Fishery and utilisation of mesopelagic fishes and krill in the North Atlantic

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Content

Preface

Mesopelagic fish and krill are widely distributed in the ocean and are two of the largest marine resources still under-exploited. In the North Atlantic there is presently no fishing on these resources. With the growing aquaculture industry there is an increasing demand for fish protein and fish oil for this industry. The objectives of the project are to explore the present knowledge about these fish in the North Atlantic, and to coordinate further investigations on these resources. Iceland has in the last few years collected information on mesopelagic fish in the Irminger Sea during their investigations on redfish and have also done some exploratory fishing trials. In Faroese waters Russian trawlers fishing for blue whiting have occasionally reported significant by-catches of mesopelagic fish, and the Faroese Fisheries Laboratory and the Marine Research Institute in Iceland have done some exploratory fishing, but so far without any success. In Norway research into the use of krill as a source for fishmeal and fish oil as feed for aquaculture has been initiated. Recently investigations on the possibility to use mesopelagic species in addition to krill have been initiated, and the present project could enhance such a development. There is a general lack of information on the biology, distribution and biomass of these species in the Northeast Atlantic, and a further complication is the limited possibilities to representatively sample such species with existing fishing gears.

The main objective in this project was to explore the possibilities of commercial exploitation and utilisation of mesopelagic fish and krill, two groups of species that presently are not utilised commercially.

The work has been done under three work packages or subtasks; (Subtask 1) to find and collect historic data and literature on mesopelagic fish and krill in the North Atlantic; (Subtask 2) to study fishing gear and fishing technology, and (Subtask 3) to establish special awareness on the mesopelagic fish during future pelagic surveys.

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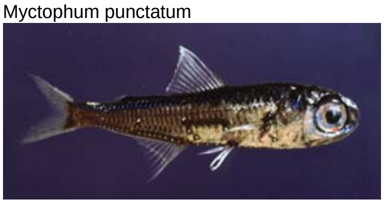
A list of the most common lanternfishes in the North Atlantic is shown below (Table 1).

Table 1 List of the most common lanternfish species in the North Atlantic.

Latin	English	Faroese	Icelandic	Norwegian	Danish
Family name: Myctophidae	Lanternfish	Prikkafiskur	Laxsíld	Prikkfisk	Prikfisk
Benthosema glaciale 	Glacier lanternfish	Lítli prikkafiskur	Ísalaxsíld	Nordlig prikkfisk	Isprikfisk
Myctophum punctatum 	Spotted Lanternfish	Stóri prikkaf-iskur	Punkta laxsíld	Liten prikkfisk	Slankhalet prikfisk
Notoscopelus kroeyerii 	Lancet fish or Kroyer's lanternfish	Mjáiprikkafiskur	Langa laxsíld	Stor lysprikkfisk	Krøyers prikfisk
Lampanyctus macdonaldi 	Rakery beaconlamp	MacDonalds prikkafiskur	Brúna laxsíld	Brun lysprikkfisk	Macdonalds prikfisk
Lampanyctus crocodillus 	Jewel lanternfish	-	Fenris-laxsíld	-	Krokodille-prikfisk
Lampadena speculigera 	Mirror lanternfish	-	Gljálaxsíld	-	Spejlhalet prikfisk
Arctozenus risso* 	White barracudina	Lítla lakstobis	Litla geirsíli	Liten lakstobis	Rissos lakstobis
Maurolicus muelleri* 	Pearlsides	Lakssild	Norræna gulldepla	Laksesild	Laksesild

*are not lanternfish but common mesopelagic fish.

Summary 1

The objectives of this project were to;

- (Subtask 1) find and collect historic data and literature on mesopelagic fish and krill in the North Atlantic. Both published and unpublished material, with special emphasis to include important Russian literature to be translated to English;
- (Subtask 2) to study fishing gear and technology with the aim to develop and test fishing gears and fishing techniques, suitable to catch mesopelagic fish and krill in commercially acceptable catch rates; and
- (Subtask 3) to establish special awareness of mesopelagic fish through additional sampling during present and future pelagic research surveys.

Work packages (subtasks)

Subtask 1: The most common mesopelagic species on both side of the North Atlantic were *Benthosema. glaciale* and *Notoscopelus kroeyerii*. The historic literature was in general about the biology and seldom on availability and abundance. The myctophids were mentioned in various references as predator on calanus or krill and as prey for marine mammals, sea birds, salmon and saithe. The articles on acoustic investigation of mesopelagic fish were mainly focused on sound-scattering layers of mesopelagic fish assemblage, and a few of the references focused on target strength measurements (acoustic backscattering from the fish) on species that inhabit other areas than the North Atlantic. There is a lack in the historic literature on fishing gear technology and on potential fishing grounds. The majority of the historic material on krill was from the southern oceans. Russia has been conducting research on mesopelagic fish and krill for decades. Twelve Russian key references on mesopelagic fishes and krill were translated to English as part of the project. A review of this translated material is presented in the report.

Subtask 2: A pelagic research trawl for blue whiting that was modified with smaller meshes in the aft part of the trawl to retain mesopelagic fish was used in the project. Additional some tests were conducted with at trawl designed for commercial krill capture during the project. A small-meshed collecting bag was attached on the outside of the top-belly to study where in the trawl belly various organisms are escaping through meshes, as a background to optimise the trawl design for capture of

mesopelagic species and krill. Observation of fish behaviour with underwater cameras inside the trawl belly was used to learn more of such behaviour. Based on these experiments and observations supported by previous experience, it was concluded that krill is escaping through meshes larger than 15-20 mm, indicating a catching area that correspond to the entrance area of bags with less than 20 mm mesh size. Mesopelagic fish, however, are to some extent herded by larger meshes, and therefore the catching area is larger than the entrance area of the codend but smaller than the entrance area of a large mesh trawl. For the purpose of density estimation of mesopelagic fish the entrance area where defined as the cross-section of the belly in front of 40mm belly meshes. Based on these assumptions the experimental fishing identified densities of mesopelagic fish and krill less than 1 g/m3 during the trial period, which is in agreement with knowledge in the existing literature on the subject. Such densities are considered too low for commercial fishing of these resources.

The collecting bags also provided useful information about escape of blue whiting and herring through the aft trawl belly.

Subtask 3: We consider that the aim to establish special awareness on the mesopelagic fish during existing and future pelagic surveys has been met, as far as we can expect to interfere with existing survey plans. Today the survey plans for pelagic surveys in the various institutes in the Northeast Atlantic include a procedure to sample all species caught during a survey. This is considered good survey practice.

1. Historic data and literature

1.1 Collection of published and unpublished material on mesopelagic fish and krill (subtask 1)

This subtask was to find and collect historic data and literature on mesopelagic fish and krill in the North Atlantic. Both published and unpublished material on the biological aspects and on capture methods of the most abundant species of mesopelagic fish and krill with special emphasis to include important Russian literature to be translated to English.

