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Zooplankton sound scattering layers in North Norwegian fjords: Interactions between fish and krill shoals in a winter situation in Ullsfjorden and Øksfjorden

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Abstract

Aspects of the inter-relationship of krill Sound Scattering Layers (SSLs) and fish were examined in Ullsfjorden and Øksfjorden, northern Norway from 2 – 8 February 1980. Diel changes in the depth distribution and biomass of krill (Euphausiacea) were compared with the depth distribution and abundance of gadoid fish using a pelagic capelin trawl, 38 and 120 kHz echosounders, and a digital echointegrator. Krill underwent vertical migrations from the surface at night to the fjord bottom at mid-day. A significant power curve relationship was found when catches of krill in the pelagic trawl (l · trawl h^{-1}) were compared with volume backscattering (dB m^{-3}) at 120 kHz, indicating that krill biomass can be reliably estimated using acoustic techniques. Krill were the dominant food item of fish caught with the pelagic trawl in the SSLs. Fish were nevertheless rare in these krill SSLs; the majority congregated under them, probably feeding extensively at their periphery. Interactions between krill and pelagic feeding gadoids in north Norwegian fjords are examined.

Introduction

The economic and ecological importance of krill (Euphausiacea) in polar seas has been well appreciated (see MAUCHLINE and FISHER 1969, EVERSEN 1977, BACKUS 1978). The ecological importance of krill in near-shore areas is less well known although investigations have emphasised that the biomass of krill over the continental shelf and in fjords may often be great (BARY and PIEPER 1971, SAMEOTO 1976, HOPKINS et al. 1978. EVANS and HOPKINS, 1981). Krill, feeding primarily at the second trophic level, are an important link in the transference of energy from phytoplankton through the food web to fish in both oceanic and neritic areas. Nevertheless, the production cycle and the dynamics of energy transfer in shallow water areas are different from those in oceanic areas (RYTHER 1969). Little information is available about the role of krill in boreal and arctic fjords.

A research project studying zooplankton sound scattering layers (SSLs) in north Norwegian fjords, using acoustic as well as biological techniques, has shown that krill is the dominant biomass organism at all times of the year. These SSLs, up to 150 m thick, with krill densities of sometimes more than 40 indicimduals m^{-3}, moving from near the fjord bottom during the daytime towards the surface at night, are probably of great ecological importance. In order to gain a better understanding of the role of krill in the fjord ecosystem it was considered necessary to combine the SSL studies with studies of their population dynamics, biochemistry and behaviour (Falk-Petersen 1981, FALK-PETERSEN and HOPKINS 1981, FALK-PETERSEN et al. 1981).

This paper examines aspects of the interactions between krill SSLs and fish (especially gadoids), and discusses the feeding strategy of fish on krill shoals.

Material and methods

The study area

The present investigation was conducted in Ullsfjorden (69°47'N, 19°47'E) and Øksfjorden (70°08'N, 22°22'E) in northern Norway between 2 and 8 February 1980. Ullsfjorden is a wide, open fjord about 85 km long. The study was carried out in the deepest basin (ca. 275 m) which is demarcated from the outer reaches of the fjord by a saddle at 170 m between Lyngstua and Skjervøy. Øksfjorden is a relatively narrow fjord, 25 km long, adjoining Stjernsundet. The study was carried out in the inner basin (ca. 240 m) of the fjord which is also demarcated by a saddle at 170 m depth.

Acoustic investigations

Zooplankton sound scattering layers were located using a Simrad EK 120A echosounder (120 kHz). Quantitative data on the depth distribution, density, and size of the SSLs were provided by the EK 120A coupled to a Scase echointegrator and computer-orientated data acquisition system. The time varied gain (TVG) depth-limit of the echosounder is 100 m but reliable quantitative data can be obtained to a depth of 200 m (HOPKINS et al., 1981).

