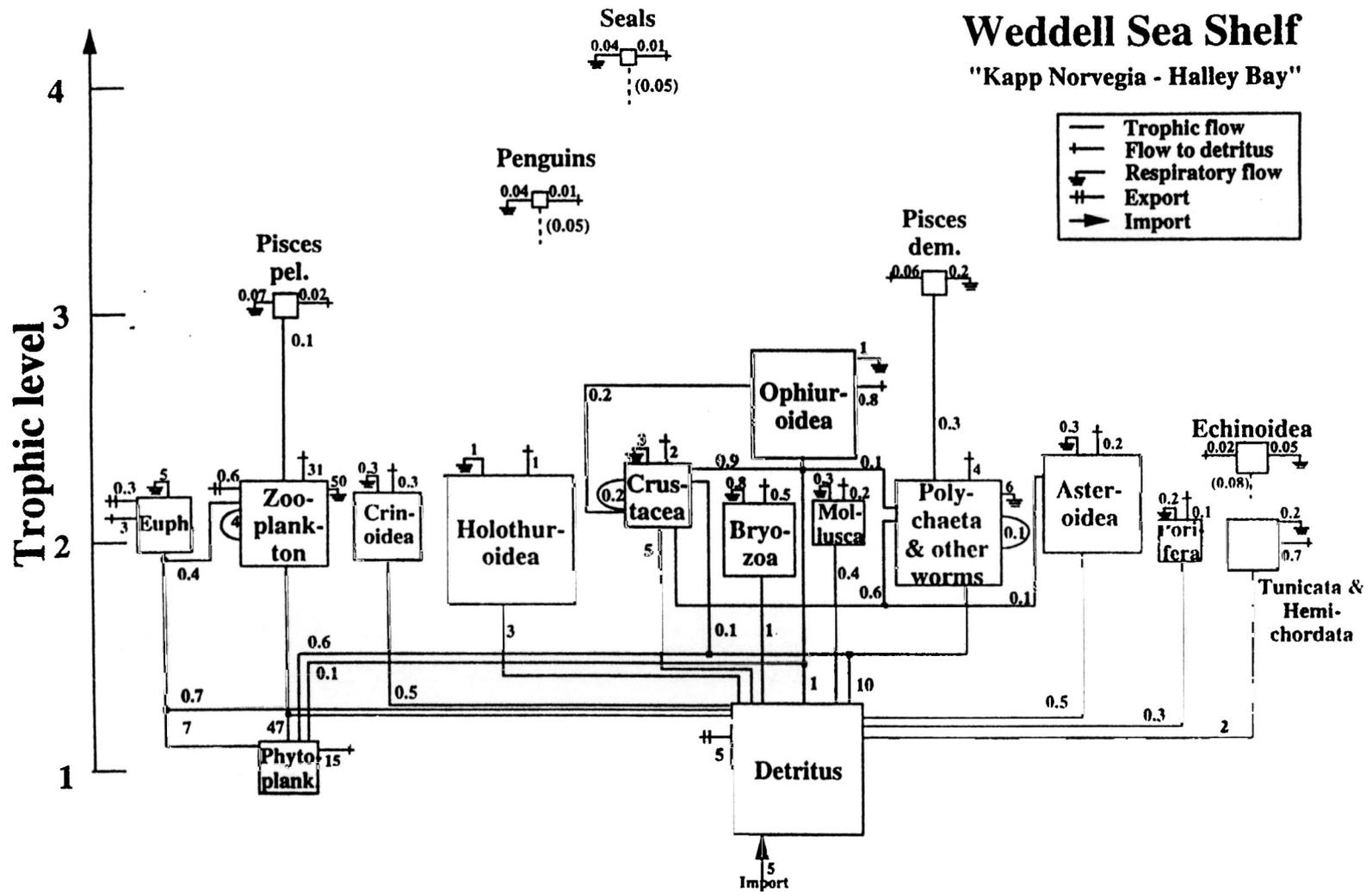


Figure 1. Diagram of carbon flows of the eastern Weddell Sea shelf (Jarre-Teichmann et al. in press). The components of the model are arranged along the vertical axis according to their trophic level. The size of the boxes is proportional to the biomass of the components in the system if they are imagined as cubes instead of squares. Respiratory flows, backflows to detritus, as well as exports from the system are indicated. Flows enter boxes on the lower half, and leave them on the upper half. Flows of 1 g C m⁻² year⁻¹ or more are rounded to integers, flows between 0.1 and 1 g C m⁻² year⁻¹ are rounded to one digit. Trophic flows of less than 0.1 g C m⁻² year⁻¹ were omitted for clarity.

Table 1 List of the 39 boxes used for a trophic model of the shelf off southern British Columbia by the participants of the workshop on "Mass-balance model of trophic fluxes in the North Pacific", held November 6-10, 1995, at the Fisheries Centre, UBC, Vancouver.

Biological group	Boxes in trophic flow model
Planktonic invertebrates	Phytoplankton Veleva, Bacteria Microzooplankton Small herbivorous zooplankton Carnivorous zooplankton Krill, Jellyfish, Salps, Squids
Benthic invertebrates	Polychaetes, Bivalves Benth. Amphipods Shrimps, Crabs Sea stars, Sea urchins Brittle stars, Other benthos
Pelagic fish	Herring, Smelts Sandlance, Resident salmon Transient salmon, Misc. pelagics
Semi-demersal and demersal fish	Rockfishes, Ocean perch Hake, Cod, Sablefish Sharks, Halibut, Misc. demersals
Homoiotherms	Toothed whales, Transient orcas Baleen whales, Pinnipeds, Marine birds
Detritus	One detritus box only, combining dissolved organic matter, particulate organic matter, and carcasses.

Table 2 Preliminary assessment of role of krill *Thysanoessa spinifera* and *Euphausia pacifica* in the food web on the shelf off southern British Columbia, Canada.

Fraction of krill in total diet (%)	Group	Fraction of total predation on krill ¹ (%)
51-100	Hake	11
26-50	Herring	88
	Ocean perch	<0.1
0-25	Sablefish	0.2
	Sharks	0.2
	Marine birds	<0.1
	Baleen whales	<0.1

¹ Initial estimates only, model not balanced to date.

ACOUSTIC ESTIMATION OF KRILL ABUNDANCE UTILIZING VOLUME SCATTERING MEASUREMENTS

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Abstract

Volume scattering measurements provide an effective tool for the enumeration of the complex distributions of krill (and other zooplankton). Krill populations exhibit frequency dependency in the level of sound scattering, complex (behavior induced) aggregations, and unusual net avoidance capabilities. Survey design and associated biological sampling requires special consideration of these features. Platform independent databases and GIS systems maximize the availability and portability of data collected on such surveys.

The Selection of tools available for acoustic measurements include single beam systems, dualbeam systems, and split beam systems. The single beam system is most commonly used for echo integration estimation of biomass. The dualbeam and split beam systems are most frequently used for measuring the target strength for scaling echointegration data or for the location of targets in an ensonified volume. It is now common practice to deploy both types of systems operating at two or more frequencies in order to produce the highest quality results from volume scattering and direct target strength measurements.

Estimation of krill abundance from volume scattering measurements requires

consideration of factors seldom used in acoustic estimation of fish abundance. Sound scatter from fish is predominantly in the geometric region of sound reflection, the target is large relative to the wavelength of sound ensonifying it, and there is little change in the strength of the echo with frequency. Sound scatter from krill, on the other hand, is often in the Rayleigh or resonant region of sound reflection, the target is small or nearly the same size as the wavelength of sound ensonifying it, and there is strong frequency dependence of the level of scattering. Concentrations of krill (in schools or patches) produce complex modes of sound scatter from the individual organisms comprising them (resonant effects). Krill exhibit a much stronger orientation dependency in their levels of sound scatter than is the case for fish.

Krill exhibit a strong tendency to aggregate in layers and in schools, swarms and patches. Consequently special consideration must be given to their behavior in designing surveys to enumerate their populations. Because krill are highly active swimmers, they are frequently capable of avoiding many types of nets commonly used to collect biological samples. Increasing the speed of the sampler or using a downward direction for sampling have proven to increase the effectiveness of such samplers.

Ecological interactions between populations of krill (or other zooplankton) and the environment or other organisms can be examined by spectral analysis of the spatial distributions observed hydroacoustically. The spectral density of these distributions often reveal scales of patchiness that are significantly different from those for purely hydrographically distributed particles. This suggests that there are certain preferred sizes to krill (and other zooplankton)

patches.

In order to provide effective management information, survey data collection systems must provide a number of items, among these are: real-time data display including position; timely production of reports following field work; platform independence of data formats and files; and manageable data volume. Flexible data export capability allows convenient use of the many commercial data analysis and display packages. Because of the rapid evolution of the tools and platforms for analysis it seems prudent to not be bound too tightly to any one system for data collection or analysis.

The final component of data management is the selection of a means to store the information collected and to make it available to the user community. While many database systems may have sufficient capacity and tools to satisfy many data storage and retrieval needs, there is an increasing tendency to use a geo-referenced database (or Geographical Information System, GIS) to provide these functions. There are many advantages to using both regular databases and GIS systems together to maximize the ability to extract, calculate and display the data from surveys in the most effective manner. Fig. 1 schematically illustrates some of these features.. An important consideration in the selection of any database tools is the selection of platform independent software. There remains significant differences between display and information management tools on the different computer platforms but generally the resulting data products can be utilized across platforms once they are produced. This is most evident in the field of multimedia production where the finished graphical and tabular information can be

integrated into a standalone data archive (CD-ROM or other optical device) with sufficient capacity to hold large quantities of data (0.5=4.3 megabytes).

Volume scattering and the measurement of its intensity provides a means of estimating biomass for many small organisms which have low target strength on an individual basis. Because these organisms frequently aggregate in large concentrations, the net effect of their combined influence on an ensonified volume produces measurable sound scatter. Krill are a typical case where volume scattering measurements can provide an effective tool for the determination of distribution and abundance.

EXPLOITATION AND MANAGEMENT OF ANTARCTIC KRILL

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Exploitation of Antarctic marine living resources has been characterised by intense boom and bust scenarios. Serious concerns have therefore been raised about the future management and sustainable utilisation of such resources. Krill (*Euphausia superba*), as a key species, has assumed predominance in this regard and the 22-nation Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) (which entered into force in 1982) was set up to address problems of managing the Antarctic marine ecosystem in an ecologically sustainable manner.

Krill catches have been reported from three major statistical areas in the Antarctic - the West Atlantic (Statistical Area 48), South East Indian Ocean (Statistical Area 58) and Pacific Antarctic (Statistical Area 88) sectors - all of which fall within the CCAMLR zone. Exploratory fishing for krill commenced in the early 1960s and catch levels were initially low. The build-up of catches was slow and it was not until the 1973/74 season that the fishery assumed commercial significance. Catches rose steadily from 1973/74 to a peak of 528 000 tonnes in 1981/82. Post-1982, catches have fluctuated and currently stand at about 120 000 tonnes. The Soviet Union and Japan have taken the bulk of the historic catch total (5.43 million tonnes) with other nations (mainly Chile and Poland) accounting for less than 3% of this total.

Annual catches in Statistical Area 48 have been consistently larger than in either Statistical Areas 58 or 88. Trends in annual catch from the three Areas have exhibited slight variations, although Soviet and Japanese catches remain dominant. To date, accumulated catches have been greatest in Statistical Subareas 48.3 (South Georgia Island) and 48.2 (South Orkney Islands) with lesser catches coming from Area 48.1 (South Shetland Islands). Monthly catch trends have been similar in all areas and are confined to the austral summer. However, catches in Subarea 48.3 are predominantly taken in the winter months most probably as an operational response to the presence of sea-ice farther south.

Despite difficulties inherent in the measurement of catch-per-unit of effort (CPUE), the Japanese krill fishery has exhibited a consistently higher catch-per-hour (CPH) in Subarea 48.1 and is markedly better than that of other nations. CPH for the Soviet fishery is highest for Subarea 48.2.

CCAMLR's efforts to develop a suitable management approach for the krill fishery have been based on the advice of its Scientific Committee (SC-CAMLR) as the "best scientific information available". CCAMLR has acknowledged that since various levels of "uncertainty" are associated with such advice, a "conservative" (i.e. precautionary) approach should be adopted in the absence of complete knowledge about krill stock dynamics. CCAMLR was subsequently the first international fisheries commission to adopt a precautionary ethic in its "ecosystem approach" to resource management.

CCAMLR has also recognised the need for "operational management principles" for the

krill fishery and has identified the following elements as essential:

(i) A basis for assessing the status (i.e. an "estimator") of krill stock(s);

(ii) A need to develop an algorithm to specify appropriate regulatory procedures [i.e. "catch control law" - chosen as Total Allowable Catch (TAC)] subject to (i);

(iii) A need to develop a basis for simulating and testing the performance of management procedures [i.e. components of both (i) and (ii)], and

(iv) A need to improve operational definition of Convention Article II (i.e. quantities measurable from field observations) to provide criteria against which the performance of management procedures may be assessed.

These elements have been used to develop regulatory measures for the fishery in specific geographic areas where krill stock size/yield have been estimated and where some attempt has been made to select acceptable levels of stock exploitation relative to the needs of both fishery and krill-dependent predators. A modelling approach based on that of Beddington and Cooke (1983) has been adopted (see Agnew this volume) to determine krill yield and as basis for setting precautionary catch limits in specific areas. While this approach only takes implicit account of predator needs, recent developments have focused on including more explicit formulations of such needs in the further development of the management paradigm. Consequently, krill management measures adopted by CCAMLR for krill to date:

* Aim to keep the krill biomass at a level higher than would be the case for single-species harvesting considerations;

* Given that krill dynamics have a

stochastic component, focus on the lowest biomass that might occur over a future period, rather than the average biomass at the end of that period, as might be the case in a single-species context (i.e. a fished species with no dependent predators);

* Ensure that any reduction of food to predators which may arise out of krill harvesting does not disproportionately prejudice land-breeding predators with restricted foraging ranges compared to predators in pelagic habitats, and

* Examine what levels of krill escapement are sufficient to meet the reasonable requirements of dependent predators.

CCAMLR has recognised the importance of accounting for possible environmental effects as these may affect estimates of yield through impact(s) on available krill biomass. To date consideration has been given to the potential effects of krill movement (i.e. flux) and the seasonal as well as inter-annual influences of sea-ice on inducing variability in krill recruitment. In addition, other efforts have addressed problems associated with determining potential overlaps between krill fishing and predator foraging as well issues affecting the spatial distribution of krill biomass as an underlying mechanism in determining krill availability. Finally, there have been preliminary attempts to develop models to assess the effectiveness of various management measures.

Compared with other fisheries conventions worldwide, CCAMLR's has undoubtedly been successful in formulating a precautionary and scientifically-defensible, management policy for the krill fishery. In this regard, CCAMLR's progress has been in part impeded by conceptual as much as practical difficulties inherent in the Commission's decision-making process, in

krill's contagious distribution and in the fishery's potentially large geographical range. Furthermore, there are still many uncertainties as to the economic future of the Antarctic krill fishery; a fact which will undoubtedly influence CCAMLR's future management initiatives.

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BY-CATCH OF JUVENILE FISHES THE ANTARCTIC KRILL FISHERY

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Abstract

One of the non-solved problems in krill exploitation has been the by-catch of fish larvae that use (or co-occurred) the krill swarms as their habitat. The detection of this problem started together with the massive antarctic krill exploitation during the 80's. There has been recognized several fish species whose larvae develop within the krill swarms, nevertheless, few have been the quantitative evaluations that give evidences that this technological interaction, is affecting the recovery of over-exploited populations or that commercial or non-commercial populations are diminishing.

Introduction

One of the greatest worries concerning the undesired effects on Antarctic Krill fishery is the continuous presence of juveniles and fish larvae in the commercial operation hauls. This, due to the use of non-selective pelagic trawls. This problem is specially sensible when it is related with larvae or juveniles of fishes under exploitation (e.g. the by-catch projection data reported by Pakhomov & Pankratov, 1993 of *Champscephalus gunnari*, results in an amount of 4% of the fishable biomass for that year (p 7.4. Annex 5 SC-CAMLR-XII).

The magnitude of this unaccounted mortality has not yet adequately studied for the antarctic krill fishery. The reasons are multiple and progress towards a complete

quantification has been submitted to a delaying process, in which political and historical conditioning of the relationships between the Antarctic countries, that finally have encountered a way since 1980, with the beginning of the Commission for the Conservation of Marine Living Resources (CCAMLR) in obtaining an adequate forum for the management of the Antarctic marine resources.

The first published observations on incidental mortality of fish larvae in the Krill fishery come from Polish ichthyologists that utilized that material for their descriptive studies concerning the early life stages of antarctic fishes. They were always impressed with the great quantity of fish larvae collected, what originated the first scientific reports (Rembiszewski *et al*, 1978; Slosarczyk, 1983). Actually, thanks to the pioneer studies of Everson (1968), Efremenko (1979 a & b) and principally the key and catalog of the antarctic fish larvae by North & Kellermann (1990) and Kellermann (1990), is that the identification and quantification of early life stages of the krill by-catch has been possible, being accessible to non specialist observers in fish larvae.

