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 to 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.

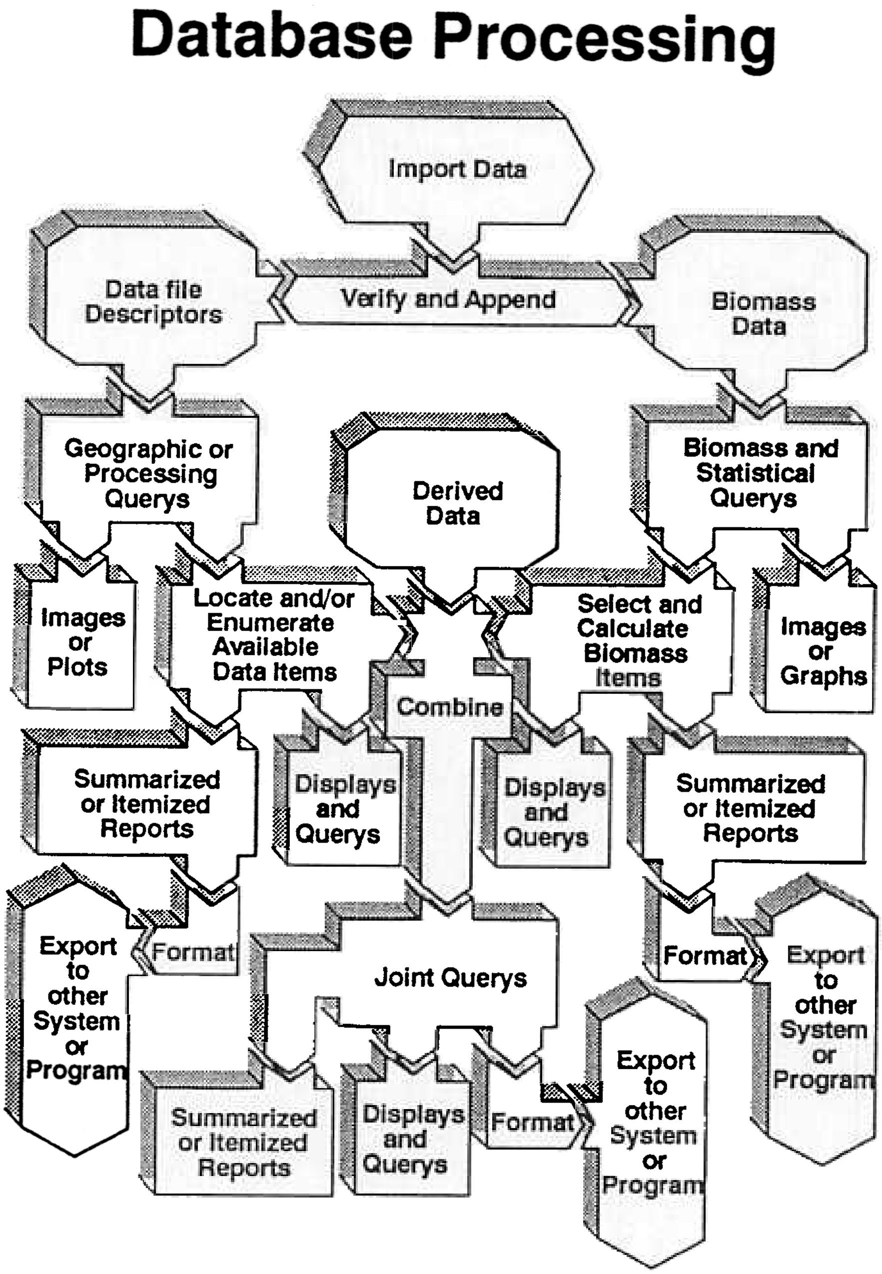

Figure 1. Schematic diagram of how volume scattering data can be combined in a database or databases to provide effective management of all related data items. Provision is made for export of the data to software other than that which is part of the database itself. This provides for platform to platform transfer and utilization of the data in ways most convenient for the user community.