Echointegrator printouts were provided over 8 selected depth intervals at 0.1 nautical mile sailed distances during trawling. Depths shallower than 10 m are not included in the integrations. Echointegrator values were automatically software standardized per nautical mile irrespective of the distance integrated. Mean volume backscattering strengths (dB m^{-3}) were calculated using a Nord-10 computer. The dB values presented in this paper are the means of at least five 0.1 nm sailed distances during trawling. Specific details of the system used in the present study as well as details of the mathematics of the volume back scattering calculations are given in HOPKINS et al. (1981).

The presence of large nekton (mainly gadoid fish and some squid *Todarodes sagittatus*) were recorded on a Simrad EK 38A echosounder (38 kHz). An index of gadoid fish abundance was calculated by counting single fish echoes in each 10 m depth interval on the echograms standardized per trawl hour.

Biological sampling

A pelagic capelin trawl with an opening of 18 x 18 m (effective fishing opening of 10 x 10 m) and 1 cm^2 mesh in the cod-end was used to sample the krill SSLs and to monitor the presence of nekton which might be associated with, or be responsible for, the SSL. A Simrad trawl eye, mounted on the headline of the trawl, monitored the trawl depth. The pelagic capelin trawl catches krill when these are present in quantity (EVANS and HOPKINS, 1981). The total volume of plankton (mainly krill) collected in the cod-end of the pelagic trawl was measured on deck and the fish caught were identified, counted, and total lengths measured.

Fish stomachs for analysis were ligatured at the oesophagus and pyloric caecae before being removed and preserved in 96 % ethanol. The degree of stomach fullness (0-100 %) was determined using the points method, and the relative abundance of the dominant taxa was recorded according to their relative mass in the stomach (HYNES 1950).