Actually the acceptance of the fishery countries of the International Scheme of Scientific Observation of CCAMLR, and the progressive incorporation of observers from non antarctic fishery countries in the last years has enabled the possibility of obtaining independent information, which will increase in the following years, been able to manage a non-bias evaluation of the amount of fishes in the krill by-catch. Consequently it is the right moment (and the right place) to perform a critical analysis of the different factors that are affecting or masking it.

Sampling Methods

The principal challenge of CCAMLR has been to standardize a sampling methodology, since the larvae distribution within the pelagic nets is not uniform, with a tendency to concentrate towards the highest zone of the codend. Different authors have use different sample sizes according to their possibilities and experience. The analysis of these problems has taken the subsidiary working groups of CCAMLR to propose a unique size sample of 40 to 50 kg of krill, taken from the superior part of the codend, expressing results in grams of larvae per krill ton or number of fish per hour of trawl. This technique is described in the pilot edition of the "Scientific Observers Manual" (CCAMLR 1993). The advantage of this technique is that it is apparently safe, since it uses the criteria of the "biggest sample" as a security element for data values confidence. Nevertheless, no studies have been developed to justify statistically the optimal sample size or the minimum number of samples.

By other hand, in the published papers there is a great diversity of trawl net models both, in sizes and designs. Table 1 shows data for some vessels that operate or operated in this fishery. Towing speed, unfortunately, is indicated only in some works, although it is an important aspect of the fishery operation. Cielniaszek & Pactwa (1994) mention that "since it was necessary to obtain krill of high quality, higher trawling speed were avoided". Besides this, many of the reports do not describe adequately the fishing gear, specially mouth size and shape, elements that must influence the amount of by-catch. The knowledge of these aspects would favor a better understanding of the problem, that could permit the design of mitigation measures.

Abundance of larvae and juvenile fishes in the krill by-catch.

The Scientific Committee of CCAMLR has recognized that the evaluation of the by-catch of juvenile fishes in the krill fishery is an urgent matter (SC-CAMLR-XI, paragraph 3.17). Nevertheless, the results presented by different authors, and that are summarized in Table 2, present some sort of methodological problem in their sampling or their analyses, or both. There is an exception that belongs to Watters (1995) with a reanalysis of Armstrong (1995) data, using a statistic methodology based in the delta distribution (mixture of other distributions) what permitted to standardize and compare all data of different combined species. Consequently all the information of Table 2 needs to be reanalyzed. Nevertheless, in spite it is statistically correct, some information concerning critical species is lost, for example *C. gunnari* in subarea 48.3.

Another critical species, strongly overfished in the early 70's *Notothenia rossii* actually protected from direct fishery, its larvae have never been reported in the krill by-catch, what means that is not a problem associated with krill fishery. Also, no attention must be paid in non-exploited species such as mictophids, with the exception of *Electrona calbergi* that also has not been reported as part of the krill by-catch.

An additional aspect, that has a great degree of concordance between the different authors (Ślósarczyk, 1983; Everson, Neyelov & Permitin, 1991; Iwami, 1994 and 1995), is that they suggest an inverse relation between krill abundance and the presence of juvenile fishes in the krill catches (Figure 1). Nevertheless, call the attention the virtual absence of intermediate points that suggest

the existence of a strong exponential decay between both variables. This could also be interpreted as two different states of krill aggregations that must occur in short time. By one hand, when krill is highly aggregated, tow time is short and the possibility of fish capturing is low. On the contrary, when the krill is dispersed, tow time increases together with the possibility of fish larvae captures. If this inference is true, then it should be a function of tow time (or amount of water filtered). This interesting topic necessarily needs analytical and practical research input.

In relation with the origin of the variability of juvenile fish abundances observed during krill catches, the following factors have been invoked.

Year Season

The season after antarctic fish reproduction has been supposed as the epoch in which the possibility that the pelagic fish larvae appear in greatest numbers as krill by-catch. Hereafter, there is a possibility that posterior to the fish reproductive season its larvae have a greater risk of been captured when reaching vulnerable sizes for pelagic nets. At South Georgia post-larvae of *C. gunnari* of 70 to 80 mm of length are found close to krill during May and July (Pakhomov & Pankratov, 1993), although the hatch time corresponds to the previous spring according North & White (1987), probably it can extend towards summer in this area (Kellermann, 1990). The consequence of this wide reproductive time is that they can be vulnerable nearly all year. Nevertheless, the by-catch observation of this area are concentrated during autumn and winter (Table 3). On the contrary, in the rest of the areas, the observations are concentrated during summer. Probably this correspond to the fleet movements.

Other temporal factor that has been indicated as a source of interannual variability, is the influence of large scale environmental factors (ENSO) as it has been demonstrated by Kellermann & Kock (1988). It is not known that this phenomenon could affect equally fish larvae and krill.

Distance to shore

This factor is the most clear pattern of all the sources of variation proposed and it is reflected in the specific composition of the by-catch. The presence of coastal fishes (Chaenocephalus, Harpagiferidae or Nototheniidae) in a great diversity are strongly associated to areas over (or near) the shelf, in eddies generated by the confluence of the marine bottom topography and marine currents (Stein, 1988; Asencio & Mujica, 1986; Kellermann & Kock, 1988). On the contrary a low diversity, with the dominance of Myctophidae, are typical of areas over the slope and open sea (Figure 2).

The most important aspect of this factor, is the seasonal presence around the antarctic islands, like Elephant Island, of eddies capable of retaining fish larvae, on summer and autumn, on the east side of the island with fluxes towards the northeast in spring (Stein, 1988). Probably at South Georgia something similar must occur. The fish larvae show coupling with these circulation as they grow, as been demonstrated elsewhere (Cowen & Castro, 1994). Such eddies have been proposed as important physical mechanisms that made recirculate the eggs and larvae of coastal fishes, thereby minimizing the loss due to transport away from suitable settlement sites (Wolanski & Hammer, 1988). These mechanisms do not generate a uniform larvae distribution, but tendencies concentrations in small area in relation to the total surface, which, if it coincides with krill aggregations can

represent the most higher potential danger if fishing operation for krill occur in the same area and time in which larvae concentrations are. First priority to investigate the processes and mechanisms concerning larvae transport so as to understand their relationship with krill fluxes.

Conclusions and recommendations

Its clear that factors involved in the incidental catches of fish larvae and fry in the krill fishery are:

1. Variations in krill abundance
 - Temporal (Interannual, Seasonal, Daily)
 - Spatial (By subarea, Distance to the shore, Aggregation state)
2. Variations in fish early stages abundance
 - Temporal (Interannual, Seasonal, Daily)
 - Spatial (By subarea, Oceanographic phenomena, Vertical movements)
3. Fishing Operations
 - Fishing gear (Net mouth size, Tow speed, Codend mesh)
 - Depth

When facing this high number of variables, the only way to "Match the Hatch" is to generated a wide data base, sustained in routinely observations from haul by haul that can be related in different ways. This requires a major cover of Scientific observers during the fishery operations, but focused on critical species and areas (e.g. *C. gunnari* in subarea 48.3), that means on fisheries potentially conflictive.

An alternative solution still non explored at CCAMLR, is to improve the design of the krill gear to avoid damage and to permit an adequate escape of fish larvae (in the case that the by-catch could be important).

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Table 1. Some Characteristics Of Fishing Gear Utilized In The Antarctic Krill Fishery. Mentioned In The Known Reports At CCAMLR.

Vessel	Size (mouth) (m ²)	Codend mesh (mm)	Towing speed (Knots)	Reference
Kirishima	1600	15 - 30	2.7	WG-Krill-92/23
Kaiyo Maru	644	10	?	WG-Krill-93/50
Prof. Bogucki	240	12	2.8-3.3	Słosarczyk, 1982
A. Knipovich	?	?	?	WG-Krill-91/25
Prof. Siedlecki	750	11	?	Słosarczyk, 1982
Chiyo Maru 2-5	1600	15	?	WG-Krill-93/51
Niitaka Maru	?	?	?	WG-Krill-94/25
Niitaka Maru	?	?	?	WG-Krill-95/56
Chiyo Maru 2	(47.9 wide)	15	?	SC - CCAMLR - XIV/BG/10Rev1
Lepus	442	15	3	WG-FSA-94/25
Grigori Kovtun	400	10	?	WG-FSA-93/8

Table 2. Estimates Of Abundance Of Fish (Including Larvae, Fry And Adults) As By-Catch In The Antarctic Krill Fishery.

Reference	Number of hauls observed /positive	Number of species/ individuals	Index of Abundance
WG-FSA-94/25	77/25	13/77	287 ind./0.1 Ton. of Krill
WG-FSA-93/8	55/10	4/1460	700-18900 ind / Ton
Slósarczyk, 1983	/15	2/?	Tb = 5.5-4438.2 ind/ 0.1 Ton. Pb = 5.5-44.9 ind/0.1 Ton.
WG-EMM-95/56	78/20	4/95	0-248.2 g /0.1 Ton.
WG-Krill-94/25	SOI 46/8 SG 163/30	1/1336 6/2639	13-1108 ind/Ton. 1-1640 ind/Ton.
WG-Krill-93/50	102/25	16/104	36ind/0.5 h.haul
WG-Krill-92/32	50/42	16/131	n.e.
WG-FSA-95/40R1	175/21	6/747	19.89 (104) ind / Ton.

Tb=*Trematomus bernacchi*. Pb=*Pagothenia brachysoma*

Table 3. Areas And Season Of The Year Of The Reported Quantitative Studies Of Fish By-Catch In The Antarctic Krill Fishery.

Reference	Statistical Subarea				Season of the year			
	58	48.1	48.2	48.3	Summer	Autumn	Winter	Spring.
WG-FSA-94/25				x	3 - 4/93			
WG-FSA-93/8				x		5 - 6/92	7 /92	
WG-Krill-93/51				x			7 - 8/92	
Slósarczyk, 1983				x		4 / 81		
WG-EMM-95/56	x				1 -2/95			
WG-Krill-94/25	x				1 -2/94			
			x		4 -5/93			
WG-EMM-95/56	x				1 - 2/ 95			
WG-Krill-93/50	x				12/90- 2/91			
WG-Krill-92/32		x			2-3/ 91			
WG-FSA-95/40R1	x				1-3/95			

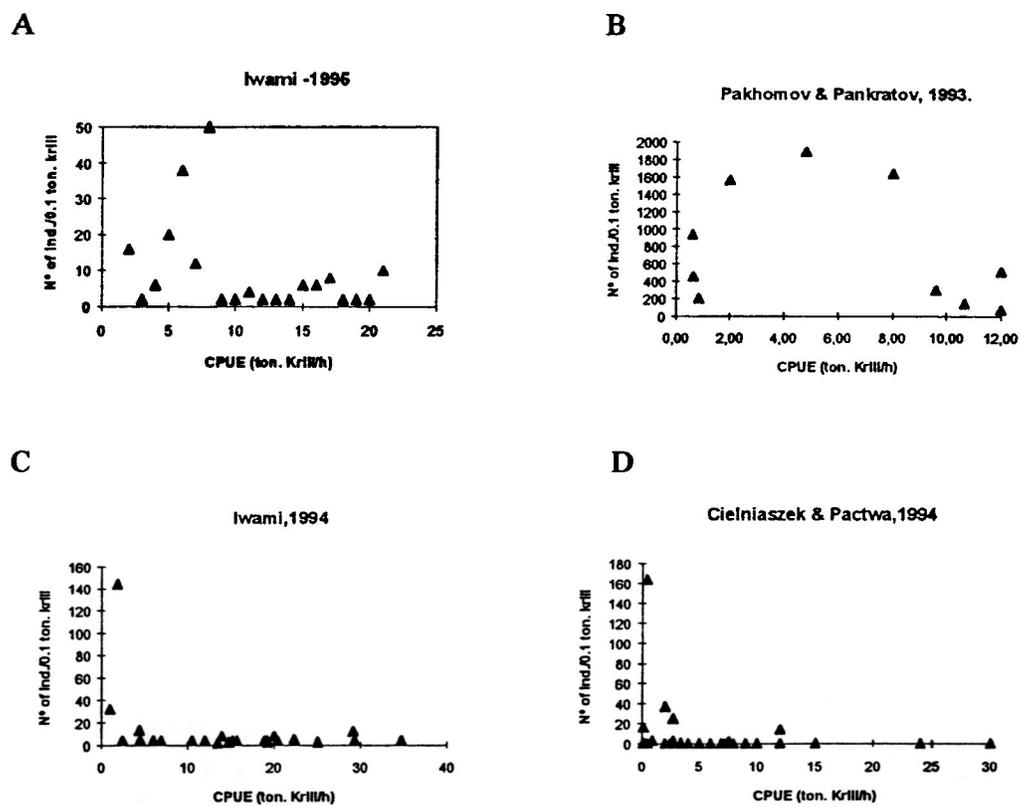


Figure 1. Relationship between the index of abundance of by-catch and the krill catches.

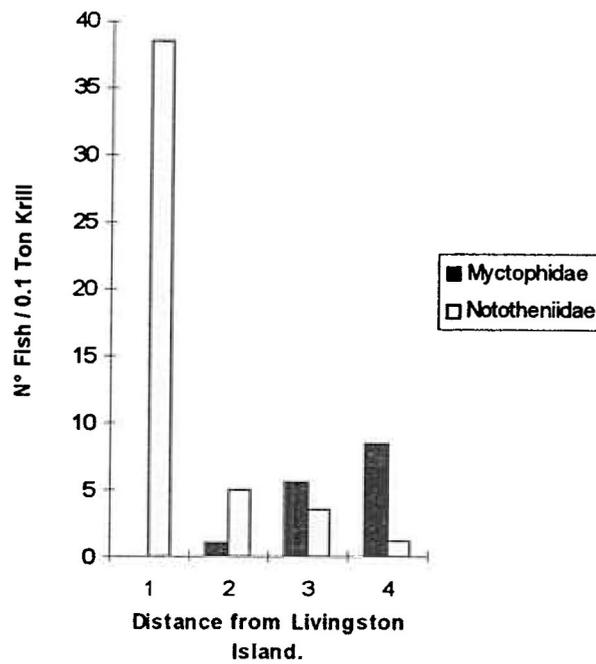


Figure 2. Presence of two groups of antarctic fishes as by-catch in the krill operations. The data were obtained from Iwami (1994 & 1995). The distance was categorized from 1 = hauls made over the shelf off the northern coast of Livingston Island to 4 = far in open sea. 2 and 3 correspond to groups of hauls made over the slope.

DEVELOPMENT OF THE KRILL FISHING INDUSTRY

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Krill of any species were little known until the middle of the last century. This is largely because of their generally pelagic habit, their small size and mostly offshore distribution. They were known by fishermen from the stomach of whales (Marr 1962). Krill normally live in fairly deep water during the day and come to the surface at night as part of a diurnal vertical migration. Sometimes they are to be found on the surface during the daytime and they can colour the water red for kilometres - the causes for this behaviour are not fully worked out and it is likely that there are several reasons why krill surface swarm. In this form, krill were first harvested; fishermen in the Mediterranean were reported to fish swarms of *Meganyctiphanes norvegica* for use as bait in the last century (Fisher et al., 1953). Early records of Antarctic krill report their presence in huge surface swarms (see Marr, 1962) and one of the earlier records also refers to attempts to use them for human consumption (von Drygalski, 1990): "We caught huge quantities of shrimps (krill) in such quantities that we were able to eat them too; they tasted quite good, but they were rather small and tiresome to peel ...". This quote presages some of the problems that the krill fishery was to face later. Harvesting of marine species in the Antarctic first concentrated on the more traditional species: the seals, whales, and fish. In turn these resources were depleted until they were economically unviable (Saharge, 1989). A number of factors conspired to shift attention to krill in the Antarctic. Firstly, the depletion of the other marine living resources of the region. Secondly, the depletion of most stocks of fish throughout

the world in the 1960s and 1970s. Thirdly, the extension of the EEZs of most maritime countries to 200nm forced many large fleets into the open ocean away from traditional catches. Finally, the results of scientific exploration in the Antarctic were beginning to reveal the size of the krill resource and there was speculation on the potential for harvesting allowed for by the decline in the whale population (Nicol, 1989). It is not surprising that the initial experiments into fishing for krill were by Japan - which had a large fleet of vessels, experience in Antarctic waters and a ready market for seafood including smaller crustaceans such as sergested shrimps and even the coastal Japanese krill. The USSR also began experimental fishing in the late 1960s and again they had large fleets of deep water vessels and Antarctic experience. (Budzinski et al. 1983). The true commercial fishery started in the early 1970s (Fig. 1). The fishery reached a peak in the early 1980s when over half a million tonnes were caught. For much of the 1980s it was the world's largest crustacean fishery and one of the world's top 20 fisheries by tonnage caught. Most of the catch in the 1980s was been taken by the USSR but now that the nations formerly in the USSR have decreased their interest in krill, most is being taken by Japan (Fig 2.). Other nations have been involved as minor players in the fishery (Table 1) but these have mostly been experimental approaches and have lasted only a few years or have been sporadic. Other nations which have formally expressed interest in the krill fishery to CCAMLR include Australia, Norway and India. Many other nations have the potential to enter the fishery if they desired.

