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ECOLOGICAL FACTORS TO BE CONSIDERED IN ESTABLISHING A NEW KRILL FISHERY IN THE MARITIMES REGION

by

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ABSTRACT

An attempt is made to try to consider all possible ecological side effects of establishing a new fishery for krill on the Scotian Shelf and environs. First, an estimate of abundance is attempted in the proposed fishing area from published estimates of krill densities and adult habitat preference. Then, the requested harvest and a calculated exploitation rate are presented. The issue of whether krill harvesting could remove a major food source from other commercial fisheries or other ecologically important species is considered. The same concern is introduced for planktivorous sea birds and certain endangered marine mammals. The issue of by-catch being a potential problem for a krill fishery also is considered. Finally, the Sheldon Size Spectrum Approach is used in an attempt to rationalize and evaluate undercutting the traditional cod-haddock-hake fishery of the region.

RÉSUMÉ

On tente de cerner toutes les répercussions écologiques de l'ouverture d'une nouvelle pêche du krill sur le plateau néo-écossais et dans les eaux environnantes. On fait en premier lieu une estimation de l'abondance du krill dans la région concernée à partir d'estimations publiées des densités de krill et des habitats préférés par les adultes, puis on détermine les prises requises et un taux d'exploitation. On étudie ensuite la question à savoir si la récolte de krill pourrait priver d'autres espèces d'intérêt commercial ou écologique d'une importante source de nourriture. La même idée est appliquée aux oiseaux marins planctivores et certaines espèces de mammifères marins en voie de disparition. La question des prises accessoires comme un problème potentiel de la pêche du krill est aussi considérée. En dernier lieu, on utilise l'approche Sheldon par spectre de tailles pour essayer de rationaliser et d'évaluer comment la pêche du krill nuira à la pêche traditionnelle de la morue, de l'aiglefin et de la merluche dans la région.

INTRODUCTION

A couple of proposals have been received by the Maritimes Regional Office, Fisheries and Oceans Canada, over the past year seeking permission to fish commercially for species of euphausiids, commonly known as krill. The market for this fishery is in the manufacture of aquaculture feed where krill is used in a processed form as a nutritional additive in pellets. Krill is known to contain a high protein content (60-70% dry weight), essential fatty acids, and flesh-pigmenting carotenoids which are more than adequate for salmonid aquaculture (Storebakken 1988).

Canada has authorized two previous krill and/or plankton fisheries. An experimental fishery existed on the west coast as early as the 1970s (Heath 1977), and this has developed into a regulated fishery since 1990, with the assistance of annual acoustic assessments of the Strait of Georgia krill populations (Mackas et al. 1996). The annual British Columbia coast-wide quota of 500 t has infrequently been reached in the intervening years, ranging from 53 t to 530 t, up to 1994. Most of these landings come from a small area near Jervis Inlet (Strait of Georgia).

On the east coast, Fisheries and Oceans Canada first issued a scientific permit to harvest zooplankton (both krill and copepods) in the Gulf of St. Lawrence in 1991. An exploratory fishery proceeded for copepods and krill in November 1993 in the St. Lawrence Estuary off Ste-Anne-des-Monts (Runge and Joly 1995). This permit was renewed with a preventative Total Allowable Catch (TAC) of 100 t of krill and 50 t of *Calanus* in 1994, but only 6.3 t and 0.4 t were harvested, respectively. The TAC was increased in 1995 to 300 t of krill and 2000 t of *Calanus*, but landings were low at 2 t and 1 t, respectively. It was felt that the designated late-fall harvest period was too restrictive to reach the quotas set due to inclement weather at this time of year (J. Runge, pers. comm.).

It is the purpose of this report to best evaluate the potential effect of a new krill fishery in the Maritimes Region, on the shelf ecosystem with the knowledge presently available.