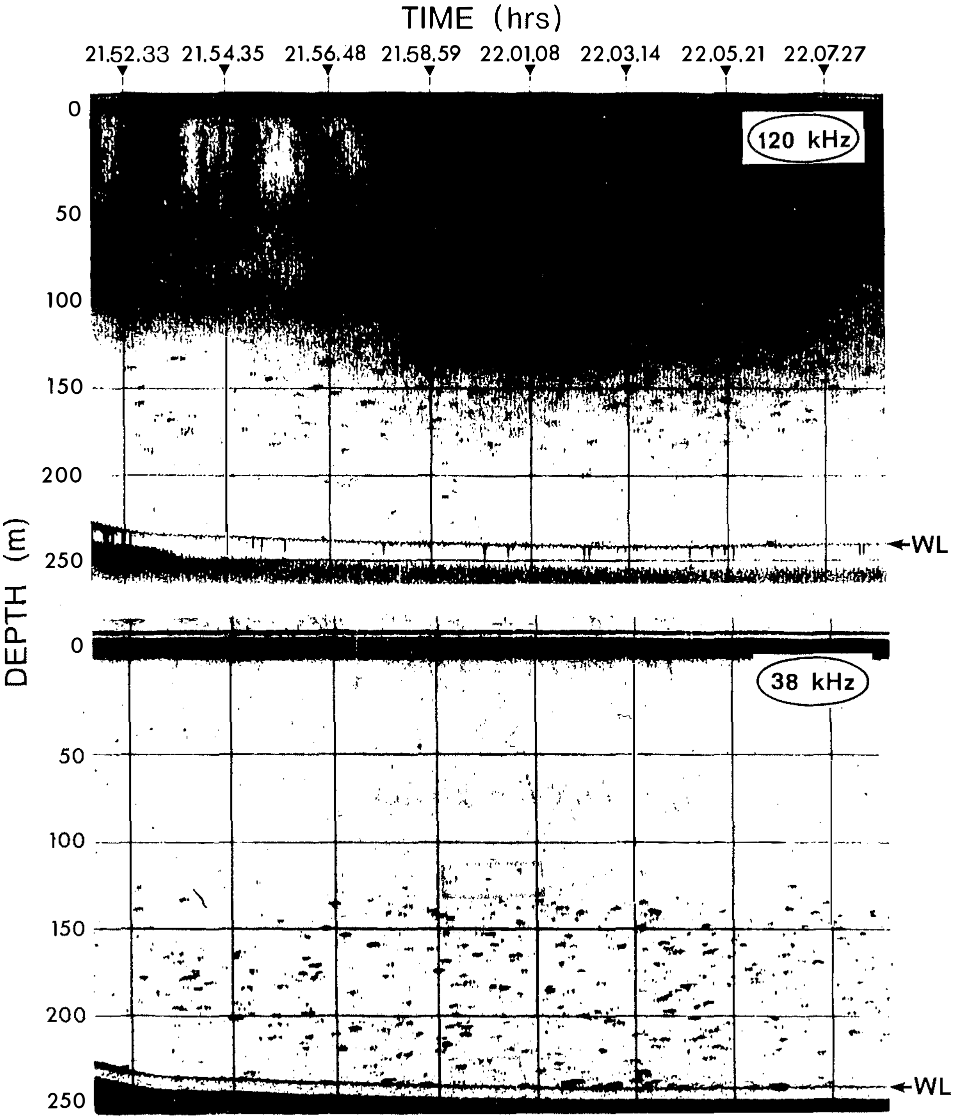

Figure 1

120 kHz and 38 kHz echograms showing the registration of krill at night (surface to c.140 m) only at the higher frequency. Single nekton (chiefly gadoids) echoes are clearly seen at 38 kHz. Time on the echograms are given for 0.1 nm intervals (vertical lines). WL = white line recording of the fjord bottom. Øksfjorden, 7 February 1980

Results

Examples of echograms from the 120 kHz and 38 kHz echosounders showing the registration of krill and fish from the dark period (22.00 hrs.) are presented in Fig. 1. The depth distribution of krill based on the typical krill "smoke" trace from 120 kHz echograms and the density of the layer expressed as krill caught (l·trawl h^{-1}) are shown in Fig. 2. Data on krill distribution based on volume backscattering (dB m^{-3}) from 10 to 200 m at 120 kHz is presented in Fig. 3 and 4. Fish abundance is expressed in Figs. 2 and 4 as an acoustic index of abundance.

Vertical migration of krill

In Fig. 2 krill are seen to be distributed from the surface down to ca. 150 m from 22.00 – 06.00 hrs with pelagic trawl catches varying from 150–175 l h^{-1}. The majority of gadoids

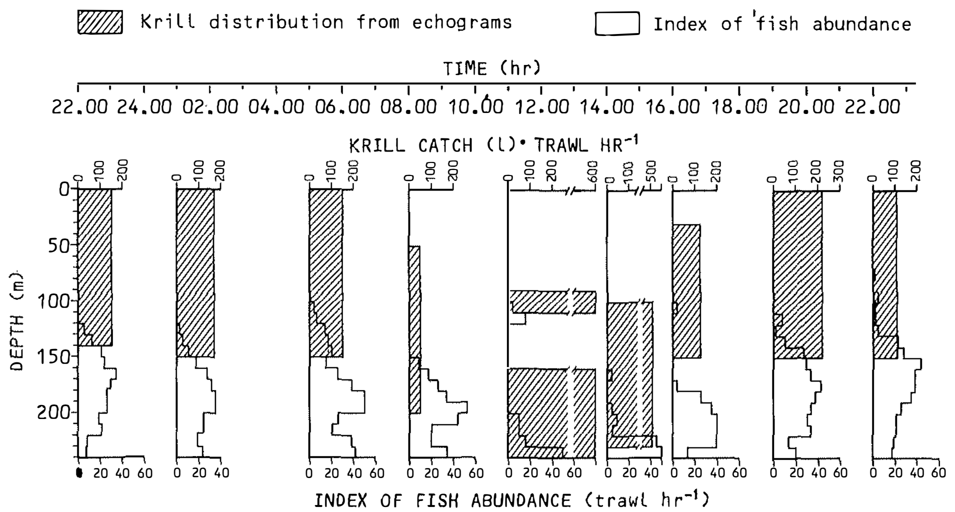

Figure 2

Diel depth distribution of krill from 120 kHz echograms, pelagic trawl catches, and fish from 38 kHz echograms (See text for futher details). 0ksfjorden, 7–8 February 1980