There are a number of difficulties associated with the krill fishery which have slowed down its development (Nicol, 1989). Distance is the main problem - it is far from

most places and is in very inhospitable seas. The geographic remoteness is reflected in the areas that have been fished for krill. Krill are found all around the Antarctic continent (Fig. 3). However, the fishery has tended to concentrate in areas close to other fisheries i.e. the South Atlantic. Other problems relate more to the nature of krill itself. Catching krill is not that much of a problem with modern echosounders. The fishery concentrates on sub surface swarms rather than the surface swarms which are rarer. Such swarms are extremely dense and catch rates of a tonne a minute can easily be attained (Budzinski et al. 1983). The swarms are also extremely large, some estimated to contain over a million tonnes of krill and stretching for over ten kilometres (Shulenberger et al. 1983). The problems emerge once the krill are in the net. Krill are thin shelled and are easily crushed this limits catches to under ten tonnes since greater catches tend to crush the krill in the net or when landed. The crushing itself causes other problems - some proteins of krill are very water soluble and start to leak out of the bodies once crushed - this also prevents their being stored in water once landed. They also have extremely powerful protein digesting enzymes which begin digesting the krill as soon as the animal is dead. This process is further enhanced by crushing and landed krill are useless for human consumption after 3 hours. After 8 hours on deck, they are useless for animal feed even at the low ambient temperatures found in the Antarctic. (Budzinski et al. 1983). The final feature that makes krill fishing extremely tricky is that the shells have extremely high levels of fluoride (up to 10,000 ppm, Soevik and Braekan, 1979). This was first reported in 1979 and may account for the large drop in krill catches that occurred in the mid 1980s. The fluoride is localised in the shell but once the animals are dead, it begins to migrate into the flesh.

This still occurs if the krill are refrigerated above -30C but the migration can be arrested if the krill are boiled. (Budzinski et al. 1983). Peeling the krill immediately is the one sure way of providing a fluoride free product at present (Nicol 1989). Whole krill are generally, even in boiled form, unsuitable for either human consumption or as food for livestock. Producing low fluoride products - either as meal or as food - is costly and makes processing krill as livestock feed uneconomic (Budzinski et al. 1983). Whole krill or other krill products high in fluoride are, however, suitable for aquaculture as many marine species seem to be able to cope with high fluoride diets without ill effects and without elevated flesh fluoride levels themselves (Storebakken, 1987). Other more minor problems faced by the krill industry relate more to the requirements of the market. The fishery avoids areas where krill have been feeding actively and the Japanese fishermen also distinguish between white and pink krill concentrating on the former which are preferred by the consumer. There is still a market in Japan for whole krill for human consumption and there is preference for the lipid rich mature females which taste better. Currently the Japanese fishery makes four types of product (Table 2). Only a quarter is peeled for human consumption but the waste from the peeling is used in meal production.

Krill products for human consumption have been varied. Early Soviet products included a paste called 'Okean' and krill butter. Krill tails were also produced in a canned form for use as a food additive. Quite how much of the Soviet catch went into products for human consumption is uncertain - official claims of greater than 50% were later disputed. Certainly there was much development of equipment for peeling krill and into new products but quality of Soviet food products was low and variability was

high so even in the USSR there was little acceptance of krill as a food source. It is rumoured that much of the Soviet krill catch found its way onto mink farms where the high fluoride levels in whole krill was less of a concern. The Japanese have produced a range of manufactured food items like peeled tails and krill sausages and some processed krill is exported to other countries to be used in food products (Nicol, 1989).

The Japanese fishery is probably best understood. They currently have between 6 and 8 (80-100 metres) boats fishing for krill most in the Atlantic though one does regularly fish in the Indian Ocean Sector where it obtains a smaller size of krill, largely used for aquaculture. Fishing occurs mainly in the summer months December to March but there has been a persistent winter fishery for krill around ice free South Georgia. Although the boats usually work close to each other, the requirement for rapid processing means that the use of mother ships is ruled out. They were used at first but quickly it became obvious that on board processing was best. The processed catch is however transhipped to reefer ships so the trawlers can spend long periods on the fishing grounds. Krill is caught in large pelagic trawls and is landed into a fish hold from whence they are sent by conveyor for processing. A proportion of the catch is roller peeled and for this product, there is strict quality control to ensure that all the contaminants - particularly the conspicuous eyeballs - are removed. Whole krill are either blanched then frozen or frozen whole in blocks. The number of trawls per day is limited by the processing capacity of the ship rather than the abundance of krill in particular areas and this, coupled with the attempts to limit the catch per trawl to avoid crushing has thrown into doubt the use of CPUE as a useful index of abundance for krill.

The current fishery at 117,000 tonnes is relatively small scale compared to the potential that had been proposed - several tens of millions of tonnes (Ross and Quetin, 1986). The fishery is currently limited by its profitability - it is costly to go fishing for krill and the returns for the existing products currently don't justify an expansion. New products are probably the key to future expansion of the krill fishery. These can range from improved efficiencies in the peeling methodologies, better use of the whole krill, methods for fluoride removal or can include the extraction of novel chemicals from krill. These new products could include chitin/chitosan (Nicol (1991), enzymes (Anheller et al., 1989) pigments or fatty acids. It is unlikely that advances in any of these products singly will produce the impetus for an expanded krill fishery, rather it will occur through an expanded market for a range of products from the fishery.

Any expansion in the fishery for Antarctic krill will probably lead for a further examination of other species of krill for their fisheries potential (Table 3). Several species have already been investigated but only the North Pacific krill fisheries have regularly operated outside the Antarctic to date. Other species, particularly North Atlantic krill, *Meganyctiphanes norvegica*, offers opportunities and this is particularly interesting in the Canadian context.

As the major fisheries of the world become fully or over-exploited, the demand for marine protein will have to be met from new sources. Krill offer one source of that protein both as a direct source and as a feed for aquaculture which is an area of considerable growth. Because of the intermediate role of all species of krill in their respective ecosystems, the transition from harvesting the predators of krill to the krill themselves must be managed very

carefully (Nicol and de la Mare, 1993). We have little experience in managing fisheries of species such as krill and have a history of mis-managing larger species. The ecological consequence of overharvesting krill are tremendous and therefore the job of CCAMLR and other bodies tasked with managing krill fisheries is both difficult and critical.

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Table 1. Nations involved in the Antarctic krill fishery

Nation	Years when fishing took place
Ukraine	1992-95
Japan	1973-95
Poland	1977, 1978, 1980, 1983, 1986-95
Panama*	1995
Russia	1992-1994
Chile	1976, 1977, 1983-94
USSR	1974-91
S. Korea	1979, 1982-1984, 1987-92
Spain	1987
France	1980
GDR	1978, 1979, 1985, 1990
Taiwan*	1975, 1977
Latvia*	1994

*Non-signatory to CCAMLR=0C

Table 2. Products, uses and yields from the Japanese Antarctic krill fishery*

a.) Products as a percentage of the total catch.

Fresh frozen 34 %
 Boiled frozen 11 %
 Peeled krill meat 23 %
 Meal 32 %

b.) Uses of products from the Japanese Antarctic krill fishery

Meal	Aquaculture
Boiled frozen	Human consumption
Peeled krill	Human consumption
Fresh frozen:	
	Sport fishing bait (70%)
	Ground sport fishing bait (10%)
	Aquaculture (20%)

c.) Yields of various krill products.

Boiled and fresh frozen	80-90 %
Peeled krill	8-17 %
Meal	10-15 %

* From information supplied by the Taro Ichii of the National Institute of Far Seas Fisheries, Shimizu, Japan.

Table 3. Proposed and actual* krill fisheries.

Antarctic krill (<i>Euphausia superba</i>)	Antarctica*
North Pacific krill (<i>Euphausia pacifica</i>)	Japan*/ British Columbia*
<i>Euphausia nana</i>	Japan*
<i>Thysanoessa inermis</i>	Japan*
North Atlantic krill (<i>Meganyctiphanes norvegica</i>)	Mediterranean*
Australian krill (<i>Nyctiphanes australis</i>)	Gulf of St. Lawrence/ Scandanavia
	Tasmania

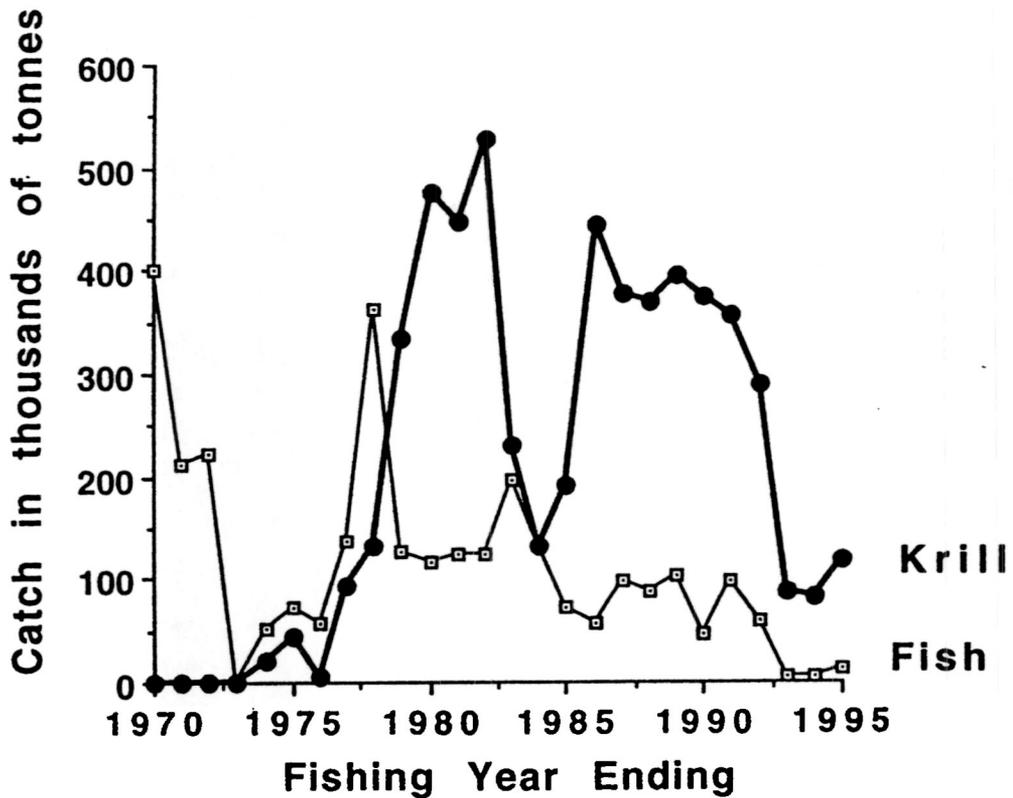
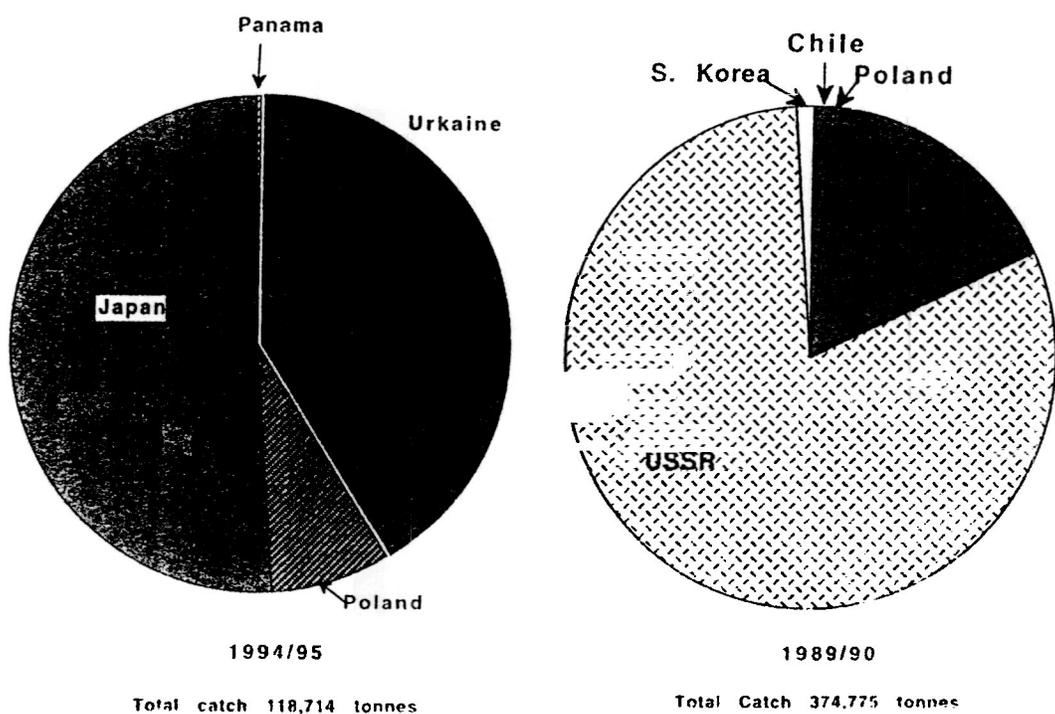


Figure The annual catch of Antarctic krill and Antarctic finfish.



Figures 2 The proportion of the Antarctic krill catch taken by fishing nations: 1994/95 compared to 1989/90.

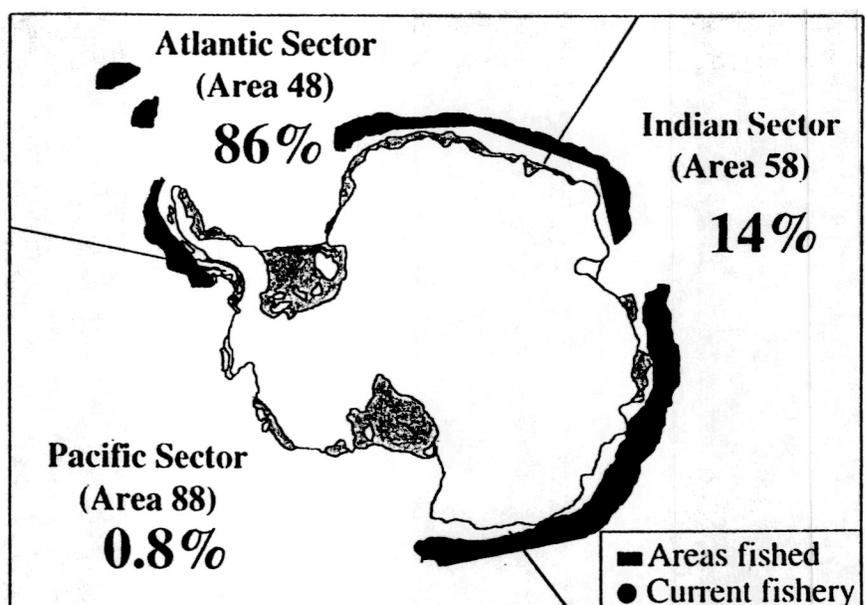


Figure 3 Location of krill catches showing overall percentage of historical catch taken from each sector

**BIOLOGICAL INFORMATION
NECESSARY FOR THE
MANAGEMENT OF THE
ANTARCTIC KRILL FISHERY**

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The model that has been developed by the Krill Working Group of the Commission for the Conservation of Antarctic Marine Living Resources to set precautionary catch limits for the Antarctic krill fishery (Butterworth et al., 1991, and see also paper by Agnew, this Report) appears to require very little biological input. The primary requirements are: an estimate of the pre-exploitation biomass of krill, recruitment proportion and its variability and some measure of growth rate of krill. However, if these parameters are examined further, each of them requires considerable subsidiary information and the acquisition of these details for Antarctic krill has been quite problematic. The aim of this paper is to highlight the difficulties that have been faced when trying to come up with the biological information needed to manage the fishery for Antarctic krill and to indicate where the lessons that have been learned in this fishery might be helpful in the management of other krill fisheries.

The first requirement of the model is some estimate of the pre exploitation biomass - or failing that, some estimate of the existing biomass. There are at least 4 aspects to this problem. Firstly, we need to know the distribution or the range of the species if we are going to manage it throughout its range. For Antarctic krill, we already have considerable information about its overall distribution; the CCAMLR area within which we are supposed to be managing this resource is some 32 million square kilometres in size and krill can be found in most parts of the area. Krill do, however,

tend to occur in aggregations and these aggregations themselves tend to be clumped. This leads to an overall picture of a very patch distribution and one that is only very rudimentarily mapped. We have a good idea of where consistent aggregations can be found in most years and indeed the fishery exploits such aggregations. What we don't know is where other such aggregations occur and what factors affect the stability of these aggregations on a short or long time scale (Miller and Hampton, 1989). This information is extremely difficult and costly to obtain. Assessing the distribution and abundance of krill requires that we understand the behaviour of the krill swarms so that the biases that their behaviour introduces into the estimates can be taken into account. Unfortunately, we lack much of the information to do this. Krill were once thought of as a species that carried out a simple diurnal vertical migration - up at night and down during the day. This now seems not to be the case. Krill may be found in most parts of the water column and where this affects biomass estimation is that they can be found in the water above the echosounder transducer when forming surface swarms or they can be found in deeper water beyond the range of most of the echosounders normally used to survey krill (see papers by Everson and Macaulay in this volume). Like other species of krill such as *E. pacifica* and *M. norvegica*, *E. superba* can be found at times in benthic-pelagic aggregations (Gutt and Siegel, 1994). The proportion of the population that forms both benthic and surface swarms at any time is unknown and this introduces some unknown error into our biomass estimates. Krill distribution, particularly in spring, is thought to be related to the pack ice and its movements. Surveys of krill are usually carried out in summer when there is minimal ice cover because carrying out acoustic surveys in ice

covered waters is extremely difficult. Krill may still be found in association with residual ice cover during the summer months and since these areas are not surveyed, there may be a proportion of the population that is going unsampled. The amount of residual ice in the fishing grounds of the South Atlantic is small - this is one of the reasons why they are chosen as fishing grounds - but in other areas of the Antarctic there can be considerable amounts of disintegrating pack ice, even late in the summer. Because the scraping of ice on the hull causes noise that interferes with the echosounder returns, it only takes a small amount of ice in the water to make surveying difficult. Software programs which will be able to eliminate much of the noise from the data are being developed and hopefully they will allow the surveying of areas that have been impossible to get into before.