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 depedent 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 *Champsocephalus 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 adequated 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 reanalyzes of Armstrong (1995) data, using a statistic methodology based in the delta distribution (mixture of other distributions) what permited to standardize and compare all data of different combined species. Consequently all the information of Table 2 needs to be reanalized. 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 calsbergi* 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 (Slósarczyk, 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). Nethertheless, call the attention the virtual absence of intermediate points thats 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 origen 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 supoused as the epoch in which the possibility that the pelagic fish larvae appear in greatest numbers as krill by-catch. Hereafter, there is a posibility 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 demostrated by Kellermann & Kock (1988). It is not known that this fenomenon 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) (m2)	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	Slósarczyk, 1982
A. Knipovich	?	?	?	WG-Krill-91/25
Prof.Siedlecki	750	11	?	Slósarczyk, 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-CAMLR-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	1/1336	13-1108 ind/Ton.
	SG 163/30	6/2639	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			

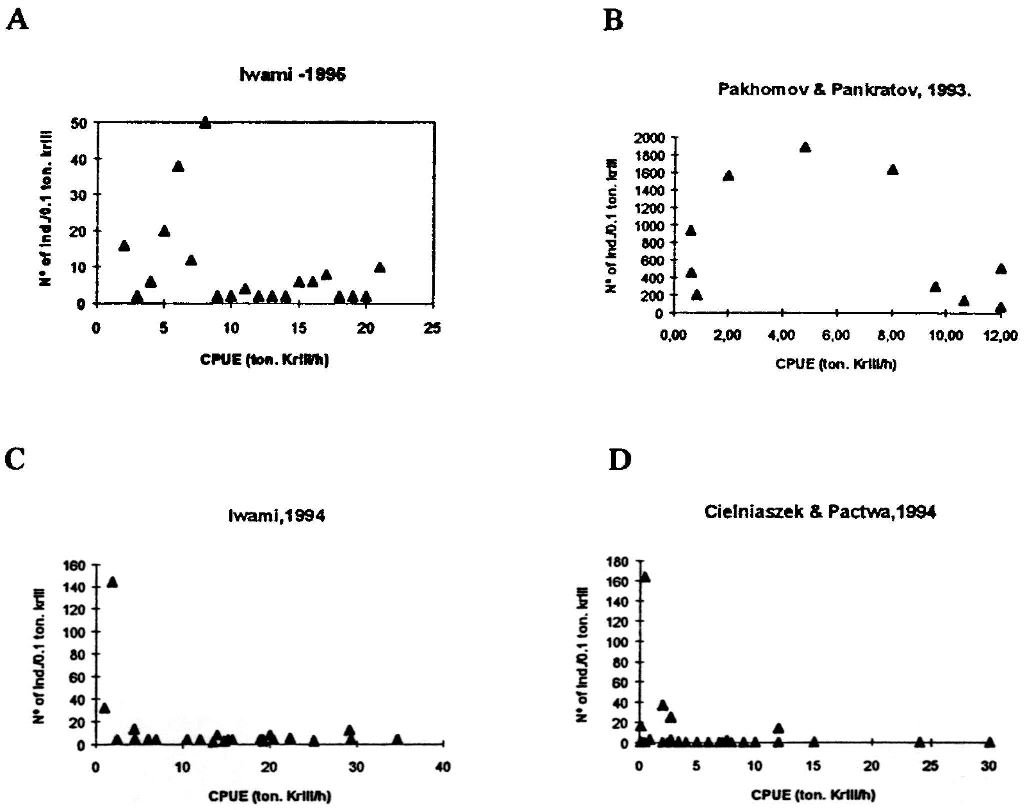

Figure 1. Relationship between the index of abundance of by-catch and the krill catches.