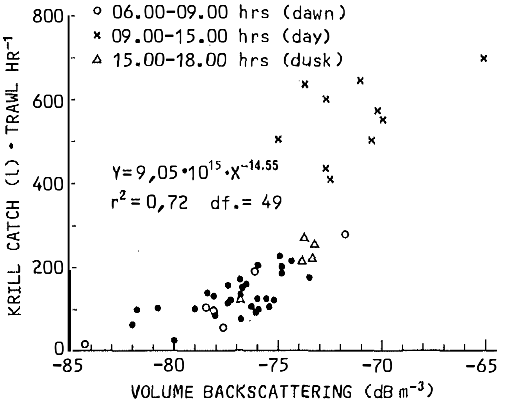

Figure 3

The relationship between volume backscattering (dB m^{-3}) at 120 kHz and krill catch (l · trawl h^{-1}) in the pelagic trawl from depths where fish were absent. 0ksfjorden, 4–8 February 1980

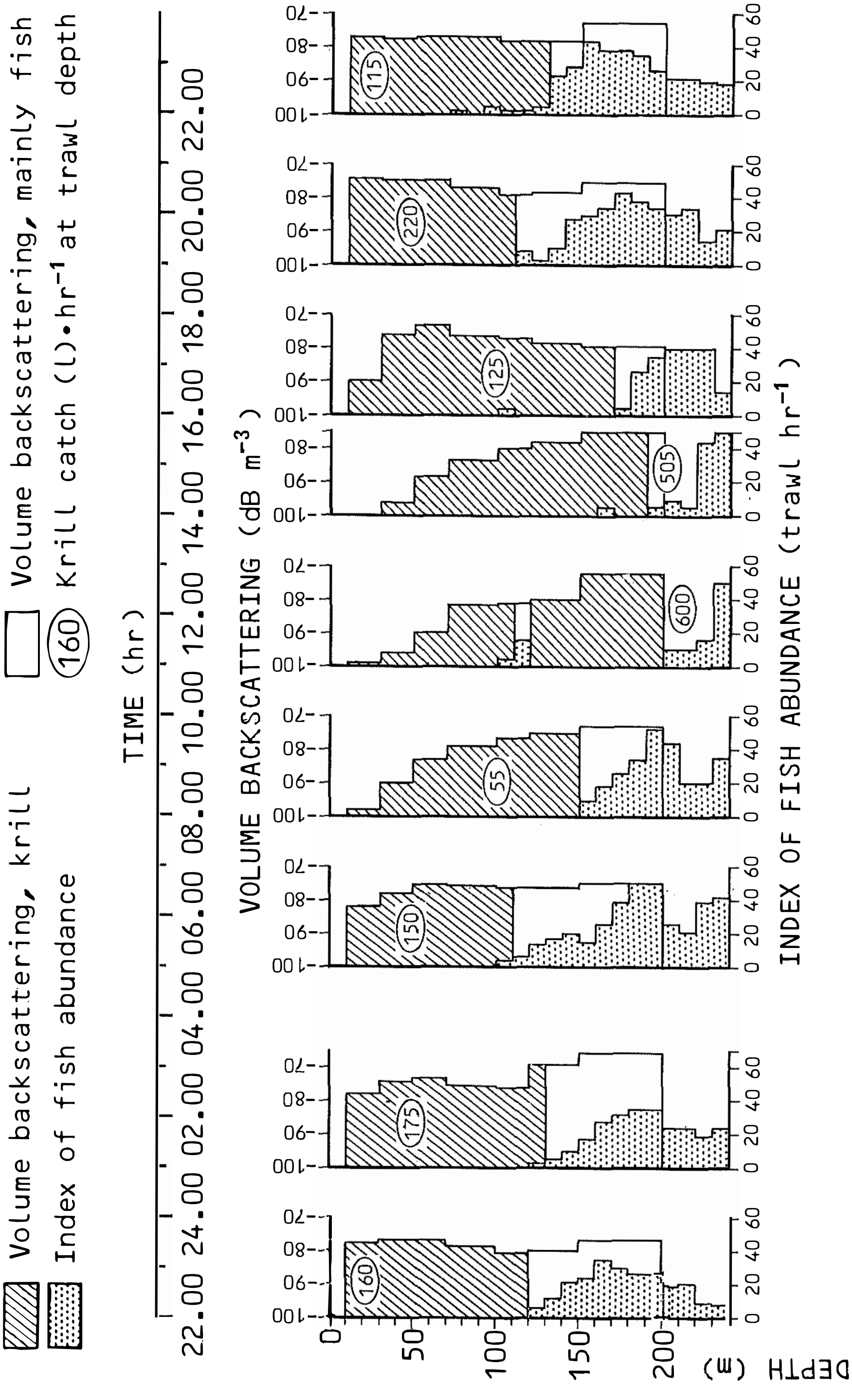

Figure 4
Diel depth distribution of krill biomass expressed as volume backscattering (dB m^{-3}) at 120 kHz, and gadoid fish abundance at 38 kHz. Øksfjorden, 7–8 February 1980

were distributed at this time well below the krill SSL, with only a small overlap between krill and fish. At dawn, at 06.00 hrs, the krill SSL began to descend resulting in an increasing overlap between krill and gadoids. During the hours of daylight, from 10.00 – 15.00 hrs, the krill SSL was found from ca. 100 m to the bottom of the fjord. At this time the krill SSLs were dense as seen from the 120 kHz echograms, and pelagic trawl catches in the SSLs produced catches of 400–700 l h^{-1}. Comparison of 120 kHz and 38 kHz echograms revealed that gadoids were found nearly exclusively within the krill SSLs. It should be noted that the abundance of fish registrated at this time of the day was noticeably lower than at night, suggesting that fish either were extremely closely associated with the fjord bottom or else that they had moved out of this area of the fjord.

Around dusk (15.00 hrs) the krill SSL began to ascend towards the surface arriving at a similar depth destribution to that found during the previous night. The density of krill found in the pelagic trawl catches was again relatively low at this time. Fish and krill were again separated in the vertical plane.