A complete search in ScienceDirect, selected databases available on the Internet and Google-search has been performed continuously since the start of this project until December 2005. There was no limitation in the initial screenings. The search terms used for Mesopelagic fish were: “Myctophid*” or “Mesopelagic fish” or “lanternfish”. Once imported to our database, additional keywords were added while screening the citations. The keywords were taken from the title, abstract, and sometimes from the article text when we read the article. The main groups were as follows: Ocean (e.g. North Atlantic, Northeast, Northwest), area (e.g. Norway, Iceland, Grandbank), common name (glacier lanternfish), species (e.g. *Benthosema glaciale*), family (Myctophidae), taxa (myctophid), level (e.g. predator, prey), subject (e.g. gear, acoustic, growth, age), gear (e.g. WP2 plankton net, pelagic trawl).

The dissemination of reports and presentations from present study, as well as a list of project meetings and surveys under the present project is listed in Appendix 1.

Russia has been conducting research on mesopelagic fish and krill for decades and a selection of 12 Russian key references on mesopelagic fishes and krill were translated into English as part of the project. The Russian references are given in Appendix 2 and can be obtained by e-mail upon request.

The literature search of Euphausiids or krill, with the most common species being *Meganyctiphanes norvegica*, *Thysanoessa inermis*, and *T. longicaudata*, has been carried out by colleagues at the Institute of Marine Research (IMR), the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), the Faroese Fishery laboratory (FFL), and the Marine Research Institute (MRI).

A review of the available historic material along with the 12 translated Russian references is presented below.

1.2 A review of historical literature on mesopelagic fish in the North Atlantic.

Mesopelagic fish are an important component of the oceanic mesopelagic ecosystem in the North Atlantic (Backus et al 1977; Nafpaktitis et al 1977; Gjøsæter and Kawaguchi 1980). The combined biomass is believed to be very high, but has only been evaluated roughly (Gjøsæter and Kawaguchi 1980). Abundant mesopelagic fish families are e.g.: Myctophidae, Gonostomitidae, Bathylagidae and Stomiidae (Kawaguchi and Mauchline 1987; Magnusson 1996). For predicting aggregations and fisheries potential of mesopelagic fish it is essential to understand their ecology, e.g. life history, distribution, foraging and behaviour. The most abundant mesopelagic fish are generally zooplankton consumers (Gjøsæter and Kawaguchi 1980), e.g. Myctophids and hence we give overview of their biology.

The majority of the scientific publications on mesopelagic fish come from biological studies, but both the sampling and data are discrete and often limited. Ecological research on mesopelagic fish has suffered from a lack of the most simple and descriptive information, like abundance, size structure, prey and predators. Most likely the strongest limitation in the mesopelagic research is the high cost of exploring the depths of the open oceans, but recently there have been technical improvements concerning the exploration of the mesopelagic ecosystem, e.g. in acoustical post processing methods, usage of advanced opening-closing trawls and submersibles.

From the literature screenings it looked like there was a lack in literature regarding fishing gear and fishing technology, and on potential fishing grounds. Therefore it was discussed by the group, that there ought to be a co-group of scientists who could discuss the mechanisms of formation of dense concentration of myctophids in the Northeast Atlantic as has been done by Russian scientists in the Northwest Atlantic. Further to analyse the fishing gear technology to catch myctophids, and thus fishery potential, bearing in mind sustainability and ecological impact of such fisheries.

1.2.1 Myctophid biology

Diet composition and abundance estimates show that the more abundant myctophid species like *Benthosema glaciale* and *Notoscopelus kroeyerii*, which are used as examples in this review, are important zooplankton consumers that make a valuable-energy transfer link to predators at higher levels in the food web (Gjøsæter 1973b; Kinzer 1977; Gjøsæter 1981b; Kawaguchi and Mauchline 1987; Sameoto 1988; Sameoto 1989).

Most myctophids undertake diel vertical migration, often for several hundred meters, but it has been shown that not all individuals of any particular, vertically migrating population move up every night. Much less extensive migration has been observed among some deeper-dwelling myctophid species. There are indications of depth stratification at both species and ontogenetic levels. In general juveniles occupy shallower reaches of the depth range of any given species (Nafpaktitis et al 1977).

1.2.2 Distribution

Myctophids have been found in considerable abundances at epi- and mesopelagic depths (0-1000 m) in most areas of the worlds oceans. Due to generally small size of myctophids, surface and midwater currents play important role in their distribution. Hence, small sized species like B. glaciale are highly dependent on those currents for their whole lifespan, meanwhile larger species like *N. kroeyerii* can act as nekton after reaching length of 80-100 mm SL (Filin 1993). As discussed below, there are belived to be more than one populations of B. glaciale in the North Atlantic (Mazhirina 1992).

There are evidence of two independent populations of *N. kroeyerii* in the Northwestern- and Northeastern Atlantic. The distribution area of the western population is limited by closed circulation of the North Atlantic, Irminger and Labrador currents, while reproduction area is to the southeast of Newfoundland. The distribution area of the eastern population is formed by the waters of southern branch of the North Atlantic current and countercurrent in intermediate layers of the eastern part of the subtropical circulation. The reproduction of this population occurs to the west of Ireland. The gillrakers on the first gill arch are the most pronounced morphometric characteristics between *N. kroeyerii* from the Northeast- and Northwest Atlantic being higher in the Northwest Atlantic (Filin 1989).

1.3 Growth

Growth rate, maximum age and maximum length vary between Myctophid species. *N. kroeyerii*, for example, has been found to have higher growth rate than *B. glaciale* (Gjøsæter 1981b). Length distributions usually show only the first one or two year classes roughly (Gjøsæter 1981b; Gjøsæter and Kawaguchi and Mauchline 1982), possibly because the extended spawning season serves to merge later modes. Annual and seasonal changes in growth rate have been observed, e.g. B. glaciale in the Rockall Trough. In that area *B. glaciale* has had variable growth rate between years and also shown seasonal growth variability, growing faster in the summer, most likely due to increased food availability (Kawaguchi and Mauchline 1982).

The lifespan of *N. kroeyerii* in the Northeast Atlantic is 6 years and in the Northwest Atlantic it is 8-9 years. Fish grow most intensively in the first 3 years, especially in April-July. The growth rate of *N. kroeyerii* in the Northeast Atlantic is higher than in the Northwest Atlantic (Filin 1993).

Reproduction

Benthosema glaciale becomes mature at size of 30-48 mm and usually at age of 2-3 years (Halliday 1970; Kawaguchi and Mauchline 1982; Mazhirina 1992). Fecundity has been found to increase with size (Gjøsæter 1981a; Kawaguchi and Mauchline 1982), but estimated number of produced eggs varies greatly between studies, e.g. (Kawaguchi and Mauchline 1982). Kawaguchi and Mauchline (1982) estimated that females produced 133-624 eggs while Mazhirina (1992). estimated 7.5 to 18 thousand eggs. The spawning period of *B. glaciale* varies according to area and environment, and progressions of spawning peaks within spawning populations have been observed (Halliday 1970; Kawaguchi and Mauchline 1982; Karaseva et al 1986; Acevedo and Fives 1992; Mazhirina 1992). B. glaciale has been found spawning from January to July, depending on area, where the period of spawning at each study area usually expands 2-4 months observed (Halliday 1970; Gjøsæter 1973a; Gjøsæter 1981a; Kawaguchi and Mauchine, 1982; Mazhirina 1992; Acevedo and Fives 2001). Differences in maturation rates and spawning terms suppose existence of at least two independent populations in the North Atlantic (Mazhirina 1992).