CCAMLR requires survey data to set precautionary limits using the krill yield model but lacks the capacity to carry out the surveys itself. It is dependent on the member nations to volunteer their ships and time to survey the relevant parts of the CCAMLR area. Those areas currently covered by precautionary limits used survey data collected as part of the BIOMASS program in the early 1980s - a multi-nation, multi-ship program which took years to work up (El Sayed, 1994). The experience of this program - its scale, scope, cost and the degree of integration necessary - has put many nations off the idea of becoming involved in further surveys for krill. None the less, CCAMLR is in the process of endorsing, in principle, a new survey for the South Atlantic region so that the data collected could replace the BIOMASS data which are perceived to have certain flaws. The South East Indian Ocean is the one remaining region of the CCAMLR Area which has been regularly fished for krill but

which has not yet been surveyed and therefore which has no precautionary limit. This is Division 58.4.1, some 4.7 million square kilometres or about one sixth of the CCAMLR Area. This summer (1995/96) an Australian research team is going to attempt to survey a large portion of this area with the aim of providing the data for CCAMLR to set a precautionary limit. This will be the first time that a survey has been specifically designed to provide the data necessary for the calculation of a precautionary limit by the krill yield model and will provide a test case to see whether it would be possible to carry out similar surveys in the South Atlantic. The final element in the survey story is that of stock separation. There has been considerable speculation about whether krill are a single circumpolar stock or are a series of smaller populations. Every study to date has been unable to find any genetic differences between krill collected from widely separated sites (Fevolden and Scheneppenheim, 1989). This, however may just reflect the lack of sensitivity of the techniques used. More advanced molecular techniques are now being used and it should soon be possible to get a more definitive answer. The question of stocks of krill is intimately related to the question of whether krill are carried between the various regions of the Antarctic and the rate of this transport. This has been called the krill flux problem and has major implications on the way that the fishery is managed. It is also one of the more complex problems, involving, as it does, the interaction between the krill and the oceanography. It is further complicated by the difficulty of maintaining sampling regimes during winter. Whether there are distinct stocks of krill or not, for the purposes of ensuring the conservation of the krill population, the model assumes that there are separate stocks as this is the most conservative of the two approaches and is the one that fits in best with CCAMLR's

objectives.

The next requirement of the model is for information on recruitment proportion and its variability - how many krill enter the breeding population each year and how does this vary with time. This requires that we have some representative samples of the population of krill - usually obtained by research net. Krill occur in swarms and swarms within a restricted area may differ considerably in the constituent individuals: they may be single sex swarms, all adults, all juvenile, all reproductive, all immature or of a restricted size range. It has been calculated that to ensure a representative picture of the individuals in a particular area, 26 separate net samples needs to be taken (Watkins et al., 1986) - this rarely occurs. This is complicated further still when the results of such net sampling are examined. Often the proportion of the adult size class far outweighs that of the juveniles. This was a major problem when krill were considered to have a two year life cycle - such an assumption was in itself based on analyses of length frequencies (Mackintosh, 1972). Once krill were maintained in the laboratory, it became apparent that a two year life cycle was probably incorrect (Ikeda, 1985) and the reason for the under-estimation, based on length frequency analysis, was revealed. Krill shrink if starved (Ikeda and Dixon, 1981). This is not just a weight loss but is a loss in overall body size and is achieved by reverting to a smaller size at each moult - roughly every 20 to 30 days. Krill also lose their primary and secondary sexual characteristics if starved (Thomas and Ikeda, 1987) so an adult that has been starved through a series of moults is indistinguishable in size and characteristics from a juvenile. This explains why the adult size class is often so much bigger than the juvenile size class - it is composed of a large number of age classes

which are homogenous because of repetitive cycles of moulting and shrinking (Nicol, 1991). Age class analysis requires a method of separating out the various ages that does not rely on size alone. To date, attention has focussed on trying to find and utilise a chemical marker of age or some morphometric measure other than simple length with some limited success (Ettershank, 1984, Nicol et al. 1991). For the purposes of recruitment, however, a new method (de la Mare, 1994 a, b) requires only information on the number of first year animals entering the breeding population and this appears to be a much more tractable problem.

For the same reason that age structure is difficult to estimate, growth rate is also a problem. Estimates that have been made on the growth rate of krill have used different sorts of information. Long-term population measurements have been extremely difficult to make because of the oceanic nature of Antarctic krill. No method has been devised to tag krill and it is therefore impossible to know whether the same population has been sampled more than once - a prerequisite for measuring growth rates. Long-term measurements of krill growth rates derived from large numbers of net tows have resulted in average growth curves but are still dependent on some assumptions about the longevity of krill (Rosenberg et al, 1986). Short term measurements of the growth of freshly caught individuals yield a range of results ranging from increases in length of 10% per moult to shrinkage of up to 5% per moult (Quetin and Ross, 1993, Nicol et al., 1993). These results corroborate with estimates obtained from length frequency analyses using the assumption that krill attain maximum size after two years and have a period of interrupted growth and possible shrinkage during winter. They also agree with

estimates derived from laboratory studies into the growth rate of krill. Laboratory growth rates (Ikeda, 1985) indicate that krill can grow to maturity in two years. All the growth estimates are still dependent on making assumptions on what happens during winter. There are remarkably few measurements of krill growth rates outside the laboratory for seasons other than summer. Further refinements in this area are going to have to come from thoroughly sampling krill throughout the year.

Conclusions

There are a number of lessons derived from the experience of studying Antarctic krill which are applicable to other krill fisheries.

Firstly, there is a need to understand the distributional biology of the species quite well and to ensure that it is adequately sampled.

Secondly, the life history of the species should be re examined - every species of krill examined so far has been shown to be capable of shrinkage and this can wreak havoc with length frequency analysis. Life histories derived from length frequencies were proved wrong for Antarctic krill and there is the possibility that similar errors.

Thirdly, adult krill are not plankton.

Fourthly, studies on live krill are essential to understand their critical life history parameters.

Finally, krill are usually critical elements of marine ecosystems and in managing the harvesting of these resources, it is prudent to follow the practice being adopted by CCAMLR which uses the most conservative assumption in the face of uncertainty.

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USING THE ECOPATH II APPROACH TO ASSESS KRILL BIOMASS AND DYNAMICS

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Summary

Krill represents, in all systems where it occurs, a major element of the diet of commercial fishes, and/or of marine mammal, and hence would be important group to study even if they had no direct use as feedstock for e.g. mariculture.

The biomass and hence dynamics of krill are difficult to estimate directly using direct sampling or acoustic methods, and it is proposed that these can be inferred indirectly based on the predation rates of krill consumers, and estimates of the production/biomass ratio of krill.

The mass-balance approach implemented in the ECOPATH II software (Christensen and Pauly 1995, Pauly 1996)*, can be used for this, and an application example is presented, pertaining to the Georgia Strait, British Columbia, for which a trophic model has recently been constructed by graduate students of this author. The many uncertainties associated with this approach can be quantified, using the Monte Carlo routine built in the recently released Windows version of ECOPATH II, and entering ranges or distributions about all inputs, including the fraction of krill in the diet of its consumers. The corresponding outputs are expressed in a semi-Bayesian context, either as posterior distributions of acceptable inputs (i.e. of those enabling mass balance), or as probabilistic distributions for estimates such as mean krill biomasses over a conventional period (e.g. a year). It is suggested that such estimates of biomass will compare favourably, both in precision and

accuracy, with estimates extrapolated from catch samples, or from hydroacoustics.

[Following the workshop where the above was presented, Dr Carl Walters of the Fisheries Centre, UBC, developed an approach now implemented as an ECOPATH II subroutine called ECOSIM, which reexpresses the linear equation system that the ECOPATH approach relies on, into a system of differential equations which can be integrated over time (Walters et al 1996). Thus, once an ECOPATH II model is constructed, its outputs can be used to run, without further input, a simulation model of the system in question; perturbations can be studied (by changing the temporal pattern of fishery mortality, e.g. on krill predators) and the temporal responses (e.g. of krill) studied. Preliminary examination with ECOSIM, of the dynamics of 50+ of the ecosystems so far described with ECOPATH II was found to be useful in characterizing the key role of prey species (such as krill) in ecosystems, thus providing additional reasons for recommending the modeling approach suggested above.]

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*available free of charge from V. Christensen, contact villychr@centrum.dk

**COMPARISONS OF REPEAT
ACOUSTIC SURVEYS IN JERVIS
INLET, BRITISH COLUMBIA, 1994-
1995**

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Currently, most of the commercial harvest of euphausiids in B.C. has come from either the mouth of Jervis Inlet or the adjacent Malaspina Strait within the Strait of Georgia, with an annual quota for the entire BC coast currently set at 500 t. Jervis Inlet is about 316 km² and since the inlet is mostly enclosed, short-term changes due to physical transport are unlikely.

We conducted repeated monthly acoustical surveys over 208 km² of the inlet from the mouth to a point north of Vancouver Bay (Figure 1). Our study had the following objectives:

- 1) To quantify the statistical precision of euphausiid stock estimates derived from replicated survey grids.
- 2) To compare alternative mapping and integration methods.
- 3) To compare alternative acoustic (target strength) calibration models.
- 4) To quantify month-to-month changes in stock size.

Methods

Sampling was completed every month from June 1994 to June 1995, except December 1994. Net tows were conducted every month

to provide both species analysis and size-frequency distribution. Two different echosounders were used in this study: a 200 kHz single beam system collected data monthly and a 100 kHz single beam provided additional data collection for November 1994 and February 1995. For months when both echosounders were used, parallel acoustic surveys were run to determine the agreement between biomass estimates from each.

Two different methods of biomass estimates were provided by our study: 1) stratified-oblique net tows at a very few sites gave "sea truth", body size, and depth distribution; and 2) acoustic surveys along zig-zag transect lines permitted spatially detailed measurements of biomass. A total of four different survey grids were run in Jervis Inlet, with the most important being the 'A' and 'B' mirror image transects that ran from the inlet mouth to Vancouver Bay (Figure 2a,b). These transects allowed the determination of agreement among replicated surveys both as a mirror image conducted on the same day or as a complete replicated survey conducted within a one day period.

Determination of biomass estimates from transects was done by both block averaging and a geostatistics interpolation method (linear kriging). Block averaging determines the average biomass for a zone (see Figure 1) and multiplies this by the area of the zone to give a biomass estimate. Zone estimates are summed to provide an overall inlet estimate. Kriging is a interpolation method in which values of biomass at known points are entered into an interpolation software application and a gridded file of interpolated point estimates are created from the known data based on proximity-weighted averaging of nearby measurements. Biomass estimates for the inlet are determined by integration of the contour map derived from the estimated grid values.

Our estimates of biomass used two models of target strengths: the first model assumed an average euphausiid length of 12 mm for all months. The second model includes effects of monthly changes in euphausiid lengths and is provided by Macaulay (1994) and is also discussed in this volume.

Results and Discussion

Over 99% of the euphausiids captured by net tows were *Euphausia pacifica*. Euphausiid lengths ranged from 8 to 27 mm, with an average of 16 mm. Two cohorts were noted in June 1994: juveniles with an modal length of 9 mm and adults with an modal length of 20 mm. Euphausiids belonging to the adult cohort were not present after the October 1994 sampling. The juveniles continued to grow to a modal length of 20 mm by May 1995. No euphausiids less than 8 mm were ever recovered from a net tow; nor does the 200 kHz echosounder detect objects less than about 8 mm.

Estimates of biomass from target strength were based on either a fixed (12 mm) or an average euphausiid length for the month. Uncertainty due to the target strength vs. frequency and body size was $\times \div 1.5$ or less, with an average difference of $\sim 40\%$. We believe that best estimate of biomass within Jervis Inlet would be new model based on a combination of the two explored models. This was a major source of uncertainty for our total stock size estimates.

Along-transect correlation between echo returns from the 100 kHz and the 200 kHz sounders was $r^2 = 0.74$. Integrated biomass estimates between the two frequencies differed on average by 27%.

Agreement between the mirror daily A/B replicated surveys (ANOVA) was 24% using kriging. Agreement between combined A/B surveys repeated within a one day period

was 15% using block averaging.

Time series biomass estimates ranged 10 fold seasonally from a low of 1.0K t in June 1994 to a peak in October of 4.3-8.1K t, followed by a winter decline to a February low of 0.9-2.0K t, followed by a rapid growth to a peak in May of 7.0-11.0K t. The commercial fishery occurs from November to February each year, when the presence of larval fish is at a minimum. Biomass estimates are represented in Figure 3, using the average monthly euphausiid length model.

Although Jervis Inlet has been acoustically sampled since c.1990, this was the first time this type of survey has been repeated monthly to give good resolution of seasonal variability. The replicated survey also provided much-improved quantification of the error bars associated with acoustic surveys. Total stock size estimates were within the range observed in previous acoustic and net tow surveys, but error bars on average stock size within a time period are now about a factor of three narrower.

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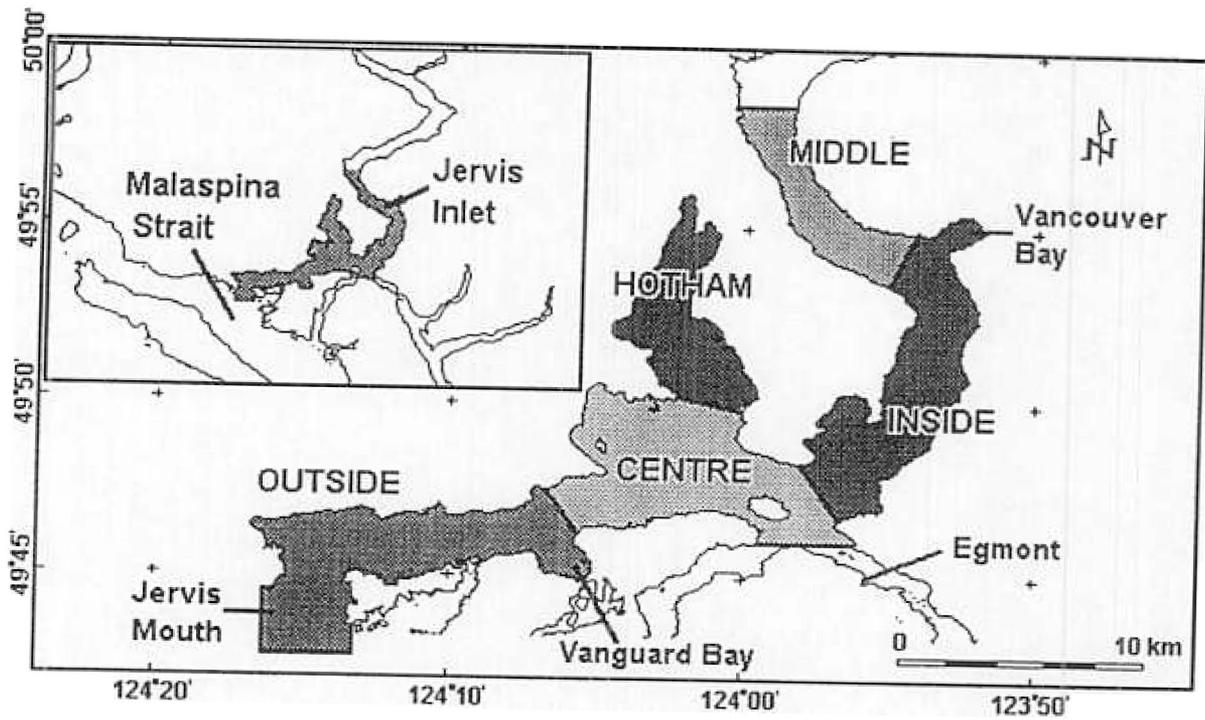


Figure 1. Jervis Inlet and associated biomass block averaging zones. The entire inlet is approximately 316 km². Biomass estimates for our study considered the shaded areas only (total = 208 km²). For block averaging, five different biomass zones (Outside, Centre, Hotham, Inside, and Middle) were used.