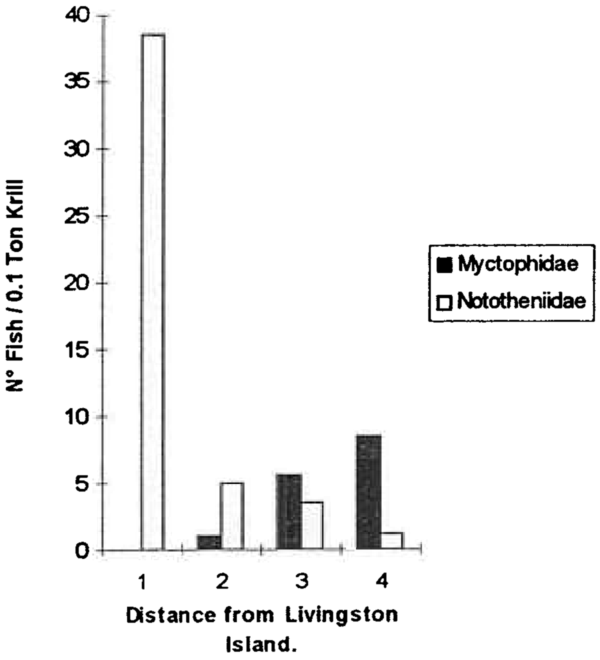

Figure 2. Presence of two groups of antarctic fishes as by-catch in the krill operations. The data were obtained from Iwami (1994 & 1995). The distance was categorized from 1 = hauls made over the shelf off the northern coast of Livingston Island to 4 = far in open sea. 2 and 3 correspond to groups of 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 ie. 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 prevent their been 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. (Budzinsk= i 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 eachother, 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 therefor 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 (*Euphausia superba*)	Antarctica*
North Pacific krill (*Euphausia pacifica)*	Japan*/ British Columbia*
Euphausia nana	Japan*
Thysanoessa inermis	Japan*
North Atlantic krill (*Meganyctiphanes norvegica*)	Mediterranean* Gulf of St. Lawrence/ Scandanavia
Australian krill (*Nyctiphanes australis*)	Tasmania

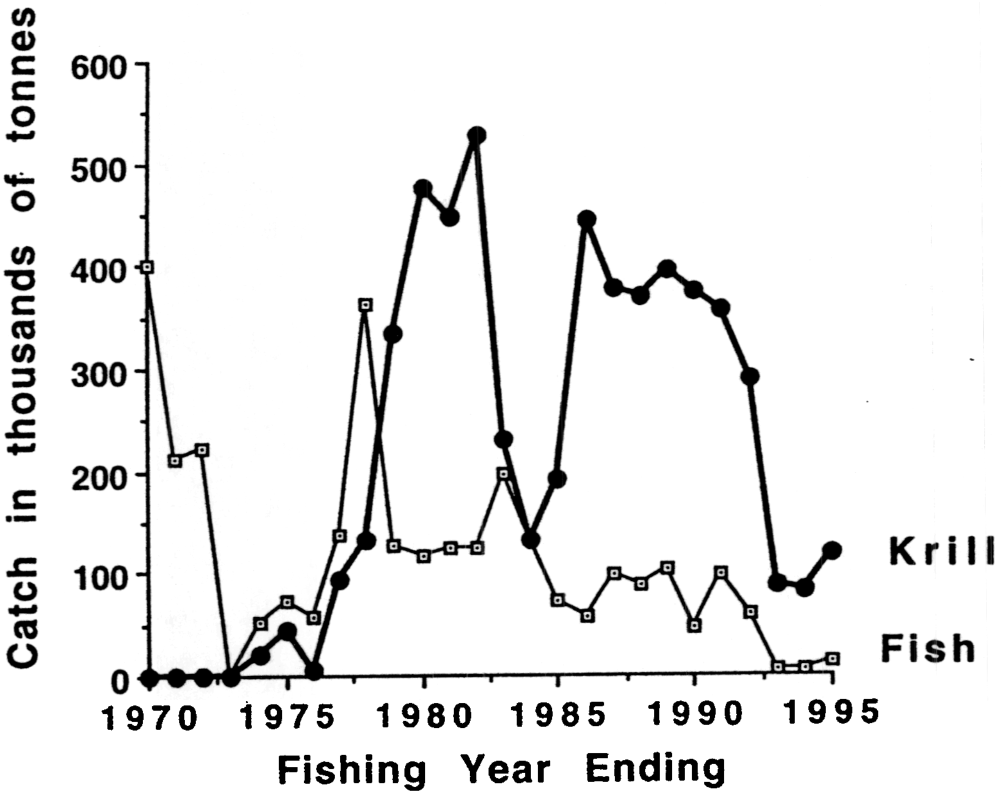
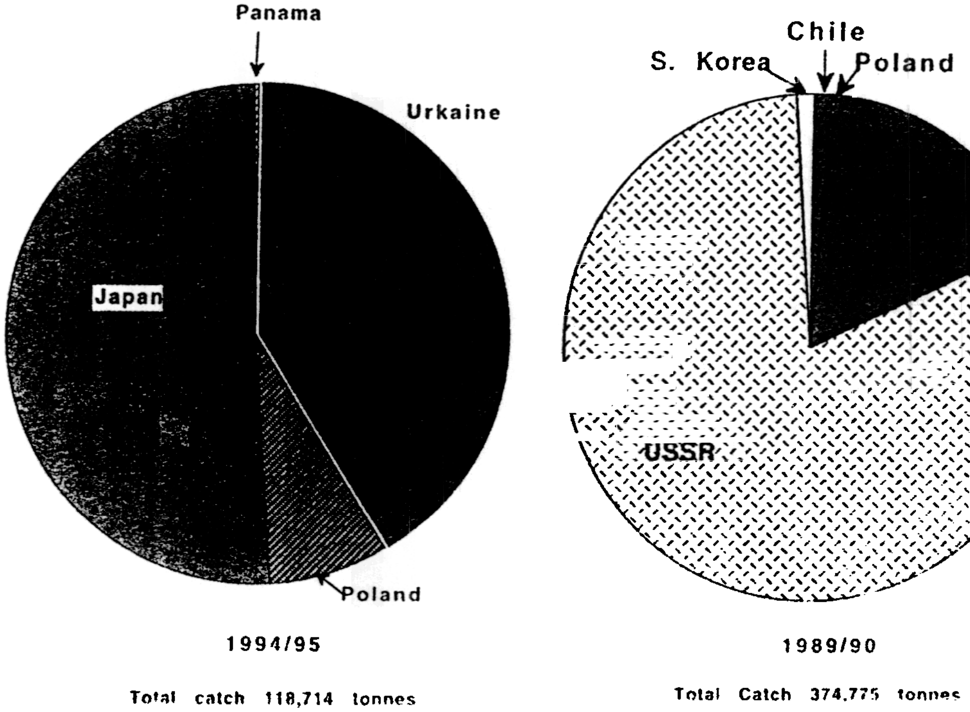