N. kroeyerii become mature at age of 3-4 years. Males are mature at length of 85 mm and females become mature at length of 90 mm. *N. kroeyerii* spawn in portions and has a polycyclic type of reproduction system. Spawning period lasts from January to April. Fecundity depends on length, age and weight of fish and has been estimated to average of about 20 000 eggs (Filin, 1993).

For all species non-spawning (expatriated) population parts are commonly observed outside their habitat (Gjøsæter 1981a; Kawaguchi and Mauchine 1982; Mazhirina 1992). This is usually explained by drift from the species habitat area emphasising the importance of surface and midwater current gyres in maintaining those high-oceanic spawning stocks.

Feeding

Copepods are the most important prey for all myctophid species, at least for younger age groups, although euphausiids, amphipods and other larger organisms also become important for larger individuals (Gjøsæter 1973b; Kinzer 1977; Sameoto 1988; Sameoto 1989; Filin 1993). Some studies have shown distinct diurnal feeding cycles, mainly supporting increased nocturnal feeding activity (Kinzer 1977; Gjøsæter 1981b; Sameoto 1988; Sameoto 1989), but others have not (Paxton 1967; Kinzer 1977).

In general there seems to be opportunistic prey selectivity (Gjøsæter 1973b; Kinzer 1977; Gjøsæter 1981b; Kawaguchi and Mauchine 1982; Sameoto 1988). Hence the mesopelagic environment appears to favour the zooplankton-eating fish that grabs the next suitably sized prey item that comes in sight. But this assumption must be taken with care, because most of the published investigations on the feeding of these species are lacking the necessary data resolution for applicable selectivity inspection. In addition to the basic variables like individual count of prey in the diet and abundance in the environment, several other factors must be thoroughly investigated to obtain usable data for selectivity studies, e.g. identification of prey developmental stages, sex, prey/predator distribution (in space and time) and morphology. For example, identification of developmental stages in the zooplanktic prey is essential because there can be strong selectivity for certain developmental stage that might not be evident when combining all stages (Sameoto 1989). There are examples of seasonal foraging changes e.g. *B. glaciale* in Norwegian waters feeds mainly on copepods in summer but during winter euphausiids become an important part of the diet (Gjøsæter 1973b). This variation may be due to prey availability e.g. the dominant copepod in the Norwegian Sea, *Calanus finmarchicus*, is overwintering in the deep from early winter until early spring (Melle. et al., 2004).

Predators

The zooplankton eating mesopelagic fish are e.g. preyed upon by other mesopelagic fish like redfish (*Sebastes mentella*) (Magnusson and Magnusson 1996; Gonzalez et al 2000) and dragonfishes (Family: Stomiidae) (Sutton 2005), but also by larger pelagic fish that forage of the shelf like tuna, swordfish, salmon, saithe and mackerel (e.g. Gjøsæter and Kawaguchi, 1980; Walker and Nichols, 1993; Filin, 1995; Jacobsen and Hansen, 2001; Lamhauge, 2004). As well as by sea mammals like beaked whale, brydes whale, dolphins (Pauly et al., 1998; ICES, 2005a), and seabirds like puffins, terns, and fulmar (Granadeiro et al., 2002; Pedrocchi et al. 2002; Piatt and Kitaysky, 2002). North of the Faroe Islands young specimens of *B. glaciale* occupying the epipelagic layer are common prey of puffin and fulmar (Falk et al., 1992; Danielsen, 2006 personal communication) which is in consistent with seabirds prey elsewhere when away from breeding areas.

Ecologists have argued that predators should prefer prey that yield more energy per unit handling time (Pinnegar et al., 2003). The proximate lipid concentration and energy density of lanternfish, when the wax esters was excluded, has been analyzed to be twice as high per gram wet weight compared to e.g. mature capelin and even more for some other forage fishes (Van Pelt et al 1997). Therefore it might be expected that larger pelagic predators that forage off the shelf would exhibit a greater preference for lanternfish when available.

Biomass estimates

The total global biomass of mesopelagic fish was in the 1970’s estimated by FAO to be one billion tons (Gjøsæter and Kawaguchi 1980). Biomass estimation has also been performed by Russian and Norwegian scientists (Gjøsæter and Kawaguchi 1980). Those estimates were largely based on acoustic measurements, although there is very limited knowledge on target strength (TS) for the various mesopelagic fish species (Table 2).

Various acoustic estimations give huge biomass estimates for mesopelagic fish, but the literature studies show a catch rate in the North Atlantic that is far from being economical for commercial fisheries. The concentrations are in general less than 1g/m3 seawater (Gjøsæter and Kawaguchi 1980; Poletaev et al 1991; Lamhauge et al 2005) when it is estimated that the biomass concentration should be at minimum of 25g/m3 seawater (Valdemarsen 2004 personal communication). Still, it should be kept in mind that scientific studies are scattered and usually are aimed to give estimates of average biomass for large areas while fisheries trials have had limited spatial and temporal coverage and with limited knowledge on how to find and catch mesopelagic fish.

Numerous research cruises have been done by the USSR (Sevrybpromrazvedka, Sevtechcenter, AtlantNIRO, VNIRO and PINRO) from 1982 to 1989 (Poletaev et al 1991; Filin 2004 personal communication) and they found no evidence for concentrations of mesopelagic fish that are dense enough for fisheries in certain season or areas. Those studies suggested the eastern slopes of the Grand Bank, outside 200nm fisheries zone of Canada (Fig. 1), as the most attractive area for fisheries, with autumn as the optimal fishing period (Filin, 1990; Poletaev et al 1991).

Table 2 Estimates of TS (Target Strength) of mesopelagic fish; based on TS = (20 log L + b).