Volume backscattering : Biomass relationship

Volume backscattering (dB m^{-3}) has been plotted against corresponding catches of krill caught by the pelagic trawl (l · trawl h^{-1}) at depths where fish were absent (Fig. 3). The relationship is significant for $p = < 0.01$ ($r^2 = 0.72$, D.F. = 49), and the regression equation is:

$$Y = 9.05 \cdot 10^{15} \cdot X^{-14.55}$$

where $Y = \mathrm{l} \cdot \mathrm{trawl}\ h^{-1}$ and $X = \mathrm{dB}\ m^{-3}$.

Splitting the data up for different times of the day reveals that there was a tendency for high values to be recorded during the day, whilst there were relatively few differences between data collected at night, morning and dusk.

Diel changes in biomass in krill SSLs

Diel changes in the depth distribution and biomass of krill SSLs expressed as volume backscattering can be deciphered by comparing Figs. 2 and 4. Where the depth distribution of krill SSLs and fish are separate it is reasonable to consider that echointegrator values corresponding to the depth distribution of the SSL are a result of variations in krill population density/biomass alone. It is also reasonable to assume that echointegrator values from depths where fish are present and krill are absent are a result of resonance from fish alone. Areas of krill-fish overlap provide echointegrator values from both these populations. Echointegrator values for depths of > 200 m have not been included due to lack of reliable quantitative data.