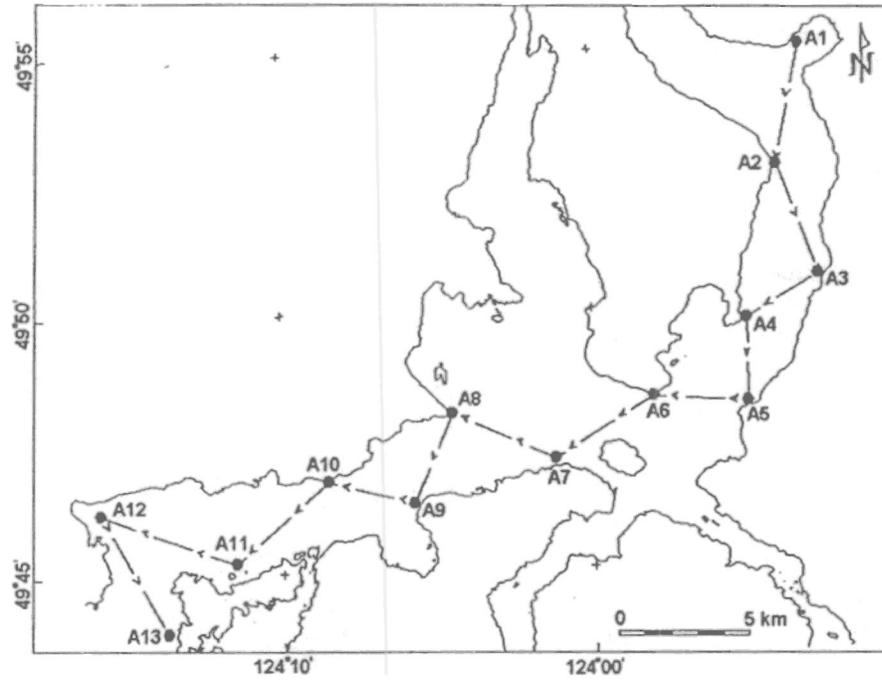


Figure 2a Jervis Inlet, transect series A

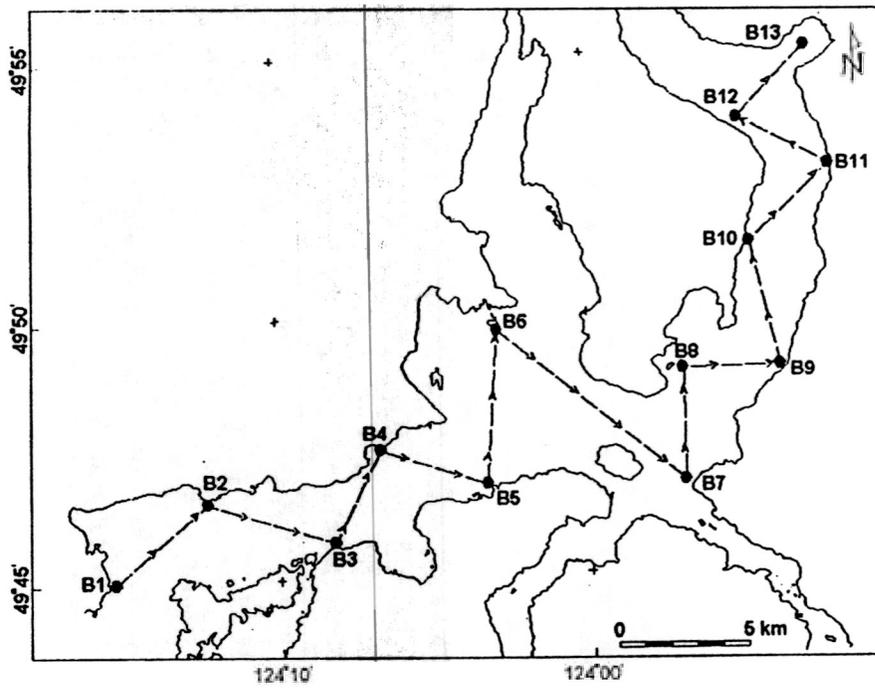


Figure Jervis Inlet, transect series 'B'

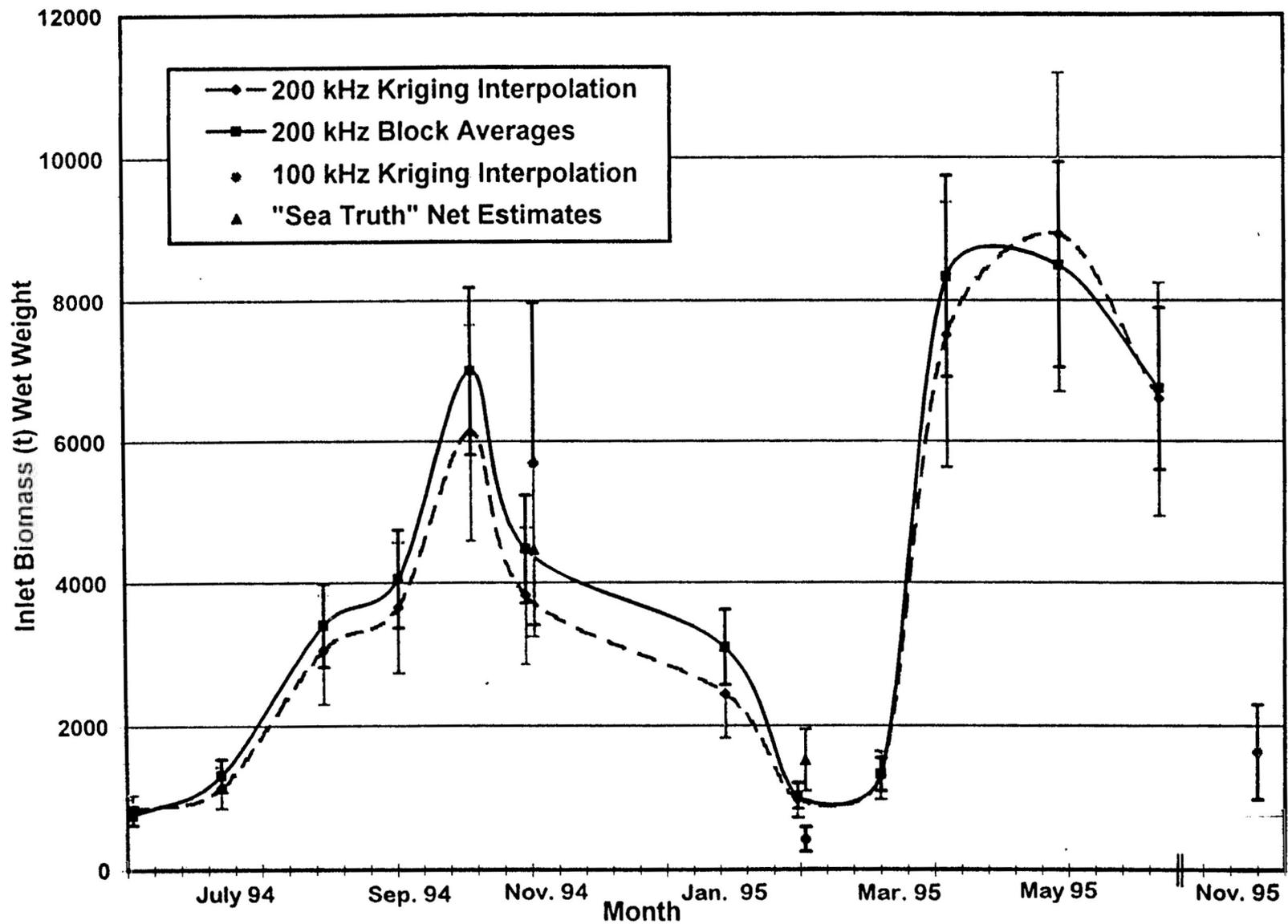


Figure 3. Jervis Inlet biomass estimates: June 1994-5, Nov. 1995. Estimates are for the shaded areas only, as noted in Figure 1. The duration of the commercial fishery occurs from November to February.

OVERVIEW OF THE KRILL OF THE GULF OF ST.LAWRENCE

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The Gulf of St.Lawrence is a canadian semi-enclosed sea connected to the Atlantic ocean by two straits, the deep (~450 m) southern Cabot strait and the shallow (~70 m) northeastern Belle-Isle strait (Fig.1). The Gulf is carved by a 3-arms channel network, about 350 m deep, merging in Cabot strait, and extending up to the continental slope between the Scotian Shelf and the Grand Banks. The circulation is the result of a complex mixture of different acting forces with a tow-layer estuarine flow, driven by the large freshwater discharge of the St.Lawrence, strongly influencing the mean circulation pattern (Koutitonsky and Bugden, 1991). The upper water mass is flowing downstream towards the Atlantic through Cabot strait. The deep water mass of the channel network is slowly moving upstream, with a cross-channel structure (Bugden, 1991). The freshwater discharge has a clear annual signature, with a strong peak in Spring. The water mass turbidity, - always higher in the St.Lawrence estuary than in the Gulf -, and the phytoplankton production also have Spring peaks, spatially-modulated (Therriault and Levasseur, 1985). All the above local features are important for determining the euphausiids abundance and its spatial sructure.

Four species of euphausiids are present In the Gulf of St.Lawrence (Berkes, 1976) but only *Thysanoessa raschi* (and sometime *T. inermis* also) and *Meganyctiphanes norvegica* are abundant. *T. raschi* grows up to ~3 cm in total length over a 2 year life-cycle and *M. norvegica* grows up to ~4 cm over the same period. The daytime depth

of the adults of the first species is generally shallower than the daytime depth of the second species, and corresponds to the cold water mass adjoining the minimum tempertature of the permanent thermocline (Simard et al. 1986a, b). The two species exhibit typical diel vertical migrations (Simard et al. b). Both species are omnivorous, but *M. norvegica* appears to have a more carnivorous diet. The general biology of the two species is properly described by Mauchline and Fisher (1976) and Mauchline (1980).

The adult euphausiids tend to aggregate at particular sites in the area (Sameoto, 1976, Simard et al. 1986a, Simard unpublished data). These sites appears to be related to the circulation and bathymetric features. The aggregation mechanism proposed by Simard et al. (1986a, 1989) seems to adequately explain the observations. It involves the mean flow at the daytime depth of the euphausiid sound scattering layers and the euphausiid behavior relative to the in situ light. The aggregation are generally found at locations where the deep flow brings the euphausiids towards bathymetric contours, corresponding to the depth of the ceiling isolume limiting the vertical movement of the euphausiid sound scattering layers during daytime. Channel heads, especially the head of the Laurentian channel in the St. Lawrence estuary, and the basins bordering the channels, are favored places for the generation and maintenance of such aggregations (Simard et al. 1986 a,b, Sameoto 1976, 1983). Coastal upwelling would also tend to aggregate euphausiids along bathymetric contours (Simard and Mackas, 1989). The aggregation sites are also baleen whale traditional feeding grounds.

The euphausiids are involved in the local diet of many predators and exploited marine fish, either directly or via longer food links.

Among those are: for pelagic fish, capelin (the dominant local forage fish species), herring, sand lance, mackérel; for demersal fish, cod, redfish, flatfishes, northern shrimp; for mammals, blue whale, fin whale, humpback whale, minke whale, belugas, dolphins and seals; and various species of marine birds.

The possibilities of exploiting the euphausiids aggregations in the Gulf of St. Lawrence has been evoked in the 1970s by Sameoto (1975). Later, the fishing industry asked for exploration permits but it is only at end of the 1980s that the real potentiel started to be examined (see, Rainville, in this report, for the fishing exploration). Since 1991, exploration permits were allocated to examine the feasibility of fishing the local concentrations of krill. In 1994, the biomass was estimated in the western Gulf of St. Lawrence from net tows and compared to estimates derived from historical data (Runge et Joly, 1995). For an area of 21000 km² in the western gulf of St. Lawrence, the biomass estimate was 500 kt. The gross estimate of predator demand for euphausiids was formerly estimated to largely exceed the probable annual production from the biomass estimate (unpublished reports). All these estimates are very rough though. Clearly, much more data is needed to produce accurate estimates, given the complex time-space fluctuations of abundance of preys and predators, at different scales, especially the interannual fluctuations.

Assuming a balanced ecosystem, fishing and unexploited resource is the introduction of a new predator in the food network. Conservation guidelines considered for the krill of the Gulf of St. Lawrence include the preservation of a large biomass for the natural predators, from a low exploitation level, and spatio-temporal considerations to avoid interference with other economic

activities, the production season of the fish larvae and to take advantage of the krill growing season (Runge et Joly, 1995). The exploratory fishing activity is monitored in collaboration with the industry.

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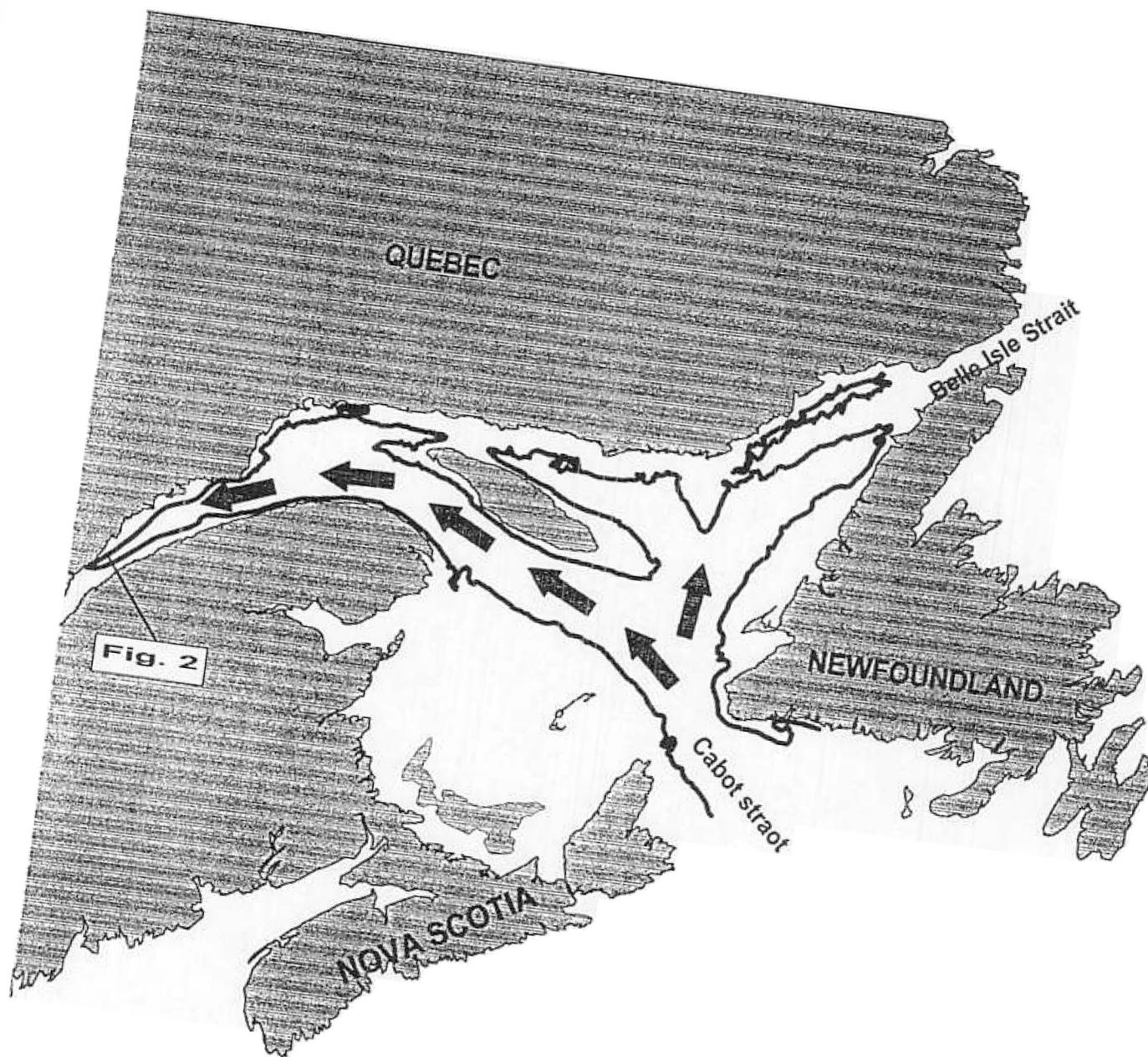


Figure 1. Gulf of St. Lawrence and its channel network delineated by the 150 m depth contour.
Arrows indicate the direction of the deep flow.