Species	Loca-tion	Depth (m)	Weight (g)	Meanlength (cm)	Range (standard length)	Swim blad-der	TS (dB)	b (dB)	Method	Ref
Benthosema glaciale	1	10 - 60		5.4			-58		1	1
Notoscopelus japanicus	2				12.6-13.3			-86.7	2	2
Symbolophorus califrniensis	2				8.5-10.8			-85.7	2	2
Diaphus theta	2				2.7-7.7			-69.4	2	2
Benthosema fibulatum (mostly)	3			5.1	2.4-8.2			-58.8	3	3
mesopelagic fish	4	0 - 100	< 3			yes	-53(-58)		4	4
mesopelagic fish	4	0 - 100	3 - 10			yes	-49		4	4
mesopelagic fish	4	0 - 100	> 10			yes	-42		4	4
mesopelagic fish	4	0 - 100				no	-73		4	4
mesopelagic fish	4	100 - 300	< 3			yes	-53(-58)		4	4
mesopelagic fish	4	100 - 300	3 - 10			yes	-49(-51)		4	4
mesopelagic fish	4	100 - 300	> 10			yes	-42		4	4
mesopelagic fish	4	100 - 300				no	-71		4	4
mesopelagic fish	4	300 - 525	< 3			yes	-52(-56)		4	4
mesopelagic fish	4	300 - 525	3 - 10			yes	-49		4	4
mesopelagic fish	4	300 - 525	> 10			yes	-42		4	4
mesopelagic fish	4	300 - 525				no	-62		4	4
mesopelagic fish	4	525 - 900	< 3			yes	-53		4	4
mesopelagic fish	4	525 - 900	3 - 10			yes	-49		4	4
mesopelagic fish	4	525 - 900	> 10			yes	-41		4	4
mesopelagic fish	4	525 - 900				no	-63		4	4

Location: 1) Norway; 2) Japan; 3) Hawaii; 4) Australia

Method: 1 in situ (individual tracks) EK 500 split-beam 38kHz; 2 Modelling from swimbladder and morphology, 38 kHz; 3 Captive fish (ex situ), 200 kHz; 4 in situ EK500 split-beam hull-mounted, and in situ EK500 split-beam deep towed, 38 kHz

Ref. 1 Torgersen and Kaartvedt 2001; 2 Yasuma et al. 2003; 3 Benoit-Bird and Au 2001; 4 Koslow et al. 1997.

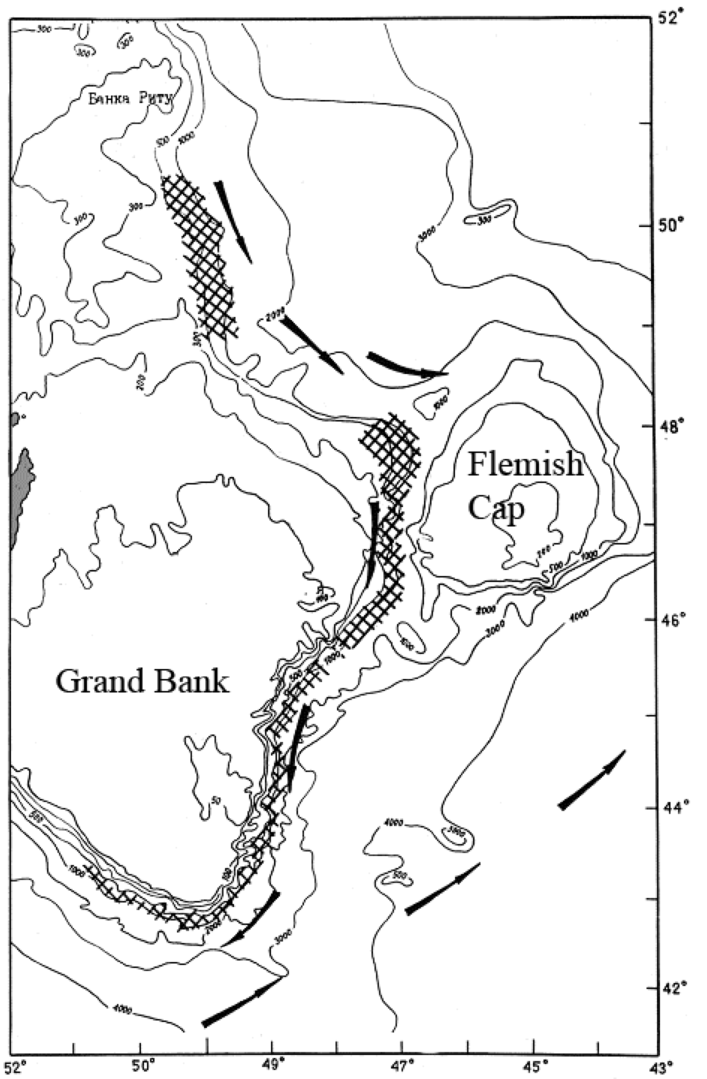


Figure 1. Location of most dense concentration of myctophids and map of currents in the Northwest Atlantic (Filin 1990).

2. Fishing gear and technology

2.1 Fishing gear and technology (Subtask 2)

This subtask was to study fishing gear and technology with the aim to develop and test fishing gears and fishing techniques, suitable to catch mesopelagic fish and krill in commercially acceptable catch rates. The initiating literature search revealed only a few published fishing gear studies for catching mesopelagic fish. The studies that have been made are done in Oman by Norwegian scientists (Gjøsæter and Myrseth 1979; Aglen et al 1981; Gjøsæter and Tilseth 1983), in the Northwest Atlantic by Russians and Norwegians and in the Northeast Atlantic by Gjøsæter and Kawaguchi (1980), Poletaev et al (1991), in this study (Lamhauge et al., 2005) and another fishing trial in Faroese waters in 2002 (Thomsen, 2002).

The main outcome, from the research in Oman, was that the optimum mesh size of the codend was recommended to be 9 mm and the recommended towing speed should be 2.5 kn (2.2-2.8 kn), which is approximately the same outcome as the research that has been done in the North Atlantic.

In the present project, a research survey with the Faroese R/V Magnus Heinason was made to estimate occurrence of exploitable densities of krill and mesopelagic fish in Faroese zone in spring 2005, to study the escape behaviour of mesopelagic species, and to evaluate various designs of survey trawls.

Materials and methods

As shown on the map in Fig. 2, the experiments were conducted in two periods south and north of the Faroe Island, respectively. During the first cruise (30/3-13/4) most of the gear experiments were conducted, whereas the last period (4/5 – 18/5 -2005) focused on testing the collecting bag attached to the 400 mm meshes of the upper belly panel. The weather condition during the first period was characterized with mostly very strong winds, and the experimental fishing was therefore limited to a few hauls. Most of the effort was devoted to searching for fishable concentrations of what was believed to be mesopelagic fish. When “suitable” concentrations of mesopelagic fish and krill were located in a layer by the echo sounder, a trawl haul was taken. The position of the collecting bag and the video camera is shown in Fig. 3.