At night (20.00 – 05.00 hrs) fish-free krill SSLs were visible from the surface to 120 m. The highest biomass was found from 30–70 m (–75 to –78 dB m^{-3}), with values decreasing down to 100 m. During the dawn descent very low values (–90 dB m^{-3}) were recorded above 70 m while the highest biomass (–75 m^{-3}) was recorded from 120–150 m. By daytime (09.00 – 15.00 hrs) the bulk of the krill were found from 150–200 m. At this time values of up to –65 dB m^{-3} were recorded (Fig. 4). Information from the 120 kHz echograms (Fig. 2) indicated that the krill SSLs at about noon occupied the deepest layers of the water column, coming into direct contact with the fjord bottom. At dusk a rapid change in the depth distribution of the krill occurred, with the bulk of the krill ascending from a depth of 150–200 m (–75 dB m^{-3}) at 14.45 hrs to a depth of 50–70 m (–75 dB m^{-3}) at 16.00 hrs; a transport of the main biomass over more than 100 m in 1 hr

15 min. During late evening (20.00 hrs) the main biomass appeared to approach the surface (–74 dB m^{-3}) from 10–30 m before becoming more evenly spread over the upper 130 m (–77 to –78 dB m^{-3}) at about midnight.

Feeding habits of gadoid fishes

The stomach contents of the 31 gadoid fish (mainly cod, *Gadus morhua* Linneus) caught in 58 tows with the pelagic trawl in the SSLs are presented in Table 1. The low number of fish caught in the SSLs clearly supports the data from the EK 38A echosounder that fish are rare in dense krill shoals.

Table 1

Stomach contents of gadoids caught in Sound Scattering Layers in Ullsfjorden and Øksfjorden, 2 – 8 February 1979. Number of of hauls = 51, n = number of fish caught and analysed, F = degree of stomach fullness, $\bar{f}$ = degree of fullness (%) of the different food items.

			$\bar{f}$			
Length	n	F	Euphausiids	Fish	Amphipods	Other taxa
10– 19	2	90	100			
50– 59	6	89	94		6	
60– 69	12	73	85	9	6	1
70– 79	7	56	86	6	6	1
80– 89	1	75	77		20	1
90– 99	2	33	97	2		
100–109	1	100	99		1	

Although relatively few fish were available for analyses a number of trends are apparent. The degree of fullness of the stomachs was high (on average 70 %), and euphausiids dominated (77–100 %) the stomach contents for all length groups of gadoid. Smaller fish (e.g. capelin, *Mallotus villosus* Müller) played a minor rôle in the stomachs examined.

Discussion

Combined use of acoustics and net sampling in north Norwegian fjords have demonstrated that 120 kHz SSLs are due to zooplankton, chiefly krill (HOPKINS et al. 1978, EVANS and HOPKINS, 1981). Scattering at ca. 100–120 kHz is often associated with krill (KINZER 1971, SAMEOTO 1976, GREENLAW 1979, PIEPER 1979) and echosounders of ca. 38 kHz frequency are well suited for registering and assessing fish stocks (MIDTTUN and NAKKEN 1971). In this paper the simultaneous use of a echosounder and a 120 kHz echosounder coupled with a digital echointegrator have shown that promising possibilities exist for studying krill SSLs and krill-fish interactions using this type of equipment. The examination of krill shoals based on catch data and volume backscattering indicate that acoustic data can be used for the prediction of krill biomass. The high values of krill biomass : volume backscattering found during the day (09.00 – 15.00 hrs) in the present study were easily distinguishable from those at other times. At mid-day the fjord bottom acted as a constraint to further descent of the SSLs, resulting in especially high concentrations of krill. Non-migrating krill are also likely to have a high target strength compared with migrating krill owing to their more perpendicular orientation relative to the sound beam (GREENLAW 1977, KILS 1979a, 1979b). Surface and near-bottom SSLs provided the highest catches per unit effort. The present investigation indicates that the echointegrator may be used both to provide data about krill depth distribution and diel migration patterns. Obviously use of nets which sample krill quantitatively will provide more certain estimates for accoustic predictions of krill biomass.