Krill sound scattering layer

St. Lawrence estuary cross section, July 1994:
Transect Trois-Pistoles - Les Escoumins

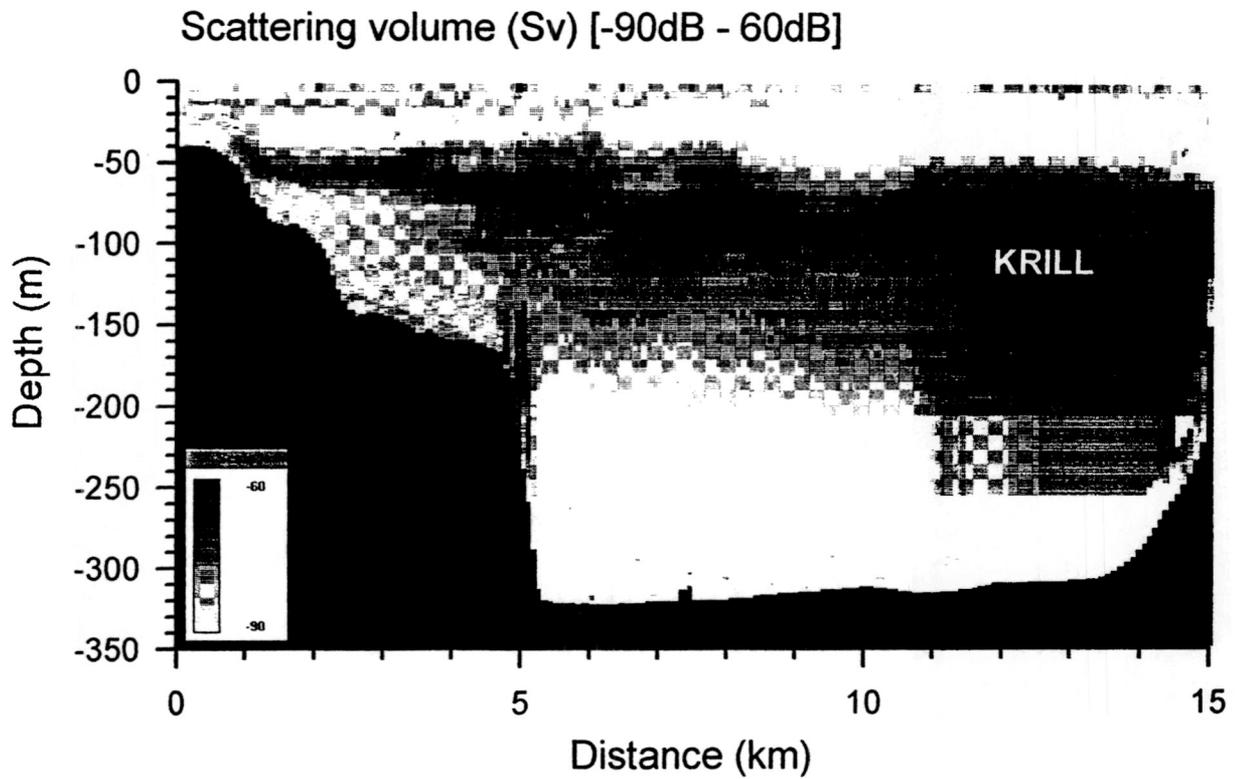


Figure 2. Echogram of a krill 120 kHz sound scattering layer in the St. Lawrence estuary in 1994.

THE IMPORTANCE OF EUPHAUSIIDS TO A BRITISH COLUMBIAN COASTAL MARINE ECOSYSTEM

R. W. Tanasichuk, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B. C.

The Department of Fisheries and Oceans began an intensive study of the La Perouse Bank area, off the lower west coast of Vancouver Island, in 1985. The aim was to understand how interannual variations in ocean climate influence commercially important fish species using the area. The impetus for the work was the detrimental effect that the 1982-83 ENSO (El Nino Southern Oscillation) event had on the lower west coast Vancouver Island herring stock. The benefit of the study would be managing fish stocks in the context of the biological consequences of changes in the ocean.

The La Perouse Bank area is extremely productive. Fig. 1 shows fish yield for the La Perouse area and for major fishing zones in the northern hemisphere. It is second only to Georges Bank in yield per unit area. The Bank area is relatively small, about 10,000 km², and therefore has a considerably smaller absolute catch. Most of the commercially exploited biomass is pelagic. The most important species are Pacific hake (*Merluccius productus*) and Pacific herring (*Clupea pallasii*). There were important fisheries for pilchard (*Sardinops sagax*) during the 1930's and 40's and for dogfish (*Squalus acanthias*).

The La Perouse Project has three components. Physical oceanographic studies examine seasonal and interannual variations in ocean circulation. The data come from many STD casts made at pre-defined sampling sites and from moorings.

Biological oceanographic studies monitor changes in zooplankton community composition and productivity. Vertical net tows are made at some of the STD locations. The aim of the fisheries oceanographic component is to understand the trophic interactions of the various fish species and how they can be affected by climate change. Fish are collected during research cruises every August. Data collected include distribution and abundance, growth and feeding.

Results of the fisheries oceanographic work show that Pacific hake is by far the dominant pelagic fish species. Mean annual biomasses are 198,000, 40,000 and 70,000 tonnes for hake, herring and dogfish respectively. Hake use the La Perouse area for summer feeding. They spawn off Baja California and then migrate northward to feed off the west coast of Vancouver Island between June and October. The biomass of hake in Canadian waters is a positive function of sea temperature. Ware and McFarlane (1995) reported that a 1° C increase in sea temperature results in a 174,000 tonne increase in hake biomass. Therefore, sea temperature variations influence hake prey strongly by affecting hake biomass.

Fish diet analyses (Table 1) show that euphausiids are the most important prey item for pelagic fish in the La Perouse Bank area. Euphausiids account for 88, 100 and 56 % of the ration for hake, herring and dogfish respectively. Hake appear so dedicated to euphausiids as food that euphausiids distributions determine those for hake. Plots of commercial tow locations show that the main concentrations of hake are near shore early in the summer and move progressively offshore (Tanasichuk et al. 1991). This is presumably because hake graze down euphausiids over time. Ware and McFarlane (1995) present a figure (Fig. 6) showing the overlap of hake and euphausiids distributions

in summer

The obvious importance of euphausiids to fish productivity in the La Perouse ecosystem led me to begin a detailed investigation of the influence of interannual variation in sea temperature on the biology and productivity of euphausiids (Tanasichuk, this volume). I began by collecting hake stomachs during the 1989 and 1990 commercial fisheries to see if hake preferred one euphausiid species. Euphausiids were identified to species and measured. Hake fed exclusively on *Thysanoessa spinifera*, the more near shore species, early in the summer when the daily ration was highest (Fig. 2). In August, when fish began moving offshore, *Euphausia pacifica* became more important. Therefore, *T. spinifera* is much more important as prey because it is the only euphausiid taken when feeding is most intense. Length frequency histograms of euphausiids show that hake fed on adults exclusively until late October when young-of-the-year entered the diet.

The preliminary results of my euphausiid work in Barkley Sound show that abundance and productivity changed markedly during and after the 1992-93 ENSO's. Presumably this is due mainly to a large increase in predator biomass during the events. The warmer water resulted in a large influx of hake as well as mackerel (*Scomber japonicus*, *Trachurus symmetricus*) and pilchard to the lower west coast of Vancouver Island. Changes in euphausiids in Barkley Sound may reflect those offshore because Summers (1993) suggested that they are part of the lower west coast Vancouver Island population.

There appears to have been a major impact on herring at least. We have had difficulty finding significant concentrations of herring on the bank areas over the last several years. This suggests that herring vacated them in

search of food. Movement of herring off the banks probably increases the risk of them being eaten by hake and Ware (1991) found an inverse relationship between hake and herring biomasses. The 1992 and 1993 year-classes were weak and the biomass of herring is at a low level.

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Table 1 Estimated summer rations (tonnes) of dominant predators around La Perouse Bank.

<u>Predator</u>	<u>Euphausiids</u>	<u>Prey</u> <u>Herring</u>	<u>Hake</u>
Hake	183,000	17,000	0
Herring	65,000	0	0
<u>Dogfish</u>	<u>20,000</u>	<u>7,000</u>	<u>7,000</u>
Total	268,000	24,000	7,000

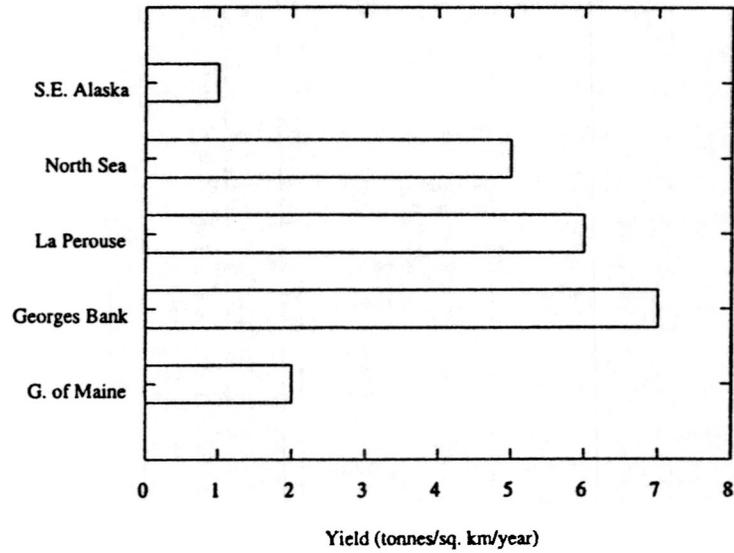


Figure 1. Average fisheries yield from major fishing grounds in the Northern Hemisphere.

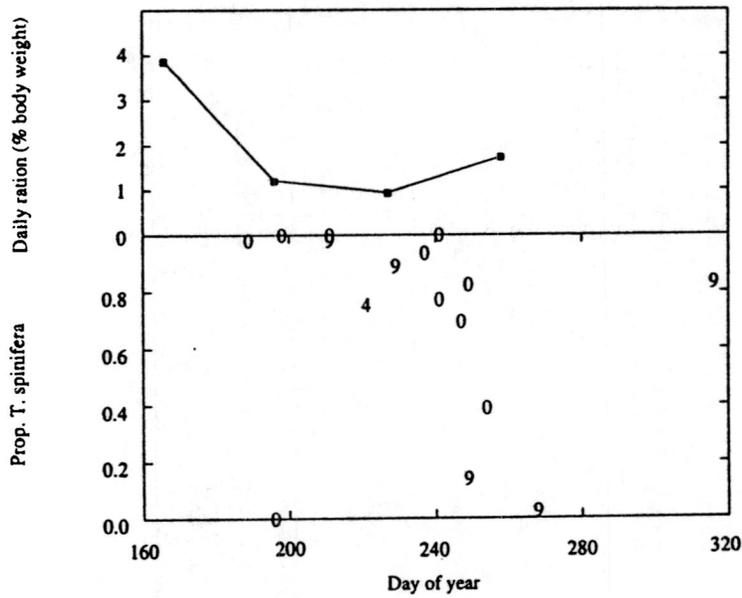


Figure 2. Seasonal variation in hake daily ration and proportion of hake euphausiid ration accounted for by *T. spinifera*. 9-1989. 0-1990. 4-1994.

THE INFLUENCE OF INTER-ANNUAL VARIATIONS IN SEA TEMPERATURE ON THE POPULATION BIOLOGY AND PRODUCTIVITY OF EUPHAUSIIDS IN BARKLEY SOUND, CANADA

R. W. Tanasichuk, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B. C.

Euphausiids are the main link between lower trophic levels and fish in many marine ecosystems. Numerous studies are examining the effect of interannual variations in ocean climate on fish populations. However, there has been little work on the influence of variations in the ocean on the biology and production of euphausiids. My work on euphausiids in Barkley Sound stems from how important euphausiids are to energy flow through the La Perouse ecosystem. It is important to understand how variations in ocean climate affect the ecosystem's key fish prey item. The goal of the work is to describe the influences of sea temperature variations on the growth, reproduction, mortality, surplus energy and ultimately production characteristics of *Thysanoessa spinifera* and *Euphausia pacifica*. I hoped for a significant warming or cooling during the study which began in 1991. There were El Nino Southern Oscillation (ENSO) events in 1992 and 1993. Annual sea surface temperature anomalies since suggest that the ocean cooled in 1994 and was as warm in 1995 as it was in 1993. Monthly anomalies show that, for both years, anomalously cool winters were followed by unusually warm summers. This would mean that summer sea temperatures were warmer than the annual anomalies would suggest. I present preliminary results of the euphausiid study here.

I have been sampling euphausiids in Barkley Sound since March 1991. I chose Barkley

Sound because it can be sampled conveniently using a small boat virtually all through the year, and it is next to the La Perouse area. Summers (1993) provides reasons for accepting that euphausiid samples in the Sound describe euphausiids in the La Perouse Project study area. I collected animals during 36 cruises so far. There are 4 sampling stations which collectively reflect the bathymetric and circulation characteristics of the Sound. Cruises were made nine times annually between March 1991 and 1994 to define accurately the seasonal growth, reproduction and mortality patterns. Since then, I collected samples five times a year to monitor interannual variations. The work will continue until at least March 1997.

I collected samples at night using obliquely towed bongo nets which traveled to within 10 meters of the bottom. Animals from one cod-end were examined fresh. Individuals were identified to species, measured, weighed, sexed and identified to maturity stage (immature - no secondary sexual characteristics; males - petasma and with or without spermatophores; females - thelycum and unfertilized, fertilized, gravid). These animals were then preserved for surplus energy analyses when the hepatopancreas and gonad were weighed. The entire sample from the other cod-end was preserved. This sample was size-fractionated using sieves to separate adults and sub-adults. All adult-sized animals (>10 mm total length) were identified to species, counted and measured. Individuals from sub-samples were weighed, sexed and their maturity described (immature - no secondary sexual characters; male - petasma and with or without spermatophores; female - thelycum and unfertilized or fertilized). Samples of sub-adults were split using a Folsom splitter. Eggs and nauplii were counted and measured. Calyptopis and furcillia larva were identified to species, stage, counted

and measured. I used MULTIFAN (Multiple Length Frequency ANalyser, Otter Research Ltd., Nanaimo, B. C.) to segregate adult length frequency distributions. These distributions were assigned to cohorts based on the assumptions that the number of animals within a cohort decreases exponentially with time and there is no increase in length over winter. (My success in developing cohort-specific growth and mortality trends suggests two possibilities. First, Barkley Sound euphausiids are discrete populations. Second, they are, as Summers (1993) suggested, part of the lower west coast Vancouver Island populations and therefore in- and out- migration have little effect on the biological characteristics of the animals collected in Barkley Sound.) Larvae were assigned to cohorts using stage durations Summers (1993) reported for *T. spinifera* and Ross (1981) described for *E. pacifica*. By knowing the stage and the time required to develop to it, I could: 1) back-calculate to spawning time and 2) decide how sampling time coincided with spawning time. Larval and adult cohort assignments were linked using the growth and mortality assumptions.

I described abundance as number of animals per square meter. The volume of water filtered was measured with a flowmeter. Number of adults was estimated as (no. animals in each cohort/m³ filtered) x 2 x wire out because euphausiids were collected during the descent and ascent of the net. I multiplied the number of larvae by 1/Folsom split size to estimate number in each sample. Numbers of adults and larvae were summed over cohorts for each sampling event. Abundances can be converted to per m³ considering an average of 110 m of wire out over time and between sampling stations.

Adult and larval production was estimated as the sum of daily biomass changes between sampling events for each cohort. Production

was considered to be larval if the initial length was less than 10 mm. I assumed that changes in weight occurred exponentially over time. Daily production of animals that survived between sampling periods was added to that for animals which would not survive to the next sampling but had not died yet. I estimated "animals yet to die" using the cohort-specific natural mortality function. The number of animals yet to die = $N_t - N_0 -$ (sum of daily mortalities based on the derivative of the mortality function). Production of adults and larvae were summed over cohorts. Daily production (mg wet weight x m⁻² x day⁻¹) was estimated by dividing the sum of the biomass change by the number of days between sampling periods.

Abundance and daily production estimates for *T. spinifera* are plotted in Figs. 1 and 2 respectively, and mean annual biomass and total annual production estimates are presented in Table 1. Adult abundance dropped in early 1992 but increased substantially later because of the appearance of a strong cohort. It then dropped and has been low since mid-1993. Larval abundance in 1993 and 1994 was negligible and the high larval abundance early in 1995, which was not produced by a high adult abundance, has not generated many adults. *T. spinifera* sub-adult abundance has remained very low since 1992. The peak in *T. spinifera* sub-adult abundance in 1995 generated no production because mortality was so high. Adult daily production rates have been low since 1993. In general, mean annual biomass and annual production dropped steadily from the peak observed in 1991 for adults and 1992 for larvae. Adult P:B ratios have remained fairly constant in contrast with those for larvae.

Abundance and production trends for *E. pacifica* are different. It produced relatively strong cohorts in 1992 and 1993. This

species became dominant but abundance has declined to or below pre-ENSO levels. Larval production by the strong cohorts in 1992 and 1993 was high. There has been no larval production since. The peak in sub-adult production in 1993 was not followed by one for adults. *E. pacifica* adult productivity has been low since mid-1994. Mean annual biomass increased in 1991 and fell in 1994. Larval P:B ratios are similar to those for *T. spinifera*. P:B ratios for adults were considerable more variable for *E. pacifica* and in general were lower.

To conclude, euphausiid abundance and productivity in Barkley Sound changed dramatically during and after the 1992 and 1993 ENSO events. I suggest that this began as a consequence of an increase Pacific hake (*Merluccius productus*) predation and the appearance of mackerel (*Scomber japonicus*, *Trachurus symmetricus*) which feed intensively on euphausiids (B. Hargreaves, DFO, Nanaimo, B. C.

pers.comm.). Based on the data in Table 1, larval biomass and production in 1994 were 88 and 82% respectively lower than in 1991; for adults, biomass and production were 64 and 56% lower respectively. Preliminary results for the March 1995 - February 1996 sampling year suggest that euphausiid abundance and productivity will be at least as low. I am just beginning the detailed examination of euphausiid population biology which is designed to explain the variations in euphausiid production. Changes in euphausiid abundance and productivity that I described would likely have importance consequences for the fish resources of the lower west coast of Vancouver Island.

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Table 1. Mean biomass (mg wet weight x m⁻²), total production (mg wet weight x m⁻² x year⁻¹) and P:B ratios for *T. spinifera* and *E. pacifica*. Values are calculated for March-February.