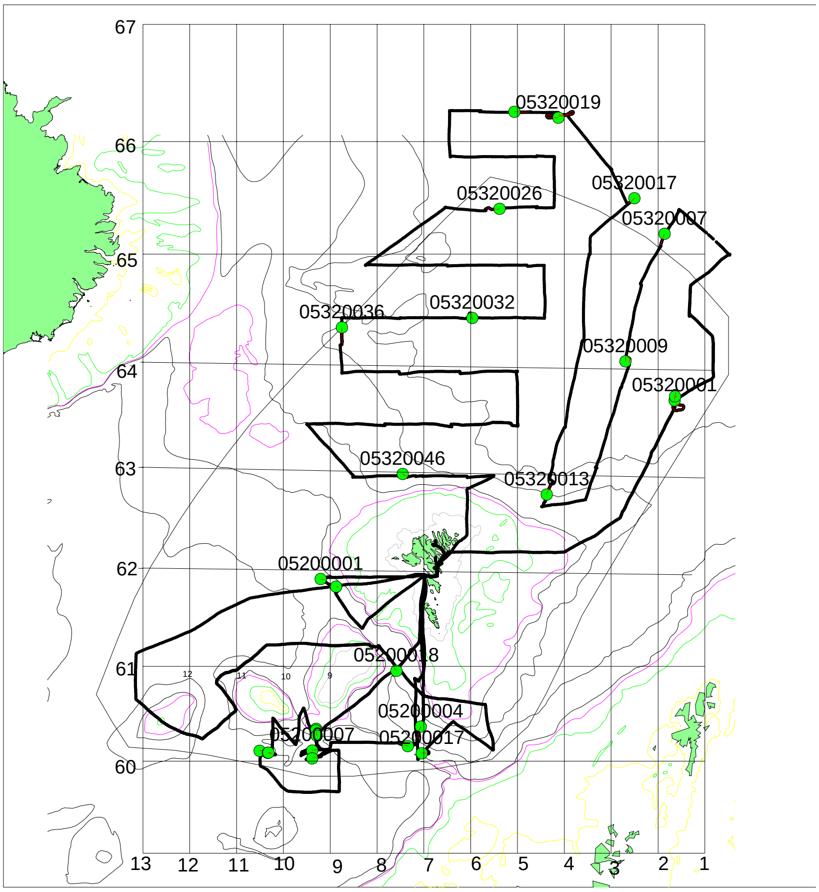


Figure 2. Cruise tracks while observing acoustic backscattering. The area south of 62° was the first part of the cruise (30/3 – 13/4 – 2005), and the area north of 62° was during the last part of the cruise (4/5 – 18/5 -2005). The biological sampling numbers are shown.

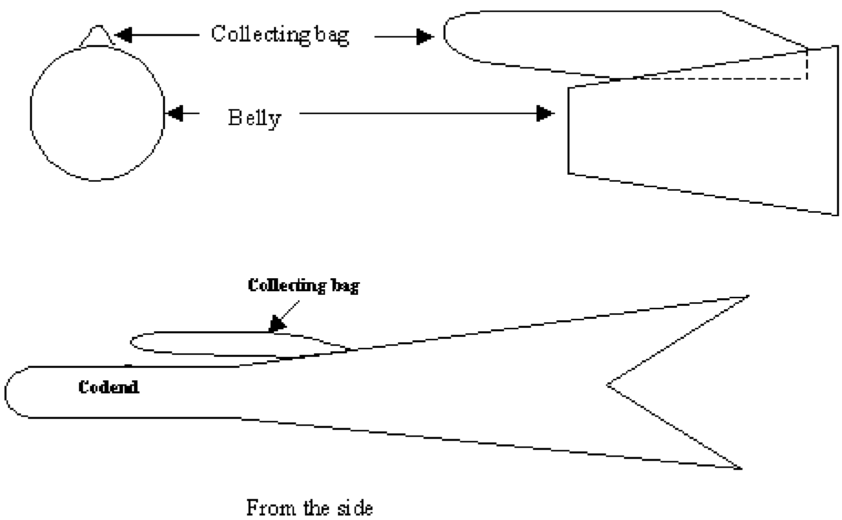


Figure 3. In the right upper corner the single collecting bag is situated on top of the trawl belly, from the side. On the left upper corner a close up of the collecting bag can be seen from the front. In the lower part of the figure, the entire trawl can be seen, with the collecting bag and the placement of the video camera.

Results & Discussion

The density of mesopelagic fish and krill was less than 1 g/m^3 (Table 3) during the trial period, which is considered far too low to make commercial fishing profitable.

The experiments clearly indicated that krill is captured by a filtering process, which means that only mesh sizes below 15-20mm will guide and mesh sizes below 10mm in the collecting bag will retain krill. Small mesopelagic species are neither capable of actively avoiding sloping large mesh belly netting (being herded) to the same extent as larger pelagic fish like Blue whiting and herring. Consequently, large pelagic trawls with large belly meshes are not suitable for mesopelagic fish capture.

Fishing for krill has recently (2004-2005) been successful in the Antarctica by the M/Tr "Atlantic Navigator", who obtained catch rates of krill corresponding to 50 tons of fish meal per day based assumed average densities of 25-50 g/m^3 (wet weight). It is roughly estimated that 25g/m^3 density of krill are required to make exploitation of krill profitable (John Willy Valdemarsen, personal com. cf. Anon., 2005). A trawl with an efficient opening area of 100 m^2 towed with a speed of 2 kn (1 m/s) will catch around 9 tonnes/hour when the average density is 25 g/m^3.

Assuming that mesopelagic fish are capable of some avoidance reaction when stimulated, a density in the order of 5-10 g/m^3 might be sufficient for commercial capture (John Willy Valdemarsen, personal com. cf. Anon, 2005). A trawl with an efficient mouth area of 400 m2 towed with a speed of 2.5 kn (1.25m/s) should be able to catch 9 tonnes/hour on average densities of 5 g/m^3.

The catch density was calculated as D = Q/F*Tl, where:

D = catch density (g/m^3)
Q = Q_o + q
Q_o = amount of catch (g)
q = amount of fish escaped from net (g)
Tl = towing length (m)
F = opening mouth area (m^2)

The towing length (**Tl**) was the actual towing length in meters measured on a MapInfo plot. In the calculation of the opening mouth area (**F**) for the collecting bags, it was anticipated (calculated) that the belly angle was 4.3°, and the covered area was 1.67 m^2 at 200 mm meshes and 1.88 m^2 at 400 mm meshes.

Table 3. Average densities (g/m^3) of large fish (blue whiting and herring), mesopelagic fish (*N. kroeyeri, B. glaciale, M. müelleri, L. intricarius*), and krill (*M. norvegica*).

			Density g/m^3		
Mesh size	**Estimated from**	**Samples**	**Mesopelagic**	**Krill**	**Large fish**
4 mm	Ccollectingbag at 200 mm meshes	3	0.01	0.22	0.19
4 mm	Ccollectingbag at 400 mm meshes	16	0.02	0.06	0.13
8 mm	Codend (krill trawl)	4	0.001	0.14	0
12 mm	Codend	3	0.23	0.53	0.004
40 mm	Codend	16	0.03	0	0.003

Valuable information on composition of fish escapement was gained from the collecting bag mounted on the outside of the upper trawl panel, and they will be used in future blue whiting and herring stock assessment cruises on R/V “Magnus Heinason”.

The catch of blue whiting and in one occasion herring in the collecting bag covering the 400 mm and 200 mm upper panels is a clear indication that the trawl belly is not optimal for catching such fish species. Although the calculation of escapement, on average 10 % through the 200/400 mm belly section, is based on only one collecting bag covering a restricted area on top of the belly, occurrence of blue whiting in most of the hauls is clear indication of frequent escapement. As the catches were rather low in all experimental tows, this loss of fish through belly meshes can not be explained by panic behaviour when fish becomes densely packed in the narrow belly section of the trawl. The assumptions of the fishable area of the Vónin 640 m trawl of 2800 m2 therefore have to be reduced. Density estimates of larger fish (herring and blue whiting) from codend catches should be considered underestimated.