KRILL POPULATION ESTIMATES

There really is not a good measure of euphausiid abundance in the Scotian Shelf (Bay of Fundy Region). There is plenty of information on tow net catch of euphausiids in the region (Lewis and Sameoto 1988a,b,c; 1989a,b; 1990); however, interpretation of these data is fraught with problems. Euphausiid avoidance behaviour of towed nets results in order-of-magnitude lower abundance estimates compared to acoustic estimates (Sameoto et al. 1993). There are also problems associated with surface acoustic measures of euphausiid abundance (Cochrane et al. 1994). It appears that the best abundance estimates that we have are from the bottom-mounted acoustic Doppler current profiler, which overcomes acoustic interference problems in the near-surface waters and enables an integrated temporal estimate of abundance. Cochrane et al. (1994) used this instrument in the LaHave Basin, in 192 m of water over a 49-day period in late fall, when the two generations of *Meganyctiphanes* would be present, and calculated that on average over this time period 81.2 g/m^2 or 81.2 t/km^2 existed. This is not very different from Cochrane's and Sameoto's (1991) earlier estimate of 79.2 g/m^2 obtained in the LaHave Basin with surface acoustic techniques. They also estimated an euphausiid density of 102 g/m^2 for the neighbouring Emerald Basin (Cochrane and Sameoto 1991).

If we use these values for LaHave and Emerald Basins, and assume a similar density of euphausiids in the Fundian Channel (ignoring the shelf break population indicated in Sameoto's and Cochrane's [1996] shaded-in chart), we arrive at:

	Area (km^2, within 100 fathoms)	Density (t)
LaHave Basin	3578	290,549
Emerald Basin	4108	419,031
Fundian Channel	9629	781,923
Total		1,491,503

If this estimate is realistic, the initial proposal received by DFO to harvest 1,000 t represents 0.06% of the standing stock.

ALLOWABLE EXPLOITATION LEVEL

The author has spoken to Dr. Robert Mohn (DFO, Dartmouth, N.S.) about the request contained in the initial proposal of allowing 2% of the euphausiid biomass to be harvested. Dr. Mohn assured that this level of exploitation was extremely low for an animal with a ~2-year life span and that 20% of an exploited species or 40% of a virgin population is frequently allowed in a commercial fishery. The present rough calculation of 0.06% is many orders-of-magnitude below the so-called safe level of exploitation.

ADULT AND JUVENILE COMMERCIAL FISH SPECIES

The next issue of concern is whether the removal of euphausiids will have a detrimental effect on existing fisheries. As a start, the summer distribution and abundance trends of species caught on the Scotian Shelf (1970 to 1992) by the research vessel groundfish survey (Simon and Comeau 1994) was used to obtain average abundances of juvenile and adult fishes which are likely to utilize krill and exhibit an overlapping geographic distribution to the proposed harvesting areas (Table 1).

Table 1. Abundance of groundfish and pelagics on the Scotian Shelf and its basins.

Species		No./tow*
Redfish	*Sebastes* sp.	1-2500***
Silver hake	*Merluccius bilinearis*	1-2500***
Spiny dogfish	*Squalus acanthias*	1-500**
Pollock	*Pollachius virens*	1-00***
Longfin hake	*Urophycis chesteri*	1-500
Argentines	*Argentina silus*	1-500**
Shortfin squid	*Illex illebruscus*	1-500
Atlantic mackerel	*Scomber scombrus*	1-250**
Red hake	*Urophycis chuss*	1-100
White hake	*Urophycis tenuis*	1-100***
Offshore hake	*Merluccius albidus*	1-50
Cusk	*Brosme brosme*	1-20

*Standardized bottom trawl to 1.75 nautical miles;
**Pelagic species such as mackerel, herring, gaspereau, etc., are underrepresented in the catch due to near bottom sampling;
***Some of the demersal fishes spend part of the time in the water column at night feeding, which means that they also would be underrepresented in the trawls, though not as much as the pelagic fishes.

Of this list of species, three are harvested by our fisheries: pollock 4VWX, silver hake 4VWX, and redfish 4WX (DFO Atlantic Fisheries Stock Status Rep. 95/6). Together they comprise 18% of the total catch in metric tons for the Scotian Shelf area in 1994. Historically, before the most recent groundfish collapse, they represented a higher percentage of the catch, e.g. 43% in 1986.