Year	<u>Larval</u>			<u>Adult</u>			<u>Weighted</u>
	Biomass	Production	P:B	Biomass	Production	P:B	P:B
				<i>T. spinifera</i>			
91-92	952	22506	24	13985	14638	1.04	2.48
92-93	1162	66014	57	6083	11505	1.89	10.69
93-94	670	8898	13	2639	3759	1.41	3.82
94-95	101	1307	13	2649	3572	1.35	1.77
				<i>E. pacifica</i>			
91-92	342	8178	24	7202	3297	0.46	1.52
92-93	1137	48215	42	11118	21561	1.94	5.69
93-94	837	62359	75	19416	-406	-0.02	3.06
94-95	131	2378	18	6685	2868	0.43	0.77

DISCUSSION PAPER

Three Components Leading to an Assessment of the Potential Yield of British Columbia Krill Stocks: A Fishery Manager's Point of View (an ad hoc workshop session).

Jim Morrison, Department of Fisheries and Oceans.

The second day of the workshop concluded with a discussion of information needs, ecological impacts, and industry/ economic factors pertaining to the potential increased yield of British Columbia (B.C.) and the Gulf of St. Lawrence Canadian krill stocks (preceding section).

Approaching this matter from the admittedly different point of view of a fishery manager working from within a government mandated framework, the three components for discussion were identified to be fundamental questions, implementation process and the economics of the process (not the fishery) leading to quota re-evaluation.

A. Fundamental Questions:

These are not questions that are biologically fundamental, but instead are fundamental to the process of establishing surveys which industry has proposed in this workshop as a mean to acquire greater harvest opportunities.

1. Described as the first and last question of this series, as a result of the workshop sessions over the last 2 days, does industry still want to pursue the process of requesting quota increases based on surveys. Another workshop participant has identified political opportunities to seek quota increases. It was noted that a response to this question may depend on the subsequent questions identified in this session which would indicate the possible complexity of the process.

2. What is the minimum information required to convince fishery managers to reconsider the present quota limits? In B.C. this was suggested to be information which would clearly establish or strongly suggest that the increased harvest of krill is not a threat to salmon and herring stocks which are the most important harvestable stocks in B.C. waters.

3. Do we need to use a model to establish this lack of threat, and if so, which model? The 3 models which had been discussed in the course of the workshop were A.) the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) model used in Antarctica, B.) the Ecopath II model which has been described by Drs. Daniel Pauly and Astrid Jarre-Teichmann in this workshop, and C.) an euphausiid predator model previously used by DFO (Department of Fisheries and Oceans) to set the original B.C. coastal krill quota (which has not been reviewed in this workshop).

The suggestion was made that if the goal was to maximize the potential success of the application for increased harvest quotas, then both the CCAMLR and Ecopath model would be used as they address different issues and achieve different ends. The CCAMLR model is built on a conservationist ethic derived from Article 2 of the Antarctic convention, is based on the largest krill harvest in the world at this time and has international qualities that will be attractive to DFO policy and decision managers. The Ecopath model is built on a description of food web relationships that may be more readily understood by DFO managers, refers directly to the interaction of herring, salmon and euphausiids, and has a foundation in the U.B.C. (University of British Columbia) Fisheries Centre which has a respected reputation among fishery managers. The benefits are that the two models address different questions which the

fishery managers will ask.

What are the fundamental questions that pertain to the CCAMLR model?

- Given the 10 to 18 fold variation in stock biomass estimates for Jervis Inlet, which estimate should be used; the lowest estimate from any survey, the mean estimate, or some lower confidence interval of the mean which would protect against the risk of high variability in the stock estimate?

- When should the biomass be surveyed; at expected peak abundance, or at the expected period of minimum abundance, or just after the juvenile salmon and herring have had their share of the harvest?

- Should the stock estimate be undertaken before or simultaneously with some conservative harvesting? This will significantly affect how industry proposes to undertake the collection of biomass survey information.

- Assuming a pattern of extending biomass surveys into other coastal areas, should the first extension of surveys be into other parts of the Gulf of Georgia where there is a perceived high risk to salmon and herring stocks, or should it be to central and north coast areas where the perception of risk is likely to be much reduced?

- With reference to the "ERIC" effect (possible longer life span), how does the lifespan of the animal affect the CCAMLR model?

Within the context of biomass surveys:

- To what extent is standardization of (hydroacoustic) gear required for biomass estimates, in that the current proposal is for many fishers' boats to be participating in these surveys?

- What is the appropriate size of the sampling gear, tow speed and search pattern?

- Are sample net results required or can we get by with hydroacoustic estimates only?

- If it is primarily hydroacoustic estimates, how critical is determination of the ratio of signal strength to biomass estimate? How often does this have to be determined?

- If it is primarily hydroacoustic estimates, do we have to standardize that equipment and if so, should it be single, dual or split beam?

- Some confirmatory published information will be required to demonstrate that hydroacoustics can differentiate between krill and other potential targets. If this is not available, then confirmatory net tow sampling will be essential throughout any survey. This is in reference to the two occasions in Jervis Inlet when biomass estimates were derived from hydroacoustic data, but no euphausiids were recovered in the sample nets.

- Do biomass surveys have to be concurrent or within some limited time frame to ensure that they are comparable from one coastal area to another?

- Is it necessary to consider or assess FLUX (immigration and emigration characteristics)?

- How do you logically/rationally define a critical level of biomass for the CCAMLR model?

- With reference to the CCAMLR model, T. Pitcher identified a possible model weakness when the P/B ratio is 4 or greater signifying a high growth rate. Is that in fact a model weakness? If so, what are the growth rate characteristics of our euphausiid species and populations in B.C.? How does this

potential model weakness affect the seasonality of sampling?

With respect to the Ecopath model:

There will be an Ecopath model for the St. of Georgia. It is important that particular attention be paid to the links between euphausiids, herring and salmon, at both juvenile and adult stages. Also, critical attention should be paid to euphausiid prey items. For example, harvest of euphausiids may release other prey items which would serve as alternate food items for herring and salmon.

We will want to refer to the Ecopath model to assess the impacts of the 10% krill biomass harvest that has variously been referred to and proposed for B.C. stocks at this workshop. If the model indicates that the harvest will have no significant effect on herring and salmon, that will be strong supporting evidence for quota increases. That may be because herring and salmon feed on other organisms. Someone will have to review the literature for available information on salmon and herring diets in the Gulf of Georgia.

There was a reference to a phytoplankton - copepod - euphausiid pathway in one of the earlier presentations. If the Ecopath model suggests that euphausiid removal will result in an increase in other salmon and herring prey items such as copepods, that would be strong supporting evidence.

- If industry wants to look outside of the Gulf of Georgia for quota increases, then how transferable is this modelling to other coastal areas?

Other (predator) models:

The existing quota was based on a calculated 1 - 3% of the estimated predator consumption of euphausiids. Presumably, if

this type of calculation was accepted to establish quotas in the past for one part of the coast, it could be revisited and applied to other coastal areas.

Other Fundamental Questions:

- How often do biomass surveys have to be revisited?

- Are on-board monitors or observers required for these surveys?

- What is the minimum data requirement to allow for a successful proposal for expansion of the harvest? Can we get by on biomass estimates or do we need to incorporate some measure of productions?

- C. Moreno has referred to the bycatch issue. In B.C. there is a public segment that is opposed to all trawl fisheries. Shrimp trawl fishing in Indian Arm has recently been shut down largely because of that pressure coupled with poor reporting from industry. It is not sufficient to state that bycatch is not an issue without a study to document that that is true.

B. Process

S. Romaine's and D. Mackas' Jervis Inlet work should be submitted through the PSARC (Pacific Stock Assessment Review Committee) process for review. If accepted, the review would substantiate the hydroacoustic method as a scientifically valid means of generating euphausiid stock biomass estimates.

It may also be important to get R. Tanasichuk's work on Barkley Sound euphausiids submitted for PSARC review.

DFO managers may ask that any proposed survey and survey protocol be submitted to PSARC for review and approval. There is good reason to do that. If approved through the PSARC process, it validates the surveys, providing approval in principal for the

generation of biomass estimates for other coastal areas.

In terms of the time frame, the next PSARC meeting is in March 1996. The one following is in late August or early September. From that September meeting, any reviewed survey method or protocol would go to RMEC (Regional Management Executive Committee) for review and approval. That review sets the framework for development of the 1997 management plan.

At the same time the Pacific Region policy on new and developing fisheries is being written. It will provide a reference against which any proposed system of biomass survey can be measured. One goal will be to funnel the CCALMR experience into this policy, notably Article 2.

Finally, there is the possible implication of the federal/provincial memorandum of understanding on underutilized species and developing fisheries that was referred to on Tuesday, that may affect all of this process.

C. Economics

The landed value of the fishery in 1994 was \$259,000. The high in 1990 was \$415,000. Trying to subsidize the further development of the fishery within the confines of the current landed value will be difficult.

This is a period of federal government downsizing, manpower and budget limitations. Time is a limited resource directly linked to the economics of the proposal. Who will develop the proposed survey methodology for presentation to PSARC or DFO managers for review? Will Dr. Daniel Pauly for example be expected to contribute his time to develop the necessary modelling, or Dave Mackas, or Ron Tanasichuk? The sampling program costs are not limited to the vessel sampling. The

costs will include time or contractor costs for data management, analysis, reporting and data quality control functions. Without speaking on behalf of my colleagues in Science who may be able to accommodate some measure of additional participation, it is the fishery managers' view that the onus is on industry to fully underwrite these costs.

So the first question of this session is also the last question. Does industry want to pursue this process?

Summary of workshop discussion (addressing issues raised by Jim Morrison)

Taja Lee, UBC Fisheries Centre, Rapporteur

Glenn Budden (Protein Plus & A.L.H. Enterprises) The answer to the first question is 'yes'. You will always find one interested fisher to do the survey. The problem I have is two-fold. First, this process you describe will take much time in negotiations. The second is the commitment for an increase in quota will come from DFO only after the surveys are done. It will be difficult to invest lots of time, money, and effort to survey unless there is some sort of commitment from DFO beforehand.

David Saxby (Specialty Marine Products) Industry has actually gone through this exercise. The Krill Trawlers Association met 2 years ago and debated over this process. We would get a sliding-scale dedicated quota and we went ahead with the Jervis Inlet survey on that basis. Many of the questions about the model are beyond us, however we have been working with Dave Mathus and Beamish, who has been keen on understanding the interaction between salmon and krill. So, the information gathered from a survey on inside waters goes beyond just trying to identify a quota for trawlers. Recently, we've been discussing with

Beamish on doing a survey based on whatever design that Dave Mathus thinks is appropriate. The input required for the models could be built into the survey/sampling design. We can easily sample 20 times a day. We were willing to do that on the basis of getting the product from two draw down fisheries. We will be presenting this with Beamish to the managers in a short while.

Completely aside from the Krill Trawler Association and the scientific permits that you have suggested, many in the industry feel there must be data collection and monitoring before and after the fishery. We are willing to do this. We understand that there is no commitment, if other people in the industry feel they need a commitment that's fine, but we feel we are on board already. Thus the questions are not new, they have been presented before.

Yvan Simard (DFO, P.Q.) suggested one approach for a cooperative hydroacoustic survey would be through the national acoustic program which has been initiated by DFO.(get more details from James)

fundamental questions pertaining to CCAMLR model

**The issues/questions on which biomass estimates to use, when to survey, and how to cope with large variance in biomass estimates were discussed.*

Denzil Miller (Sea Fisheries Institute, South Africa) Ideally you would survey at every possible opportunity, over the entire range of the species, and do surveys in a stratified manner. In less than ideal conditions you are limited to what you can do. So the question is how many biomass estimates do you want and over what range?

Inigo Everson (British Antarctic Survey, U.K.) Why were the surveys only done for the Jervis Inlet? The krill is much more wide-spread than just the Inlet, and there

seems to be strong evidence for flux in and out of the Inlet which is responsible for the extreme variations in biomass.

Dave Mackas (Institute of Ocean Sciences, B.C.) We focussed our efforts to the Jervis Inlet because that is where the commercial fishery is presently operating. At the time of the surveys we knew neither the precision nor the repeatability within time series of succeeding surveys, nor the magnitude of seasonal variance between time periods.

Inigo Everson (British Antarctic Survey, U.K.) The point is are you interested in the long-term in just the Jervis Inlet or are you interested in the expanse of the resource in BC, but selecting areas in which one may develop models for?

Dave Mackas (Institute of Ocean Sciences, B.C.) To determine the reliability of the acoustic surveys we felt we had to focus on one area and hit it hard and hit it often. This meant we had to take a restricted area- that area being where the fishery is operating. The next step is to expand the spatial coverage and to focus our effort during the times of the year where we have the biggest questions, that is, the winter decline and the spring increase. How much (of the variance) is natural change in population change? How much is due to immigration or emmigration (fluxes)? How much is due to fishing? Note that we are also trying to find the relationship between euphausiid aggregations and ocean currents off the west coast of Vancouver Island.

Tony Pitcher (Fisheries Centre, UBC) It seems to me for many areas of the coast there is some biomass information. The question I have is how to combine those figures to get a biomass figure?

Inigo Everson (British Antarctic Survey, U.K.) That is related to the question when to survey: during the peak or during the

minimum or after the salmon have fed? You've got the information I suggest from Ron Tanasichuk's presentation which is telling you information on the growth patterns, and the production patterns going on within the Inlet. From that you can sort out what is going on throughout the year. To a certain extent you're a lot better off in Jervis Inlet than we are in the Antarctic.

David Agnew (CCAMLR, Australia):

One of the things we are trying to establish is what the most suitable area for surveys in order to get the whole range of the population and Denzil has already talked about that. In terms of the timing if you are worried about how the model works: it allows you to input when you are surveying (whether in the summer or the winter). As a result from the computer simulations you will get a distribution of biomass that you would expect from a survey. What you assume is that your original, single biomass estimate or multiple biomass estimates in the field are represented by that distribution. You can adjust the model. If you would rather survey in the winter, then do a survey in the winter and adjust the way the model thinks it is surveying the population. There are problems with the model, but I think there are more fundamental questions of where you think the krill are during different parts of the year, and whether in the winter you think it is possible to survey the animals because you are missing the very small krill. These are biological questions; the modelling questions can be dealt with.

Dave Mackas (Institute of Ocean Sciences, B.C.): That is basically the approach we have been taking but basing it on observations rather than model outputs. Over a span of several years, we try to estimate an average seasonal cycle, and then look for deviations from that average seasonal cycle for the time period you happen to make those measurements. Then you can look at the deviation from the

winter and summer norms. They tend to covary.

David Agnew (CCAMLR, Australia): So, in fact you already do have some feeling for the expected distribution of biomass.

Tony Pitcher (Fisheries Centre, UBC) I get the impression from Jim Morrison's discussion presentation that the decision-makers (the managers) will get more confidence from more direct, concrete, local measurements of biomass rather than the outputs of a model. Yet from the discussions there is a realization that both 'real data' and 'models' have their problems. Regarding the CCAMLR approach do you still have any specific concerns?

Jim Morrison (DFO, Nanaimo) I can see how the CCAMLR model can generate the expected distributions, and the way to get around the issue of summer or winter variation. As for the surveys, I know that we are only going to end up with a single biomass estimate for various coastal areas. What I have concern about is how well the model deals with the possibility that the minimum biomass is much less because of fluxes than the estimate from a survey.

Tony Pitcher (Fisheries Centre, UBC) One way around that problem is to have an annual number for the minimum from a survey during the winter.

David Saxby (Specialty Marine Products) From my own point of view we should use the minimum. If it is 800 tonnes in Jervis Inlet then so be it. Be conservative until we have more confidence on the acceptable level of harvest. Furthermore, do accompanying tows to get more confidence in the acoustic work. In regards to area, we intentionally chose Jervis Inlet because there are no other fisheries there, and it is an area with a lot of data. The error to date is we did not look at

this migrating population (flux) closely enough. We are already having discussions to go back this month and measuring again during that low period. Regarding the information that Michael Macaulay gave about 6 mm animals not being detected: we can sample with double-bongo nets and get an estimate for that number. I think we should be conservative because we are paranoid about models and collapsing fisheries. We have very little confidence in models.

Inigo Everson (British Antarctic Survey, U.K.) About the Jervis Inlet point, how far would you be able to extend your surveys out into the sound?

David Saxby (Specialty Marine Products) Our program right now is to take the next step and do a Jervis Inlet-type survey for the whole of the inside waters.

Dave Mackas (Institute of Ocean Sciences, B.C.) What Dave is proposing is to get the extent of a closed population, not in the genetic sense, but in the sense of 'population dynamics'.

Inigo Everson (British Antarctic Survey, U.K.) If you are heading in that direction then you will probably answer many of the biomass and flux questions.

**discussion of question whether to target the Strait of Georgia, where there is a lot of data to address the problem of herring, salmon and hake consumption of euphausiids, or the north coast, where there is probably less potential for conflicts with other fisheries but for which there is less data to address those concerns.*

David Saxby (Specialty Marine Products) To begin, we think the Strait of Georgia should be surveyed. We don't anticipate a fishery in the Strait of Georgia, but we would like a look at it. Our feeling right

now is when we go through the impact of the salmon, herring and euphausiid populations in the Strait of Georgia, we are going to find that the herring and the salmon are not as dependent on the euphausiids as everyone thinks. On the other hand, I think the hake population does depend on euphausiids, which returns to Jim Morrison's point about taking down a predator species. I think we are going to see some management opportunities to take a good crack at the hake population. We believe that the inside waters should be surveyed for all of the reasons that Beamish wants and also that the mid-coast is going to be a very good place for an euphausiid harvest. It would be nice to see a simultaneous plan to survey areas of the mid-coast and Jim Morrison has already taken that request to management or is in the process of doing it for the Krill Trawlers Association. I think we should have a plan established so we can fit back into models and in the long-term that can be reinforced as Jim has requested.