Figure The annual catch of Antarctic krill and Antarctic finfish.



1994/95

Total catch 118,714 tonnes

1989/90

Total Catch 374,775 tonnes

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

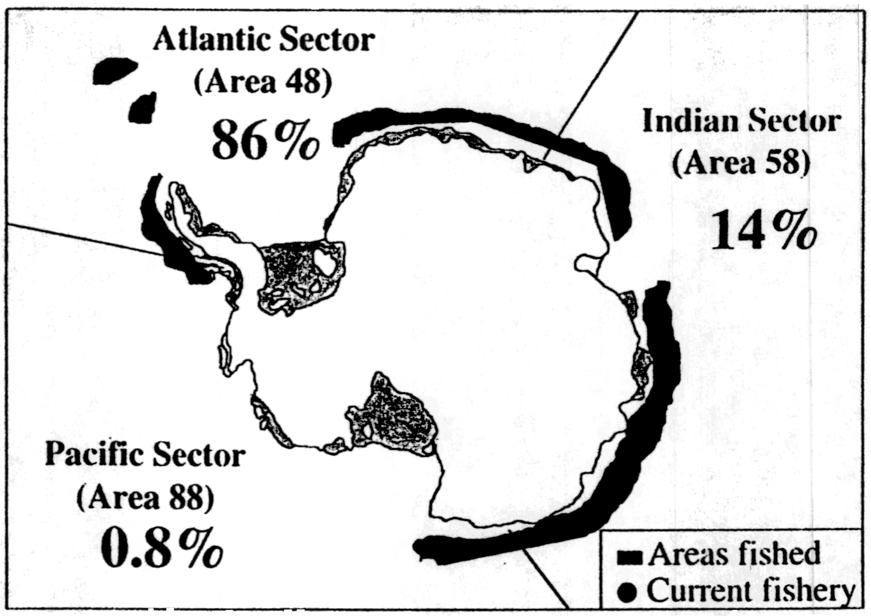


Figure 3 Location of krill catches showing overall percentage of historical catch taken from each sector