Almost all of the fish species which overlap geographically with euphausiid concentrations feed on crustaceans with small fish making up a greater proportion of the diet as they grow in size (Scott and Scott 1988; Maurer and Bowman 1985) (Table 2).

Table 2. Scotian Shelf (including basins) fish species and diet.

Species	Diet
Redfish	Amphipods, copepods, and euphausiids are primary food
Silver hake	Euphausiids are an important food source (up to 28%)
Spiny dogfish	Feeds chiefly on fish, but will feed on whatever present
Pollock	50% of diet crustacean with euphausiids an important component
Longfin hake	Feeds on crustaceans, euphausiids, shrimps, and amphipods
Argentines	Food primarily euphausiids and amphipods
Shortfin squid	Fish, squid, and crustaceans, including euphausiids
Atlantic mackerel	Feeds on crustaceans and small fishes
Red hake	Crustaceans major prey
White hake	Crustaceans 17% of diet
Offshore hake	Not known, but probably similar to silver hake
Cusk	Feeds predominantly on crustaceans

Thus, it can be seen that the diet of the dominant fish species in Emerald Basin and LaHave Basin, and the Fundian Channel, not surprisingly is composed of euphausiids; and in most species this makes up a considerable portion of their diet.

The next question is whether the removal of euphausiids would effect the productivity of other fisheries in the neighborhood. It is notable that neither Atlantic cod nor haddock overlap in distribution with the bulk of the adult euphausiid populations from the summer groundfish survey (Simon and Comeau 1994), preferring to frequent waters shallower than 100 m deep, chiefly on the offshore banks. However, cod are known to inhabit the deeper waters of the basins on the Scotian Shelf during the winter months (L. Paul Fanning, pers. comm., DFO, Dartmouth, N.S.). This is not to imply that cod and haddock do not eat euphausiids during the summer, because juvenile euphausiids are carried onto the shoaler areas; but they would comprise less of the diet than fish species habitating the deeper waters year-round where the euphausiids are more dense. In fact, one coastal study of the Passamaquoddy Bay area proposes that *Meganyctiphanes*, particularly the juvenile stages, are widespread in shallower waters during the summer months and somehow migrate, or are carried by residual flow to deeper waters of the Grand Manan Basin for overwintering (Hollingshead and Corey 1974; Kulka et al. 1982).

Evaluating the importance of krill as a direct (food) or indirect (food of prey) source of energy which fuels the higher trophic levels represented by the above fishes is more difficult. One would need to know the individual energy requirements not only of each mature fish species, but a continuum of all their developmental sizes above say twice the biomass of their krill prey (see Sheldon Size Spectrum Approach below).

MARINE MAMMAL INTERACTIONS

A number of marine mammals also depend on plankton and nekton for food. Some of these species are considered endangered, such as the humpback, blue, and right whales. In particular, the right whale, which used to number in the tens of thousands in the North Atlantic, is reduced to hundreds in spite of a total hunting ban since 1935. There are presently estimated to be only 350 individuals left in the North Atlantic (M. Brown , East Coast Ecosystems Research, Nova Scotia, pers. comm.). Right whales are baleen plankton feeders believed to feed primarily on copepods but also consume euphausiids (Dr. Paul Brodie, Halifax, N.S., pers. comm.). Their northern migration brings them to the Bay of Fundy and Scotian Shelf region, together with their young, presumably for food (Kraus et al. 1986; Winn et al. 1986; Mate et al. 1992). Their centres of abundance, in the Canadian leg of their annual migrations, occur at the mouth of the Bay of Fundy and Roseway Basin (north of Browns Bank). The Bay of Fundy appears to be the sole feeding ground for calves and their mothers in Canadian waters (Kraus et al. 1986). Both these areas should be excluded from any krill fishery. The whale-watching portion of local tourism is worth tens of thousands of dollars each year off southern Nova Scotia and New Brunswick. At last count there are 24 boats equipped and ready to take tourists whale watching this summer (i.e. 1996) along the east and west coasts of the Bay of Fundy (Moira Brown, pers. comm.).

