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DEEP-WATER RESOURCES OF THE NORTHEAST ATLANTIC: DISTRIBUTION, ABUNDANCE AND EXPLOITATION

By

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ABSTRACT

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An account of conventional and potential deep-water fishery resources of the Northeast Atlantic, with emphasis on areas surrounding the Norwegian Sea, is presented. Information on distribution, abundance, exploitation and potential of resources inhabiting continental slopes, deep shelf areas and to a limited extent, deep fjord environments and the meso- and bathypelagic zones is reviewed. The primary objectives have been to produce a better basis for future research and to point to areas or species which may support an expansion of deep-water fisheries.

As usual, the amount of documented knowledge is generally proportional to the commercial importance of different areas and species and inversely proportional to depth. Even for highly

priced traditional species, there is a definite need for future basic biological and ecological research.

There are no indications of major unknown slope resources below the transition layer between the warm Atlantic water masses and the cold Norwegian Sea Deep Water (at 500-800 m depth). In and above the transition layer the biomass is relatively high, and a certain potential for increased exploitation of some species like Greenland halibut, roughhead grenadier, redfishes, greater argentine and others is likely to exist. In deep shelf areas and the deeper fjords of Norway, there are accumulated populations of greater argentine and roundnose grenadier of unknown potential. The basis for exploitation of mesopelagic resources remains uncertain, although certain fishes, e.g. Müller's pearlside (Maurolicus muelleri), are widespread and locally highly abundant. Some interest has been focused on exploration of unidentified mesopelagic scattering layers often observed in the Norwegian Sea and on deep-water phases of squids (Gonatus fabricii and Todarodes sagittatus).

It appears probable, however, that optimization of exploitation patterns and management may enhance yield and economic return from traditional easily marketable resources of redfishes, Greenland halibut, blue whiting, ling, tusk, blue ling and halibut. Indeed, this may, at least in the long-term, be highly profitable compared with developing new fisheries based on presently unexploited resources of unknown potential.

Future research and fisheries at greater depths and rough bottom will depend on improvement of gear and techniques, primarily hydroacoustic, for observation and quantification. Development of towed transducers with increased maneuverability appears as a first promising step towards systems allowing direct observation of resources at relevant depths and close to steep slopes. The opinion is expressed that major exploratory surveys in unknown parts of the Norwegian Sea should be postponed until some advances along these lines are seen.

INTRODUCTION

Most conventional demersal and pelagic fishery resources of the shelves of the Northeast Atlantic show clear signs of being either fully exploited or overexploited. This has lead to efforts being focused at developing strategies for long- and short-term optimization of exploitation patterns, but also at assessment of the potential for fisheries in new areas and on rather unconventional resources. This paper gives an overview of deep-water fisheries and resources as one of the alternatives with supposed potential for further development.

In the late sixties interest arose for increased exploitation of deep-water species, and since then major efforts to explore new areas and resources along the slopes off Iceland, the British Isles and, to some extent, Norway, were made by several countries, primarily the USSR, the United Kingdom and the Federal Republic of Germany (PECHENIK and TROYANOVSKII 1970, BRIDGER 1978, EHRICH 1983). These efforts, supplemented by more sporadic work by other nations, led to some increased exploitation, primarily by trawler fleets fishing for Greenland halibut, redfish, and recently, for roughhead grenadier, and improved the basis for further research.

Despite these rather extensive programs, the amount and quality of information is still considered to be unsatisfactory for major areas and resources. This is especially true for the slopes surrounding the Norwegian Sea (Fig. 1), while areas of the North Atlantic proper (i.e. areas to the south of Iceland, the Faroes and to the west of the British Isles) are comparatively well known. This fact and the general demand for alternative resources motivated the Norwegian Council for Fisheries Research to appoint a committee with a mandate to compile and review information on biological resources of waters deeper than about 300-400 m, primarily within the basin of the Norwegian Sea. Also, relevant technology for fishing and observation should be included. The review should form a basis for specific recommendations for future research.

This paper is a summary of the committee's report, dealing primarily with slope resources, whereas the committee also considered deep shelf areas, the meso- and bathypelagial and the deeper fjords of Norway. The catch history, distribution, biology and state of exploitation of conventional deep-water resources are covered, whereas information on unconventional species is emphasized. The committee's major recommendations concerning future research and development of fisheries and technology are discussed.

BATHYMETRY AND PHYSICAL OCEANOGRAPHY

The bathymetry of the Norwegian and Greenland Seas is shown in Fig. 1. The borders to the south are the submarine ridges between Greenland and Scotland, while to the north similar ridges separate the Greenland Basin from the basins of the Arctic Ocean. The Barents and North Seas to the northeast and south-southeast respectively are the two marginal seas.

The continental shelf off Norway, the Faeroes and Iceland are rather wide, and the shelfbreak is found at 300-500 m depth in most areas. There are several small and large 300-700 m deep indentations and basins in the shelf, e.g. the Norwegian Deeps of the northeastern North Sea, the Vestfjord of North-Norway, the Bear Island Channel of the southwestern Barents Sea and numerous minor basins and channels between the banks off Norway.