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 precuationary 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 bentho-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 that 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 imputs, 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 ×÷1.5 or less, with an average difference of _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 r2 = 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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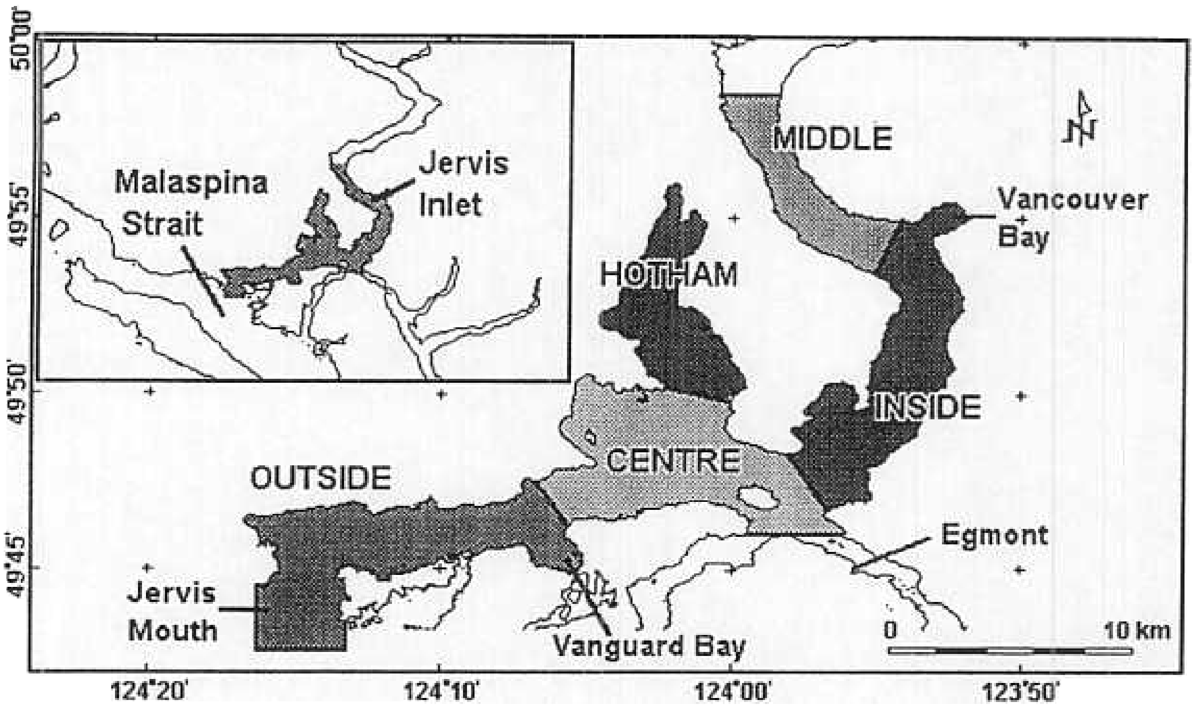

Figure 1. Jervis Inlet and associated biomass block averaging zones. The entire inlet is approximately 316 km2. Biomass estimates for our study considered the shaded areas only (total = 208 km2). For block averaging, five different biomass zones (Outside, Centre, Hotham, Inside, and Middle) were used.