MARINE BIRD INTERACTIONS

There are a number of pelagic bird species which inhabit the Scotian Shelf and the waters off the Bay of Fundy and southwestern Nova Scotia, at least part of the year (Lock, et al. 1994). However, the number of species which feed primarily on plankton and macroplankton can be reduced to four main types. Dovekies are concentrated along the Shelf break and off southwestern Nova Scotia during the winter months, particularly in February. Black-legged kittiwakes are present in the same area between October and February. On the other hand, greater shearwaters frequent the deeper waters off southwestern Nova Scotia between May and October, with greatest abundance from June to August. Shearwaters are know to concentrate in late summer off Brier Island, N.S., feeding primarily on the large krill *(Meganyctiphanes novegica)*, which concentrate at the sea surface (Barker 1976; Brown et al.; 1979; and Nichol 1984). Leach's storm petrels are also very abundant during the summer months off southwestern Nova Scotia, with one of the biggest breeding concentrations in the Maritimes of 50,000 pairs occurring on nearby Bon Portage Island (A.R. Lock, Canadian Wildlife Service, Environment Canada, Dartmouth, N.S., pers. comm.). Storm petrels nesting on Pearl Island and feeding on the Scotian Shelf feed mainly on euphausiids; however, on a volumetric basis fish larval remains predominant over crustacean (Linton 1978).

LARVAL AND JUVENILE FORMS LIKELY TO BE HARVESTED WITH KRILL (BY-CATCH)

It is also important to consider whether the proposed krill fishery would interfere with either a spawning ground or nursery area for important species in the area. Larval lobsters are present in the waters proposed for this fishery, but they originate either from the offshore banks, notably Browns and Georges Banks, or inshore of the 15 fathom depth off southwest Nova Scotia (Stasko and Gordon 1983; Harding and Trites 1988). Only the fourth and final planktonic-pelagic stage occurs in the proposed fishing areas; and these are dispersed enough, yet restricted to the near-surface waters, not to represent a significant by-catch.

Silver hake are much like the offshore lobster in that they migrate from deeper waters off the continental slope and shelf basins onto the offshore banks to spawn (Waldron 1988). The larval and juvenile hake remain over the offshore banks, so there is little likelihood of their being removed by a krill fishery.

Pollock are also bank spawners and are known to use Browns Bank in the spring and Emerald and Western Banks in the fall; but, it is uncertain whether the larvae are maintained in these areas (Neilson and Perley 1996). The young-of-the-year migrate to the coast and reside in the estuaries and embayments along Nova Scotia. Juvenile pollock (Ages 0-2) have a distribution which matches the predicted and observed distribution of *Meganyctiphanes* with high catches in the summer groundfish surveys of 1970-1995 in The Gully, Emerald, and LaHave Basins, Crowell Basin, and the mouth of the Bay of Fundy (Black 1996).

Cod, haddock, and flatfish spawn over the offshore banks, and lesser spawnings occur close to shore, with most of the larvae remaining near the banks (Hurley and Campana 1989; Brander and Hurley 1992) but with some documented leakage from the Browns Bank area (Suthers et al. 1989). Juvenile cod and haddock (Ages 0-2 years) caught during the summer groundfish surveys (1970-1995) tended to be highly associated with the offshore banks (Black 1996). However, the cod may move into the deeper waters of the basins during the winter months like the adults.

Redfish young are released as egg-yolk larvae by the females in deep water (>350 m) in July and settle to the bottom by October; however, they are quite broadly dispersed over the Scotian Shelf (Kenchington 1984).

Most other meroplanktonic larvae of bottom-living organisms (e.g. scallops) and planktonic organisms would simply pass through the coarse mesh (1/4 inch) planned for the krill fishery, with the exception of decapod shrimps, amphipods, and mysiids. Major concentrations of shrimp occur on the northeastern sections of the Scotian Shelf which are outside the currently proposed krill fishery.