The density estimates of mesopelagic fish based on codend catches in the large Vónin 640 m trawl with a small mesh aft belly and codend are in the order of 10 times higher than that estimated from catches in the collecting bags. A possible explanation is that the herding of the aft belly meshes was better than used in the calculations. Based on this new information 25 m2 fishing area should be used for such species.

The catches of mesopelagic fish in the 40 mm codend were very low in all trials. Such meshes are far too big to retain these species. It is therefore necessary to use collecting bags attached to the trawl belly to get information about presence of these fishes in surveys or commercial fishing with a blue whiting trawl with 40 mm codend mesh size.

The small concentrations of krill and mesopelagic fish in this trial are in agreement with the estimates given by Poletaev et al (1991), one of the articles translated from Russian in this project. In April - June 1984, three investigations according to PINRO research programme were conducted with the vessels MG-1341 “Lensk”, MG-1362 “Vilnus” and MB-2645 “Suloy” The investigations were carried out in the international waters of the Northeast Atlantic along the economic zones of Iceland, UK and Ireland. No commercially attractive concentrations of lanternfish were found and catches did not exceed 24 kg (Poletaev, et al, 1991).

Icelandic investigations

During surveys conducted by the MRI in recent years, it has been a part of a routine to measure and count all species. Results obtained during pelagic redfish cruises in the Irminger Sea and adjacent waters during the period 1996-2001 have been reported (Sigurdsson et al, 2002). For mesopelagic fishes, the aim during these cruises, was to identify and measure species, to map the distribution of the deep scattering layer (DSL), and to map the distribution pattern of selected species within the DSL. Based on the analysis of the data a total of 99 fish species was identified, from 43 families, and 4 families accounted for 35% of the species. The most common families were Myctophidae, 11 species - 90% of stations, 44% of total number caught, Bathylagidae 3 sp., 86% of stations, 21% of the number caught, and Stomidae 9 sp. 94% of stations, 13% of number caught. There was an underestimation of smallest fish due to large mesh size in the cod-end (40 mm). The Myctophidae Protomyctophum arcticum was common in "small mesh size" trawl in the northern part of the investigation area (Magnússon, 1996) - only identified from one tow during the surveys from 1996-2001.

In summary there was continuous distribution throughout the survey area (between 22°W and 48°W and 54°N-65°N) (Fig. 4). In all trawl hauls, the abundance of mesopelagic fishes was low, usually lower than 10 k/h.

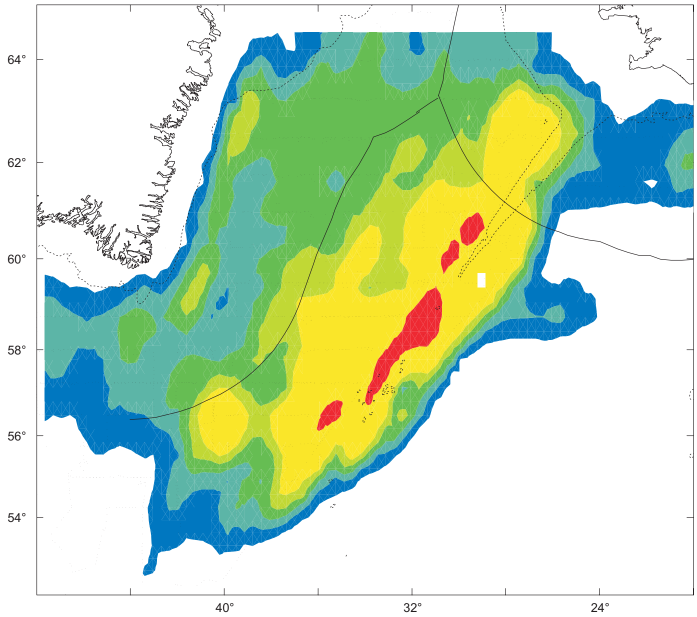


Figure 4. Relative density of the Deep scattering layer in June/July 2001. Blue is the lowest density as the red colour denotes the highest density (From Sigurdsson et al, 2002).

In 2003, experiments were performed using the research vessel Arni Fridriksson. The net used was a Gloria type trawl with modified cod-end with 9 mm mesh size. The main objectives was to examine the organization and tropic structure of the pelagic ecosystem over the Reykjanes Ridge from phytoplankton to fish as apex predators. Target groups were copepods, euphausiids, chaetognaths and fish. During that survey, a Gloria type pelagic trawl #1024, was used with 9mm codend. More than 70 species were caught in the trawl during the experiment, but the catches were only few kilos in all the hauls. The 6 most common fish species were Benthosema glaciale, Protimyctophum articum, Maurolicus muelleri, Arctozenus rissoi, Bathylagus euryops and Chauliodus sloani.

The average catch in each tow was below 50kg and often below 10kg in 60 min. tows. While trawling shallower than 500m, the average size of the fishes caught were smaller than while trawling at greater depths. There was also a diurnal change in DSL, resulting in variation in the density throughout the day. As a rule, the density was highest during the light hours.

Since 2002, the Federation of Vessel owners, in cooperation with the Marine Research Institute in Reykjavík have conducted several experimental cruises. So far, none of the trials have resulted in commercially exploitable catches. The experiments were performed along the Reykjanes Ridge with commercial vessels, using a Gloria #1280 type trawl. Modifications was made on the belly part and the codend had 9 mm mesh size. In summary there were low catch rate in all hauls, but also low acoustic recordings during the surveys, according to the fishermen. Highest catch rate during these experiments was 3 t/h of *Maurolicus muelleri*. Since the last survey in 2004, there has been work ongoing in developing new trawl in collaboration with Hampidjan Group. During the design of the trawl, experience from this project has been evaluated and used. It is expected to try this trawl onboard r/s Arni Fridriksson in August 2006.

3. Future surveys

3.1 Incorporation of sampling routines for mesopelagic fish in future surveys (Subtask 3)

This subtask was to establish special awareness of mesopelagic fish through additional sampling during present and future pelagic research surveys, by coordinating sampling and investigations of mesopelagic fish and krill in existing surveys as well as to implement such procedures in future surveys.

In this subtask we have tried to modify existing routine surveys on pelagic species in the Northeast Atlantic either directly or indirectly, so they would target all species (including mesopelagic species) and acoustic scattering layers of mesopelagic fish/krill. The direct method was used for the surveys on blue whiting in the area West of the British Isles in 2005 and 2006, while the indirect method, i.e. via spread of information to bodies such as ICES Working Groups, has been used for other surveys, e.g. in the herring and blue whiting surveys in the Northern Seas in 2005 and 2006.

Materials and methods

In order to modify surveys on pelagic species to also include information on mesopelagic species and krill, two options were proposed.