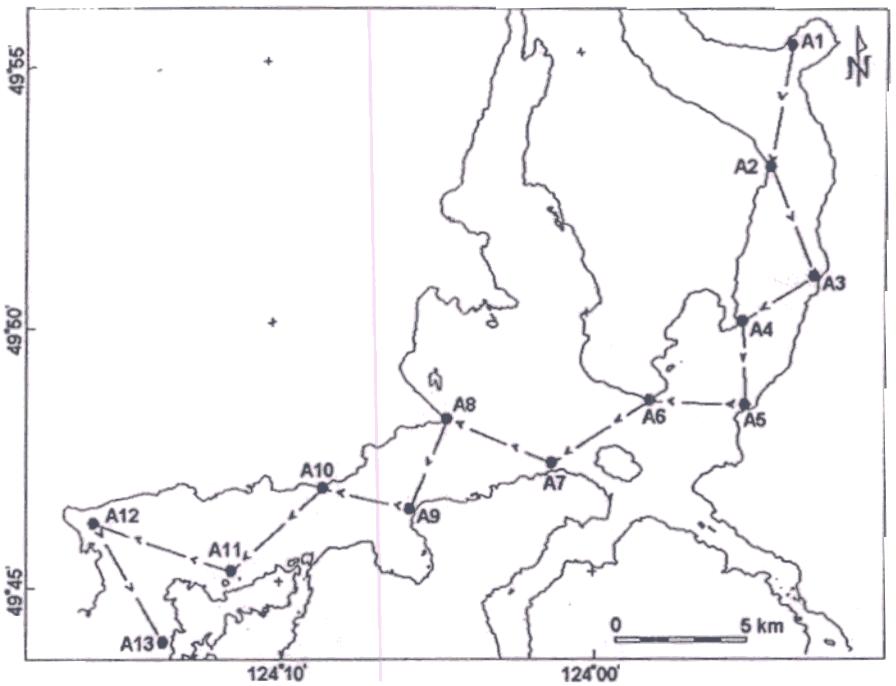

Figure 2a Jervis Inlet, transect series A

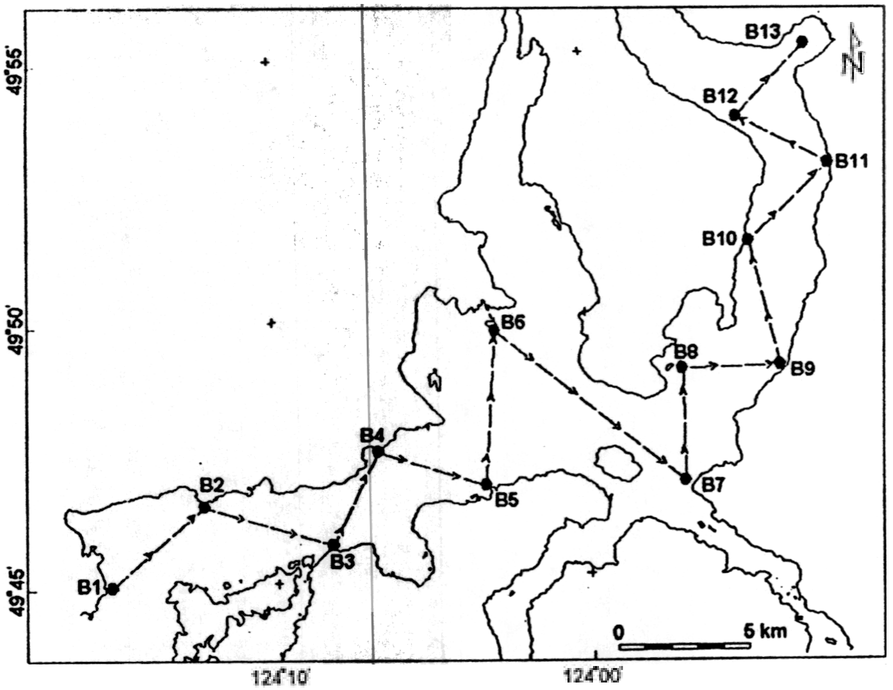

Figure Jervis Inlet, transect series 'B'