The present work agrees well with previous studies in north Norwegian fjords (HOPKINS and GULLIKSEN 1978, HOPKINS and EVANS 1979, EVANS and HOPKINS, 1981) which show that krill undergo diel vertical migrations from close to the bottom at mid-day to the surface at night. The proximate stimulus for vertical migration in most zooplankters appears to be the level for ambient light (LONGHURST 1976). The light regime in northern Norway in early February had not yet fully returned to an equal day-night situation after the winter darkness, resulting in a late dawn and early dusk. The krill SSLs examined in this study also appeared to be vertically migrating in response to changes in ambient light as seen by corressponding late descents (ca. 06.00 hrs) and early ascents (ca. 16.00 hrs).

The diel depth distribution of gadoid fish as calculated from an acoustic index of abundance indicates that they are chiefly distributed below the krill SSLs with little overlap between them at night. However, during the day the descent of the krill SSLs towards the fjord bottom is associated with a corresponding descent of the gadoid population. This appears to indicate that there is a negative association between gadoids and dense krill shoals. Nevertheless, stomach analyses of gadoids caught in the SSLs by the large pelagic trawl show that krill account for more than 70 % of the food. Studies of the feeding habits of cod in north Norwegian fjords show that capelin (*Mallotus villosus*), deep-sea prawn (*Pandalus borealis* Kröyer), and krill (*Thysanoessa raschii* M. Sars, *Thysanoessa inermis* Kröyer, and *Meganyctiphanes norvegica* M. Sars) are the principal food items, with krill being increasingly important in smaller cod and pelgically caught cod (WIBORG 1949; PEARCY et al. 1979; FALK-PETERSEN and HOPKINS 1980; KLEMETSEN 1981). Cod often leave the proximity of the bottom for extended periods of time (TEMPELMAN and FLEMING 1962) and may perform daily vertical migrations from the bottom into midwater being attracted by the swarming of pelagic prey (BRUNEL 1965, 1972). Cod are thus able to feed pelagically as well as demersally.

It is known that the formation of shoals by marine animals can protect the individuals by causing predators to delay their attacks by distracting them to different targets (see RADAKOV 1966, NEILL and CULLEN 1974). The production of light by the photophores of krill may play an active part in this process (see MAUCHLINE and FISHER 1969). Even though shoaling in marine animals can be a protection mechanism it is evident that predators may be able to obtain sufficient food by selective predation (NEILL and CULLEN 1974). Cod in north Norwegian fjords probably obtain enough food from krill SSLs by feeding intensively at their periphery. In addition the distribution of cod under the dense krill shoals would present them with a choice between pelagic and demersal feeding. There is still, however, a lack of information about the food of fish feeding at the periphery of krill shoals. The interaction of diurnally migrating SSLs with demersal and mid-water fishes is probably an important mechanism for the transfer of energy in shallow water marine food webs (ISAACS and SCHWARTZLOSE 1965, HOPKINS et al. 1978).

Acknowledgements

We thank the captain, Instrument Chief Fritz Pettersen, and crew of RV "Johan Ruud", Computer Engineer Ivan Ahlquist and Senior Technician Jan Evjen for their help at sea. We also acknowledge the assistance of technicians Sigrun Espelid, Astrid Hermannsen and Helen Mowinckel ashore.

This work was supported, in part, by the Norwegian Fisheries Research Council, Project No. I.401.09.

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