- Plan new dedicated surveys for mesopelagic fish and krill.
- Modify existing surveys as to include sampling of mesopelagic fish and krill.

Results & Discussion

The first option was used by the Faroese Fisheries Laboratory on the dedicated cruise on mesopelagic fish south of the Faroes in late 30/3 – 13/4 2005 (Lamhauge et al., 2005). This was part of the 14 days cruise for blue whiting and mesopelagic fish in co-operation with Norwegian and EU vessels. The second option has been used on the regular cruises for blue whiting, herring and other pelagic species in the areas around the Faroes and in the Norwegian Sea since early 2005.

In the project it was anticipated that the second option would be more feasible, and would yield some results with relatively minor investments and effort. This has been done in the survey included in the ICES “Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys” (PGNAPES, ICES, 2005b), including two major joint surveys, one on the spawning grounds for blue whiting on the Porcupine Bank and west of the British Isles, and the second in the Norwegian Sea aiming at the Norwegian spring spawning herring and blue whiting during their feeding phase in the sea. Results from these surveys are reported to local authorities (survey reports) and in the present report.

We consider that the aim to establish special awareness on the mesopelagic fish during existing and future pelagic surveys has been met, as far as we can expect to interfere with existing survey plans. We anticipate that once implemented, the future survey plans in the various institutes in the Northeast Atlantic will include the procedure to sample all species caught during a survey, this is considered good survey practice. E.g. during the Faroese pelagic surveys all catches are routinely screened for presence of mesopelagic fish and krill, if found, a sample is taken and is recorded in the report from the survey (Jacobsen et al., 2006a, 2006b). In the surveys conducted under the “Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys” (PGNAPES), i.e. blue whiting and Norwegian spring spawning herring surveys in spring and summer in the Northeast Atlantic, this sampling procedure has been duly accepted and is now part of the survey routine (ICES, 2005b).

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Sammendrag

Fangst og utnyttelse av mesopelagisk fisk og krill

Prosjektet er overordnet delt i tre dele:

- Historiske data og litteratur
- Redskaper og teknologi
- Fremtidig toktvirksomhet

Resultater

I del 1) har vi samlet eksisterende viden på det viktigste artene, inkludert fra toktvirksomhet hvor artene er forekommet, og almen biologisk forskning på artene. Videre har vi samlet og gjort tilgjengelig eksisterende litteratur på området. Dette inkluderer også 12 russiske nøkkel studier (artikler), som er blitt oversatt til engelsk som del av prosjektet (Appendix 2).

I del 2) har vi utviklet en finmasket pelagisk trål, som et redskap for fangst av mesopelagiske fisk og krill. Med de relativ små midlene vi hadde til rådighet, valgte vi å modifisere en eksisterende pelagisk trål på Færøyene, ved å lage en ny ”bakre” del av trålen i små masker, helt ned til 12 mm i trålposen. Hensikten var at øke det volum i trålen, som effektivt fisket disse små organismene. En spesialutviklet norsk ”krilltrål” ble også prøvd under et av de to forskningstoktene i prosjektet, men det viste seg at vi ikke fant konsentrasjoner, som var store nokk til å vise effektiviteten av en slik finmasket trål. Konsentrasjoner av mesopelagisk fisk og krill var under 1 g/mm^3 i de forsøkene ble gjort under prosjektet, og dette er flere størrelsesordener for lite til økonomisk drivverdig utnyttelse.

I del 3) har vi forsøkt at koordinere og planlegge survey i nordøstlige Atlanterhav med tanke på at inkorporere undersøkelser av mesopelagisk fisk og kril i eksisterende tokter så vel som på fremtidige tokter, for at identifisere konsentrasjoner av mesopelagisk fisk og krill for mulig kommersiell utnyttelse.

Vi har sett på koplingen mellom mesopelagisk fisk og krill og andre arter høyere oppe i fødekjeden som kan tenkes å beite/spise disse artene. Resultatene tyder på at mesopelagisk fisk er vanlig føde hos laks og sei i åpent hav, mens den meget sjelden er å se som føde for fisk, som lever nær land og på platået. Det er også sannsynlig at noe av mesopelagisk fisk yngre enn 2 år blir spist av sjøfugl ute på havet, spesielt havhest (fulmar).

For det vitenskapelige samfunn er resultatene fra prosjektet nyttige. Det gjelder den store samling av litteratur om emnet i elektronisk format, dvs. som en ”Reference Manager” bibliografi på CD, som også kan importeres i andre typer bibliografi programmer på PC. Denne referanse samling kan brukes som grunnlag for eventuell videre forskning i dette emnet. De elektroniske referansene er sortert, nummerert og delt opp i kategoriene mesopelagisk fisk og krill, samt en rekke emner (redskap, biologi, fangst, osv.), slik at de er lett tilgjengelige fra bibliografi programmene for nærmere studier. Inkludert er også de 12 utvalgte nøkkelreferansene, som er blitt oversatt fra russisk til engelsk (referanselisten og de oversatte referansene kan fåes ved å sende en elektronisk post med forespørsel til: janarge@frs.fo) . I denne rapporten er et ”review” eller oversyn laget over de viktigste artene i Nordøstatlanteren, basert på alle tilgjengelige referanser som grunnlag.

Konklusjoner

Det ble ikke funnet drivverdige forekomster/konsentrasjoner av mesopelagisk fisk eller krill, verken på forskningstoktene eller under gjennomgang av eksisterende og oversatt russisk litteratur. Redskapsforsøkene viser at fangbarhet av småindivider krever småmasket trål, som igjen fører til reduksjon av trålåpning pga. økt drag. Derfor er tettheten av mesopelagisk fisk og krill avgjørende i forhold til aktuell redskap. Konsentrasjoner av disse artene på under 1 g/mm^3 er flere størrelsesordener for lite til økonomisk drivverdig utnyttelse med nåværende teknologi. De omfattende litteratur studiene viser også at fangstraten av mesopelagisk fisk og krill ikke er i nærheten av økonomisk drivbarhet (for industrielt fiske) i Nordatlanteren. Studiene viser heller ikke noen systematiske eller sesongmessige konsentrasjoner, som kunne være aktuelle å fiske på.

Appendix 1

Prepared reports and presentations from the project

Anon. 2004. Workshop on mesopelagic fish. Tórshavn, Faroe Island, 7-8 February 2004, 9 pp.

Anon., 2005a. Report of the “Project meeting on mesopelagic fish and krill”. Nordatlantsbrygge 91, 4sal. Copenhagen, Denmark, 2 - 3 March 2005. 6 pp.

Anon., 2005b. Report of the “Project meeting on mesopelagic fish and krill”. Nordatlantsbrygge 91, 4sal. Copenhagen, Denmark 11 - 14 October 2005, 3 pp.

Anon., 2006. Report of the “Project meeting on mesopelagic fish and krill”. Nordatlantsbrygge 91, 4sal. Copenhagen, Denmark 20 - 21 Marts 2006, 2 pp.