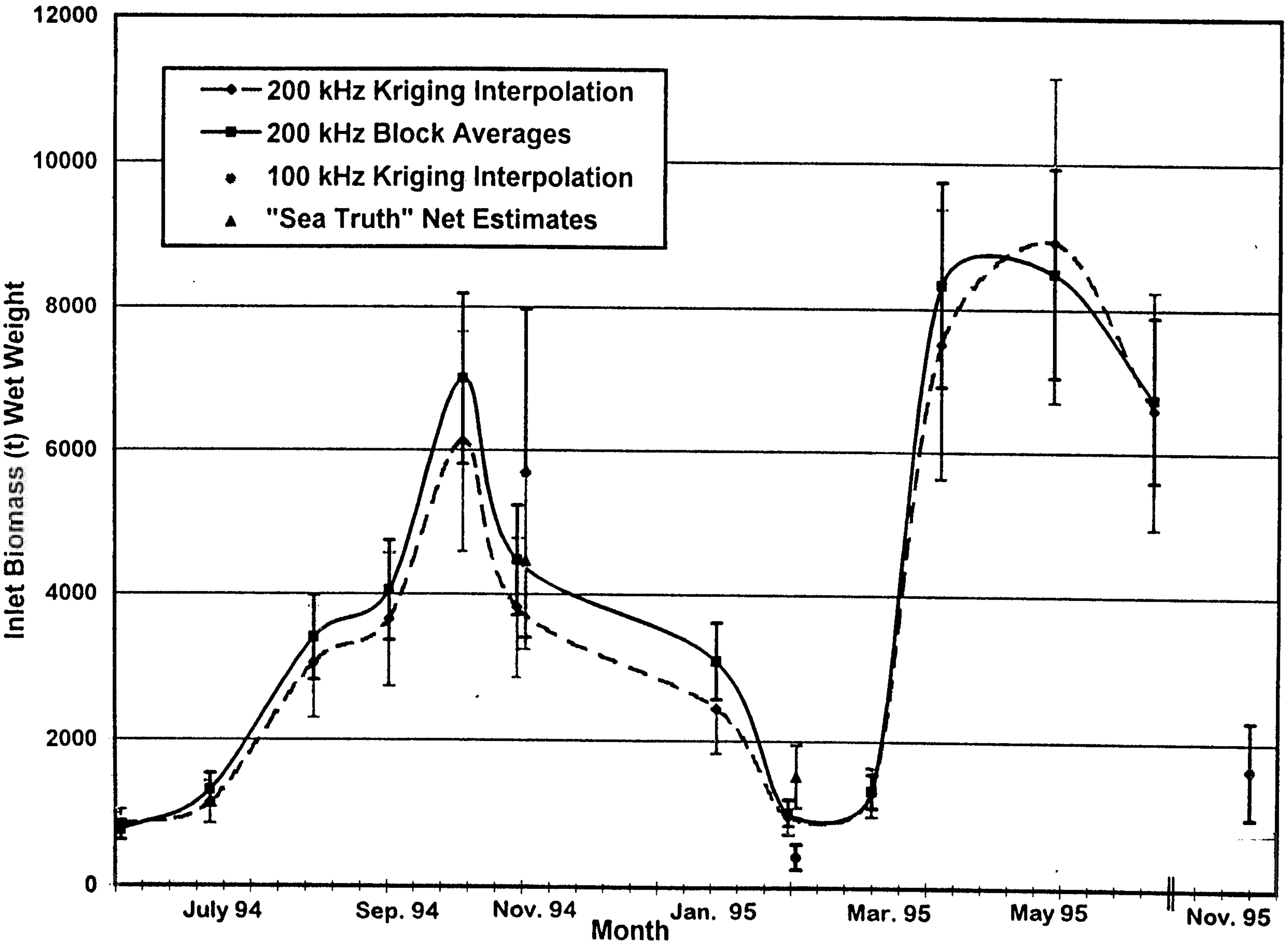

Figure 3. Jervis Inlet biomass estimates: June 1994-5, Nov. 1995. Estimates are for the shaded areas only, as noted in Figure 1. The duration of the commercial fishery occurs from November to February.

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 downstrean 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 unpulished 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, mackerel; 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 exploitating 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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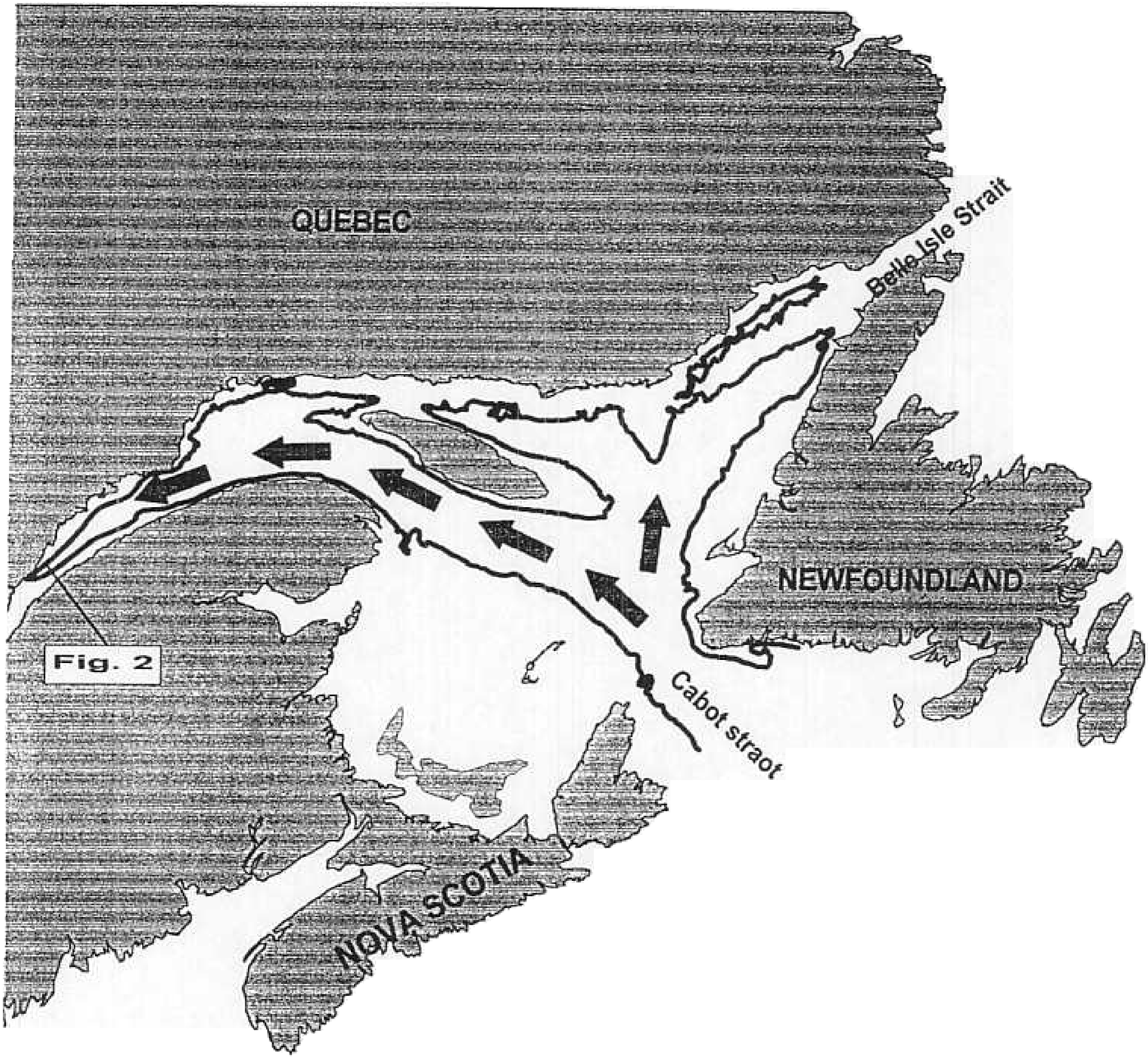