It does not appear that by-catch of other key species of the Shelf ecosystem presents a problem, though this concern should probably be monitored if a krill fishery is allowed.

Information from the Scotian Shelf Ichthyoplankton Program (SSIP), conducted in the late 1970s and early 1980s, could be examined in any future reviews of this nature.

THE SHELDON SIZE SPECTRUM APPROACH

Another approach to the problem is to determine whether short-circuiting the food web will have detrimental effects on the entire ecosystem. Sheldon et al. (1972; 1982) advocated that the biomass (per-unit volume or area) of a marine pelagic food web was constant or flat when plotted against the logarithm of body size. With this assumption they predicted that the fishable standing stock of cod, haddock, and silver hake on the Scotian Shelf (Northwest Atlantic Fisheries Organization [NAFO] Areas 4VS and W) was 6.8 g/m^2 based on a measured phytoplankton standing stock of 1.7 g/m^2 and with four logarithmic size units representing the fishable stocks. Over the past 10 years it has been generally agreed that the marine size spectra has secondary structure with rather regular predictable peaks and troughs (Schwinghamer 1985) and that overall a slight negative slope occurs (Boudreau and Dickie 1992). If we use Boudreau's and Dickie's (1992) equation for the size spectra of Browns Bank (NAFO Area X) as representative of the Scotian Shelf, the fishable standing stock of groundfish would again be 1.72 x 4 or 6.8 g wet weight/m^2, but the standing stock of nekton-macroplankton in the size range of adult euphausiids would be 8.7 g wet weight/m^2. Sheldon et al. (1982) calculated that 2.6 g wet weight/m^2 per logarithmic size interval were produced in a fish population from the northern section of the Scotian Shelf in the 1954-1962 era before exploitation became excessive (mid 1960s). The euphausiid estimate given by Cochrane et al. (1994) for the LaHave Basin of 81.2 g/m^2 is an order-of-magnitude greater than needed to support historic groundfish population levels in the 1950s and 1960s. However, the associated Regional Assessment Process document by Sameoto and Cochrane (1996) guestimates the euphausiid biomass on the Scotian Shelf basins at 10 g wet weight/m^2, which nicely matches predictions based on the Size Spectrum Approach. In the present case, the groundfish stocks are so low that the production of euphausiids is bound to be excessive for the needs of the current fish population. It would be fair to summarize that production removed from one trophic level is bound to reduce the yield from higher trophic levels in a reasonably stable ecosystem and that economics and good ecological management should ultimately determine which product (krill or fish) is harvested and in what quantities.

CONCLUDING REMARKS

Caution should definitely be the overriding principle when we harvest lower and lower in the marine food web. If we apply the logic and advice of Ken Frank (DFO), as contained in DFO Atlantic Fisheries Stock Status Report (95/6, p. 133-134) concerning sandlance exploitation, we would not recommend a fishery for krill because it has a prominent position in the middle of the food web of the deeper regions of the Scotian Shelf and Gulf of Maine. Furthermore, the author of this paper has documented above that almost all commercially important species in the area utilize euphausiids as a primary food source. However, given the present modest request to harvest 1,000 t of krill, it is considered that this could be allowable as an exploratory venture providing that a better estimate of their abundance be obtained in the future. DFO might consider deploying several bottom-mounted acoustic Doppler current profilers (Cochrane et al. 1994) at different times of the year, particularly in regions where we presently have no information, i.e. Fundian Channel and the Scotian Shelf break. Sameoto's recommendation (unpubl. document) that the inshore area of southwestern Nova Scotia and the mouth of the Bay of Fundy be excluded from the possible krill fishery is supported here because of the presence of a lucrative herring fishery, the largest concentration of breeding petrels in the Maritimes, and the fact that these areas are also the feeding areas for the endangered right whale, not to mention the commercial whale-watching enterprises in the area. Finally, an ecological-economic study should be done to evaluate the relative potentials of fish and krill fisheries given the carrying capacity of the environment and the dependence of fish on krill for food.

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