Filin, A. 2004. Experience and some results from research of mesopelagic fishes as fisheries resources by PINRO in the North Atlantic in 1982-1989. Powerpoint presentation, presented at the Workshop at the Faroese Fisheries Laboratory, February 2004.

Lamhauge, S. 2005a. Russian lantern fish by-catch in Faroese water (2000 - 2003). Powerpoint presentation, presented at the Faroese Fisheries Laboratory, 2005.

Lamhauge, S. 2005b. Previous results of analysis of Russian literature on mesopelagic fishes and historic data on Notoscopelus from database of PINRO. Powerpoint presentation, presented at a project meeting in Copenhagen, March 2005.

Lamhauge, S. 2005c. Faroese investigations on by-catch on northern anchovy (lanternfish). Working Document for the 29th Joint Faroese-Russian Fisheries Commission. December 2005, Tórshavn, Faroe Islands. 5 pp.

Lamhauge, S., Valdemarsen, J.V. and Zachariassen, K. 2005. A study of the availability and catchability of mesopelagic fish in the Northeast Atlantic during a research cruise with R/V “Magnus Heinason” 30/3–13/4 and 4/5–18/5 2005. FRS Smárit 05/05, Faroese Fishery Laboratory, 17 pp.

Lamhauge, S. 2006a. Predation of mesopelagic fish in Faroese waters. ICES CM 2006/F:24 (poster).

Lamhauge, S. 2006b. By-catch of saithe in the Faroese and Icelandic blue whiting fishery. Powerpoint presentation to the ICES “Northern Pelagic and blue whiting Working Group” (NPBWWG) in 2006.

Lamhauge, S., Filin, A. and Oganin, I. 2006. Origin of Notoscopelus kroeyeri in the Northeast Atlantic. ICES CM 2006/B:18 (poster).

Sigurðsson, T. 2004. Deep scattering layer - Icelandic research. Powerpoint presentation, presented at the Workshop at the Faroese Fisheries Laboratory, February 2004.

Valdemarsen, J.V. 2004. Oral presentation of “Wilfried Thiele and John Willy Valdemarsen 2004. Efficient capture and handling of myctophids in Oman. FAO.” Presented at the Workshop at the Faroese Fisheries Laboratory, February 2004.

Project meetings

- Workshop at Faroese Fisheries Laboratory in 7-8 February 2004 (preparatory meeting):
- Project meeting Copenhagen 2 – 3 Marts 2005.
- Project meeting Copenhagen 11 – 14 October 2005.
- Final project meeting Copenhagen 20 – 21 Marts 2006.

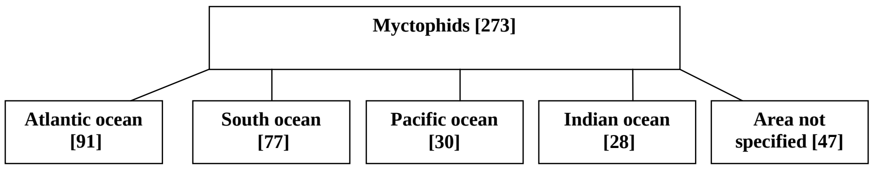
Surveys

- R/V ”Magnus Heinason” 30/3 – 13/4 2005. Blue whiting survey south off the Faroes.
- R/V ”Magnus Heinason” 4/5 – 18/5 – 2005. Norwegian spring spawning herring and blue whiting survey north of the Faroes and in the Norwegian Sea.

Appendix 2

The 12 Russian articles translated into English

A graphic presentation of the screening of the catalogue library of PINRO is shown below:



Literature: Distribution of Russian literary references on mesopelagic fish by research areas from catalogue library of PINRO in September 2005. Number of references in each category is shown in brackets in the heading.

With special emphasis on mesopelagic fish and krill Dr. *Anatoly Filin* selected 12 references to be translated and these are listed below, and the full papers are appended here. The articles were translated by Svetlana Kornilova, Sergey Sennikov, Natasha Kovalenko, and Katya Volkovinskaya.

Upon request it is possible to get the 12 translated articles in electronic format, either as MS Word or Adobe pdf format (please send an e-mail with the request to: janarge@frs.fo).

1. Albikovskay,L.K. 1989. Biological specific features of Bentosema glaciale from Flemish Cap and eastern slopes of the Grand Newfoundland Bank. In Bioresources of meso- and batypelagical zones of open part of the North Atlantic. PINRO, Murmansk p. 141.
2. Drobisheva,S.S. 1985. The role in plankton community, zoogeography, population structure, life cycles and dynamics of abundant species. In Life and conditions of life in the pelagic zone of the Barents Sea. - Apatity. p. 162.
3. Filin,A.A. 1989. Comparative biological characteristic north notoscopelus (Notoscopelus kroeyerii, Myctophidae) from Northeast and Northwest Atlantic. In Bioresources of meso- and bathypelagic zones of the open part of the North Atlantic. PINRO, Murmansk p. 128.
4. Filin,A.A. 1990. On the probable artificial aggregation of small mesopelagic fishes. In Improvement of commercial fishing gears in relation to behavior of hydrobionts. VNIRO, Moscow p. 167.
5. Filin, A. A. 1993. Biology and outlook of fishing of northern notoscopelus (Notoscopelus kroeyerii). Moscow.
6. Filin,A.A., Zhukova,N.G., and Nesterova,V.N. 2004. Euphausiids. In Investigations by PINRO in the Spitsbergen Archipelago area. PINRO, Murmansk p. 82.
7. Gluchov,V.M., Kondratyuk,U.A., and Lisovskiy,S.F. 1990. Some approaches to creation of trawls for fish-

ing of mesopelagic fishes. Express information of CNIITEIRCh 1: 8.

8. Karaseva,E.M. 1986. Peculiarities of distribution larvae and juveniles of lanternfish Bentosema glaciale in the open waters of the North Atlantic. In Life history, distribution and migrations of commercial fish in the Atlantic and Pacific Oceans. AtlantNIRO, Kaliningrad p. 77.
9. Mazhirina,G.P. 1992. Peculiarities of ovaries development of Benthosema glaciale from various areas of North Atlantic. In Researches of bioresources of Noth Atlantic. PINRO, Murmansk p. 203.
10. Poletaev V.A.,Gorchinsky K.V.,Filin A.A.,Chumakov A.K. 1991. Preliminary results of studies on lanternfishes from the Atlantic and South Oceans. In PINRO complex fisheries researches in the North Basin. PINRO, Murmansk p. 118 - 129.
11. Vasilieva,T.E. 1986. On the mechanism of formation of commercial concentrations of mesopelagic fishes in the open waters of ocean. In Oceanologic conditions of the mesopelagial zone of the Global Ocean. VNIRO, Moscow p. 26.
12. Zozulya,S.A., Polonsky,V.E., and Popkov,V.V. 1986. Water circulation and its effect on forming mesopelagic fish concentrations in the Northwest Atlantic. In Hydrographic conditions in the mesopelagial of the World Ocean. Selected papers. All-Union Research Institute of Marine Fisheries and Oceanography (VNIRO), Moscow pp. 49-68.