Figure 1. Golf of St.Lawrence and its channel network delineated by the 150 m depth contour. Arrows indicate the direction of the deep flow.

Krill sound scattering layer

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

Scattering volume (Sv) [-90dB - 60dB]

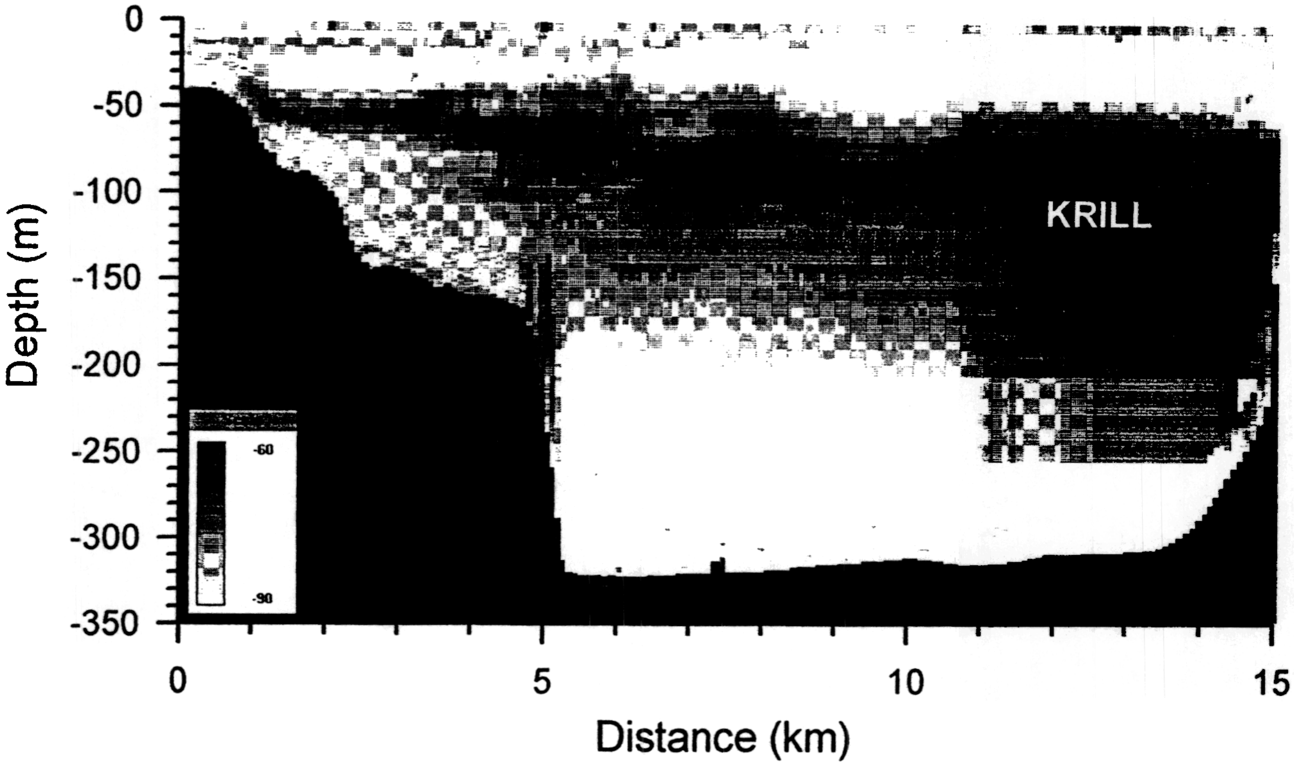

Figure 2. Echogram of a krill 120 kHz sound scatering layer in the St. Lawrence estuary in 1994.