Dave Mackas (Institute of Ocean Sciences, B.C.) As opposed to industry involvement, where it is in their best interest to put most of their effort to where they can get the most euphausiids for their costs of operating, for DFO science involvement, and I expect externally-funded university research, the largeness of the other fisheries interactions problem is an attractant not a deterrent. It is far easier for me to get authorization to work in the Strait of Georgia than it will be to work in the Northcoast, and I expect that to be true for getting funding for Daniel Pauly to work on his ECOPATH model and for someone to work on a northwest version of the CCAMLR model.

Jim Morrison (DFO) There is more political and management sensitivity to issues in the Strait of Georgia than for other parts of the coast. As well we have the entire Fraser river salmon run that passes through there twice a year (an out and in-migration).

Salmon of course is one of our 'golden cows'.

Glenn Budden (Protein Plus & A.L.H. Enterprises) Well, if the concerns of salmon and herring feeding on euphausiids is a political problem because there are a lot of people living on the beaches while we are trying to harvest the krill then that is what you should state.

Jim Morrison (DFO) The problem is we had significant declines in salmon stocks leaving from the Strait of Georgia this year. So they are getting extra attention. They always have and now even more than ever.

David Saxby (Specialty Marine Products) Because of that problem industry can get science funding to do surveys because it's a bigger problem than just a krill problem. So it can work together.

** The next issue discussed dealt with how does the life-span of the euphausiid affect the operation of the CCAMLR model (the "ERIC" effect)?*

Stephen Nicol (Biological Science Program, Australia) It's a question of what data you have. See if there are any doubts about the life-span. If there is any doubt be conservative, in which case: the quota will be lower but you will address some of the concerns. So it is a matter of going back to the data and seeing what it shows. If you find two interpretations for the growth and mortality rates, and recruitment data, then take the most conservative interpretation until proven different.

Daniel Pauly (Fisheries Centre, UBC) I'd like to mention that I have offered to look at Ron's length-frequency data using a different approach than he is currently using. In any case even if there are doubts about the exact value of the von Bertalanfy K, one can get an estimate of Z/K. (This means

one has later a scaling factor, the P/B ratio, with which one can play with) The value of Z/K does not give one the specific value of K. But given that there is strong seasonality in the system, and given the range of lengths that Ron has covered, I tend to think it should be quite straight-forward to reliably estimate growth and mortality (P/B) parameters. I also think it's quite possible that the bulk of the animals go through a cycle of 1 or 2 years. This should be detectable.

Denzil Miller (Sea Fisheries Institute, South Africa) In terms of the CCAMLR model, length-at-age can be taken into account of, i.e. inputted into the model. The real issue is how will that impact the recruitment function of the model.

David Agnew (CCAMLR, Australia) Daniel Pauly was right about Z/K. I'm not sure if we were successful in building that in because we couldn't clearly determine what an appropriate figure was for superba due to holes in the data. As Denzil Miller said it is just a matter of reformulating the model, as I understand it. You cannot just transfer the model as is to BC. You need to revisit all the assumptions of the model and change it for the context of the fishery you want to apply it to.

Tony Pitcher (Fisheries Centre, UBC) As I understand the CCAMLR model, in the worst case, the uncertainty of the parameters can be built into the simulations.

Carl Walters (Fisheries Centre, UBC) In terms of planning...Fishery after fishery you have biologists agonizing how to apply the fishery response to a system prior to exploitation. Our track record at predicting recruitment responses has been zero. One approach is to propose taking a relatively small area, where its relatively safe to do so, and pound it down and hold it down, and look at the response to the animal after it is

exploited. Do it directly and in a relatively safe fashion. This would solve all the this modelling messing around with the recruitment and provide a direct demonstration of what the stock can take and what happens to the biology when under exploitation.

Tony Pitcher (Fisheries Centre, UBC) How does DFO respond to hammering the population in Jervis Inlet?

Dave Mackas (Institute of Ocean Sciences, B.C.) My concern about that approach is I suspect that in some years the environmental conditions hammer it a lot harder than whatever level DFO will permit the commercial fishery to do. So teasing out of fishery effects from good or bad year environmental effects would be difficult.

Carl Walters (Fisheries Centre, UBC) The way I looked at it was you are going to find out the hard way if the fishery develops anyway. So why not find out in a restricted area even if you have to deal with a lot of variation.

David Agnew (CCAMLR, Australia) Quite apart from the planning/policy aspect of that approach, there is a real question whether the fishery could in fact hammer it hard enough. If you are dependent on fishing swarms and concentrations, you will want to look at the ratio between the concentrations to dispersed krill, and what the economic viability of that is. The message we've had whenever we've raised this sort of issue is: 'it's not just environmental', 'it's not just management', but it's the fishery itself. The message we get is 'You can't expect us to keep on fishing when you are only getting three krill in the trawl.' Even when that in fact is what is expected. That's just a warning from our experience with this.

** Discussion on the biomass survey questions:*

Do we need to standardize the gear and search patterns for the surveys?

David Saxby (Specialty Marine Products) Yes. I think it the survey should be reviewed. Set a standard, and everyone would conform to that. I'm not sure if we are taking about multiple vessel surveys even. At one point we were discussing that in the Association and having units that Michael Macaulay was referring to where it was not as expensive as master units that you calibrate against and whenever you have a vessel going some place you are going to be gathering information. We are willing to go along with standardization, but who is going to do the standardization? Someone is going to have to say this would be an acceptable standard, then we would be happy to conform to that.

Denzil Miller (Sea Fisheries Institute, South Africa) From our experience setting up the biomass project in the Antarctic, where there was a variety of ships from a variety of nations, two messages came out. The first is pessimistic. Despite the great deal of effort, the standardization did not come up to what was anticipated. Different treatments and nets were used, used in different ways and, the survey designs were changed. The second point that came out of the CCAMLR experience was in fact that, surprisingly, quite a lot could be done with the data afterwards. That's the positive message. Quite a lot can be done. You don't have to make every net comparable, and every single binding on the net comparable.

Michael Macauley (College of Ocean and Fisheries Sciences, U.W.) I agree. Standardization does not necessarily mean you have to have the same make or model. There are standardization techniques, such as calibration to standard spheres, that can be used. If one are using pre-existing sounders there will be a need for standardization.

However, we are not talking about 100's are even dozens of systems, we are talking about two or three systems in BC.

** discussion on types of hydroacoustic equipment that should be used*

Michael Macauley (College of Ocean and Fisheries Sciences, U.W.) Split or dual beams are for direct measures of target strength. The only way one can get direct measures of the size of euphausiids requires equipment that does not exist. You need a 2 MHz frequency range to get a reliable echo off the target.

Inigo Everson (British Antarctic Survey, U.K.) We addressed many of these technical questions which have been published. You will need to calibrate it to your systems in BC. If you follow the guidelines of the ICES Fisheries Acoustics Technical Working Group, which provides a close compliance to calibration methods and ensures the interrelationship between the equipment used on one vessel does relate to others. If this particular methodology is followed then I would be very confident in the acoustic results. In comment to single vs dual vs split beams; the more sophisticated the better. I would advocate using a multifrequency system provided that's available.

Denzil Miller mentioned survey design and problems associated with FIBEX. The bulk of the work done during the FIBEX survey did follow the survey design, and once the raw data was collected it worked quite well. The problem with FIBEX, with the use of nets, came about because of the number of different nations and research institutes involved each with their own particular sampling gear. One cannot tell a research institute to buy a 50K net just because FIBEX decides that's how the survey will be done. But if one recognizes the strengths and weaknesses of each type of gear there are techniques to calibrate them.

In BC you are in much better shape because the options for nets in Nanaimo and Victoria are fewer so you should be able to work that out with much less difficulty.

Yvan Simard (DFO, P.Q.) commented on the National Acoustic Programme set up to help deal with the issue in Canada.

David Saxby (Specialty Marine Products) We already have sampling systems in place, working with DFO. To satisfy the management side, we would gladly retain some experts to review the system and report on changes that may be needed. We are trying to build confidence in the data to satisfy the management group.

Dave Mackas (Institute of Ocean Sciences, B.C.) It is quite straight forward to recalculate data compared to collecting the data.

Michael Macauley (College of Ocean and Fisheries Sciences, U.W.) commented on hydroacoustic and survey design standardization techniques.

Stephen Nicol (Biological Science Program, Australia) Details on standardizing survey design are available from a previous workshop for *Euphausia superba*. In terms of standardizing data collected, we've outlined a set of parameters to be recorded from an acoustic survey. The next question is what to do with all the data collected. The more complex and more data you have the more useful in the long run

Denzil Miller (Sea Fisheries Institute, South Africa) It is important to record how you recorded and derived the data, allowing one to breakdown data from different sources to their basic forms

Yoshinari Endo (Lab. for Biol. Ocean., Tohoku Univ., Japan) commented on ongoing survey programs in Japan. A

variety of nets have been used but the data is still in analyses phase. The hydroacoustics being used are the multifrequency type.

Dave Mackas (Institute of Ocean Sciences, B.C.) PSARC is very insistent on proper documentation so that is not a problem. The aspect that will be important is in survey design. Compared to Antarctica, BC has more complex coastline and bathymetry which will impose different rules on how patches behave and the spatial-structure of the population

Inigo Everson (British Antarctic Survey, U.K.) The advice from this group is-Yes, do standardize-and there is information available from a variety of sources

Dave Barrett (Murex Aqua Foods) advocated an adaptive management approach to answer many of the biological questions. Stressed that if industry is expected to pay for this research, DFO must ensure industry can harvest enough to generate money.

**comment on need for confirmatory net tow sampling*

Inigo Everson (British Antarctic Survey, U.K.) David Saxby already answered that with continuous net sampling-do as many net hauls as possible to cross-reference to your acoustic data. Acoustics is not a technique done in isolation.

**discussion of assessment of flux-the movement of krill from one area to another-will we able to get reliable data from an inlet if there is flux-an underlying pattern of movement of the stock?*

Inigo Everson (British Antarctic Survey, U.K.) If considering just the Jervis Inlet, you must monitor and quantify flux. It will depend on the spatial-scale one is dealing with. The Georgia Strait can be considered as a closed system.

**discussion over the trigger level of CAMMLR-the critical level of biomass for the CCAMLR model*

Denzil Miller (Sea Fisheries Institute, South Africa) There are two trigger levels: (1) trigger level set for experimental/exploratory fisheries reaching the scale of commercial fishery; (2) trigger level for spatial disaggregation of catch-to avoid concentration of fishery in one area once some level is reached for protection of land-based predators with limited foraging range. This trigger level has been based on historical catch level. I suspect the same for BC. This is a negotiated level unless there is some level of certainty on the biological limits

Tony Pitcher (Fisheries Centre, UBC) suggested for BC such a trigger level may be based on the impact level on herring, salmon, hake and other predators

Inigo Everson (British Antarctic Survey, U.K.) commented the various trigger levels will again depends on the scale of the fishery-coastwide vs a limited area

**ECOPATH Questions*

-what are the kinds of links between krill and salmon, hake and other predators?

-what supports the euphausiids and how does that influence the dynamics of the model?

-implications of harvest on the model?

Daniel Pauly (Fisheries Centre, UBC)-The Georgia Strait model was an exercise done mainly by students. If a model is to be applied properly we will need to hire a Masters student for a year to interact with experts and assimilate the available knowledge. The present model can then be used as a base starting point. Many of the questions asked can be answered. I suggest establishing a partnership with DFO/Nanaimo scientists interested in using

this approach.

Dave Mackas (Institute of Ocean Sciences, B.C.) commented on separation of numerical abundance and biomass in the model

David Saxby (Specialty Marine Products) suggested if interest is present then funding can be found

Other fundamental questions

** discussion over the need for observers question*

Inigo Everson (British Antarctic Survey, U.K.) For a survey it is not a question of observers but need for experts in field of acoustics and other scientists to monitor and review

David Saxby (Specialty Marine Products) A precedent has already been established with a DFO nomination of a person on vessel to accumulate data

Dave Mackas (Institute of Ocean Sciences, B.C.) With acoustic data, it is more a question of ensuring availability of data not misreporting since bad acoustic data is very easy to pick out

**discussion over the need production-based or biomass-based models?*

Dave Mackas (Institute of Ocean Sciences, B.C.) suggested a need for biomass-based models for the management screening process

**discussion over the by-catch issue*

Jeff Marliave (Vancouver Aquarium, BC) commented on frozen products with some myctophids

Dave Mackas (Institute of Ocean Sciences, B.C.) commented on some recent data now showing some by-catch of fish larvae from

April-May catches.

Denzil Miller (Sea Fisheries Institute, South Africa) By-catch is an important issue and you need to establish a screening process. The philosophical basis in CAMMLR is by-catch is money out of fishers' pockets. Fishers need to show bycatch is not happening or minimized and scientists need to show how much (numerate) bycatch is happening

Inigo Everson (British Antarctic Survey, U.K.) If one knows the time of the season that larval fish is at a minimum in the plankton then one can minimize the amount of bycatch

David Saxby (Specialty Marine Products) A statutory closure of the fishery has been setup from June 1st to August 15th.

Carlos Moreno (Universidad Austral de Chile) The most important thing is to monitor levels of bycatch and take decisions, an adaptive management approach, as you go along. Information is the most important issue at this stage.

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Harvesting Krill: Ecological impact, assessment, products and markets

Workshop Programme November 14-16, 1995

Tuesday November 14, 1995

- 0845 - 0915 Continental breakfast
 0915 - 0930 Opening remarks – About the workshop (focus, scope and outputs from the workshop).....*Prof. Tony Pitcher*

Session 1: Krill sustainable harvest (Moderator: Inigo Everson)

- 1000 Exploitation and management of Antarctic krill.....*Denzil Miller (Sea Fisheries Institute, South Africa) and David Agnew (CCAMLR, Australia)*
 1000 - 1030 Fishery biology of *Euphausia pacifica* in the Japanese waters*Yoshinari Endo (Tohoku University, Japan)*
 1030 - 1100 Coffee break
 1100 - 1130 The importance of euphausiids to a British Columbia coastal marine ecosystem.....*Ron Tanasichuk (Fisheries and Oceans, Nanaimo)*
 1200 Development of krill fishing industry.....*Stephen Nicol (Australia Antarctic Division, Australia)*
 1330 Sandwich lunch in Ralf Yorque Room

Session 2: Ecological implications of krill harvesting (Moderator: David Agnew)

- 1330 - 1400 Putting Antarctic krill into ecosystem models.....*Astrid Jarre-Teichmann (Institute of Marine Science, Germany)*
 1400 - 1430 Juvenile fishes in the krill swarms and the bycatch problem.....*Carlos Moreno (Universidad Austral de Chile, Chile)*
 1430 - 1500 The CCAMLR experience.....*Inigo Everson (British Arctic Survey, U.K.)*
 1500 - 1530 Coffee break
 1530 - 1600 The influence of inter-annual variations in sea temperature on the population of biology and productivity of euphausiids in Barkley Sound, Canada.....*Ron Tanasichuk (Pacific Biological Station, Canada)*
 1630 Overview of the krill of the Gulf of St. Lawrence....*Yvan Simard, (Dept. of Fisheries and Oceans)*
 1700 Using the Ecopath II approach to assess krill biomass and dynamics.....*Daniel Pauly (Fisheries Centre, UBC)*
 1600 - 1730 Discussion: (Moderator: John Spence)
Krill harvest in British Columbia: issues and potential
 (Identify issues to be discuss on Wed. pm)

Wednesday November 15, 1995

0830 - 0900 Continental breakfast

Session 3: Krill resource assessment methods (Moderator: Denzil Miller)0900 - 0930 Biological parameters necessary for the management of the krill fishery.....*Stephen Nicol (Australia Antarctic Division, Australia)*0930 - 1000 Acoustic methodology.....*Inigo Everson (British Arctic Survey, U.K.)*1000 - 1030 Acoustic estimation of krill abundance utilizing volume scattering measurements.....*Michael Macaulay (University of Washington, USA)*

1030 - 1100 Coffee break

1130 - 1200 Comparisons of repeat acoustic surveys in Jervis Inlet.....*Steve Romaine (Institute of Ocean Sciences)*1200 - 1230 Modelling and data requirements for the management of the Antarctic krill-based ecosystem.....*David Agnew (CCAMLR, Australia)*

1230 - 1330 Sandwich lunch in Ralf Yorque Room

Afternoon session:1400 - 1500 **Discussion:** (Moderator: *Stephen Nicol*)
Resource utilization: products and markets for krill
(Identify more issues to be discussed)

1500 - 1730 Divide into working groups to discuss selected issues

Thursday November 16, 1995

0830 - 0900 Continental breakfast

0900 - 1030 Reports from working groups

1030 - 1100 Coffee break

1100 - 1230 Planning of book output

1230 - 1400 Sandwich lunch in Ralf Yorque Room

1400 Adjourn