The hydrography of the Norwegian Sea is comparatively well described due to several major studies, among them the monumental "The Norwegian Sea" by HELLAND-HANSEN and NANSEN (1909). BLINDHEIM (1986) reviewed the relevant literature and provided a summary of current knowledge on water masses, currents and structure.

Fig. 2 shows the major surface currents and the hydrographical structure as seen from sections across the Norwegian Sea. Omitting coastal water masses, there are three major water masses. About 2/3 of the volume is the homohaline Norwegian Sea Deep Water with salinity 34.92 ‰ and temperature below 0^0C, decreasing gradually with depth to near -1.0^0C. The two major

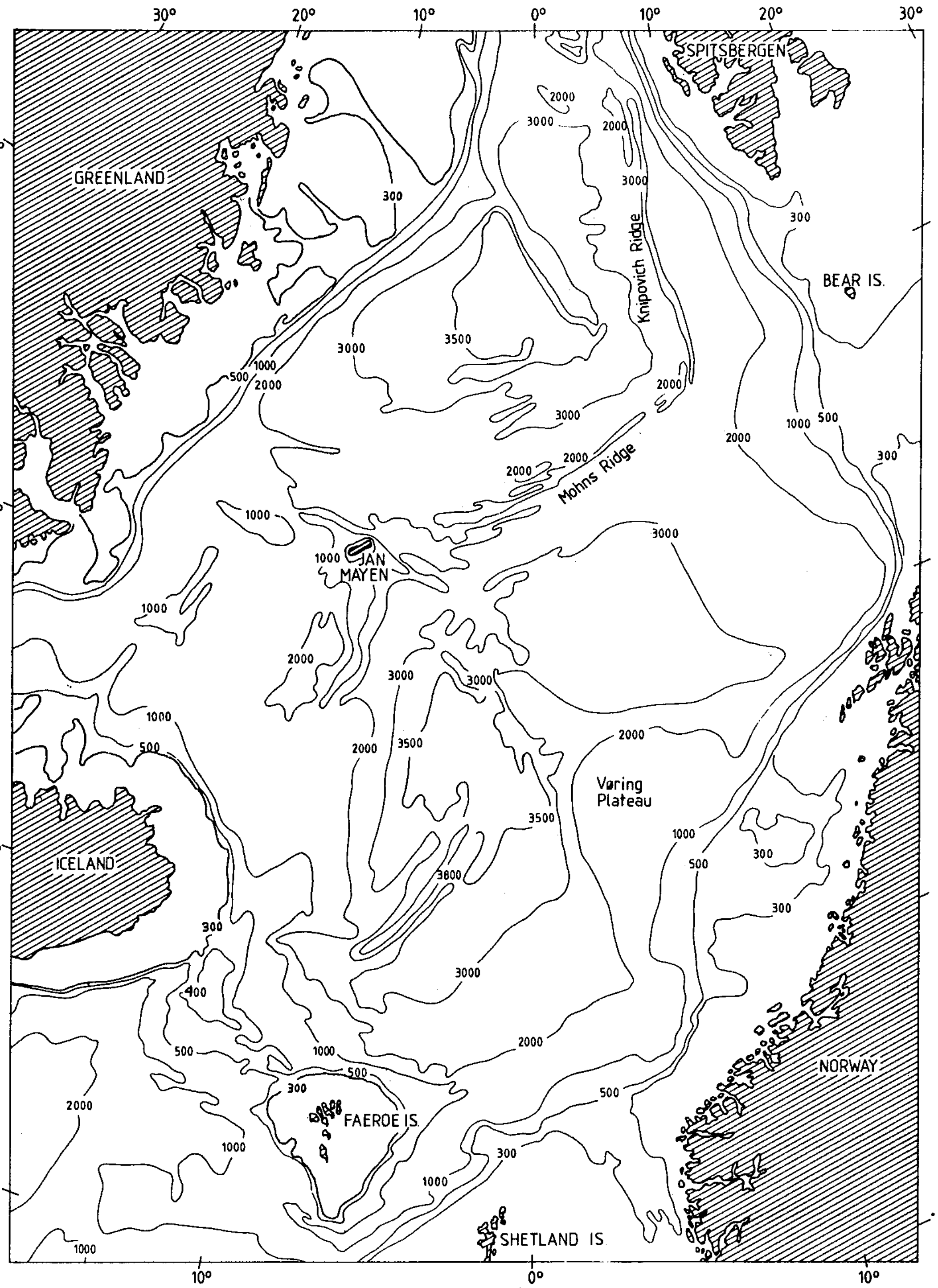

Fig. 1. Bathymetry of the Norwegian and Greenland Seas (Modified from Eggvin et al. (1963)).

water masses of the upper strata are the warm and saline (S‰ above 35.0) Atlantic water mass entering from the south, primarily through the Faroe-Shetland Channel as the Norwegian Atlantic Current, and the cool Arctic Intermediate Water entering from the northeast as the East Icelandic Current.

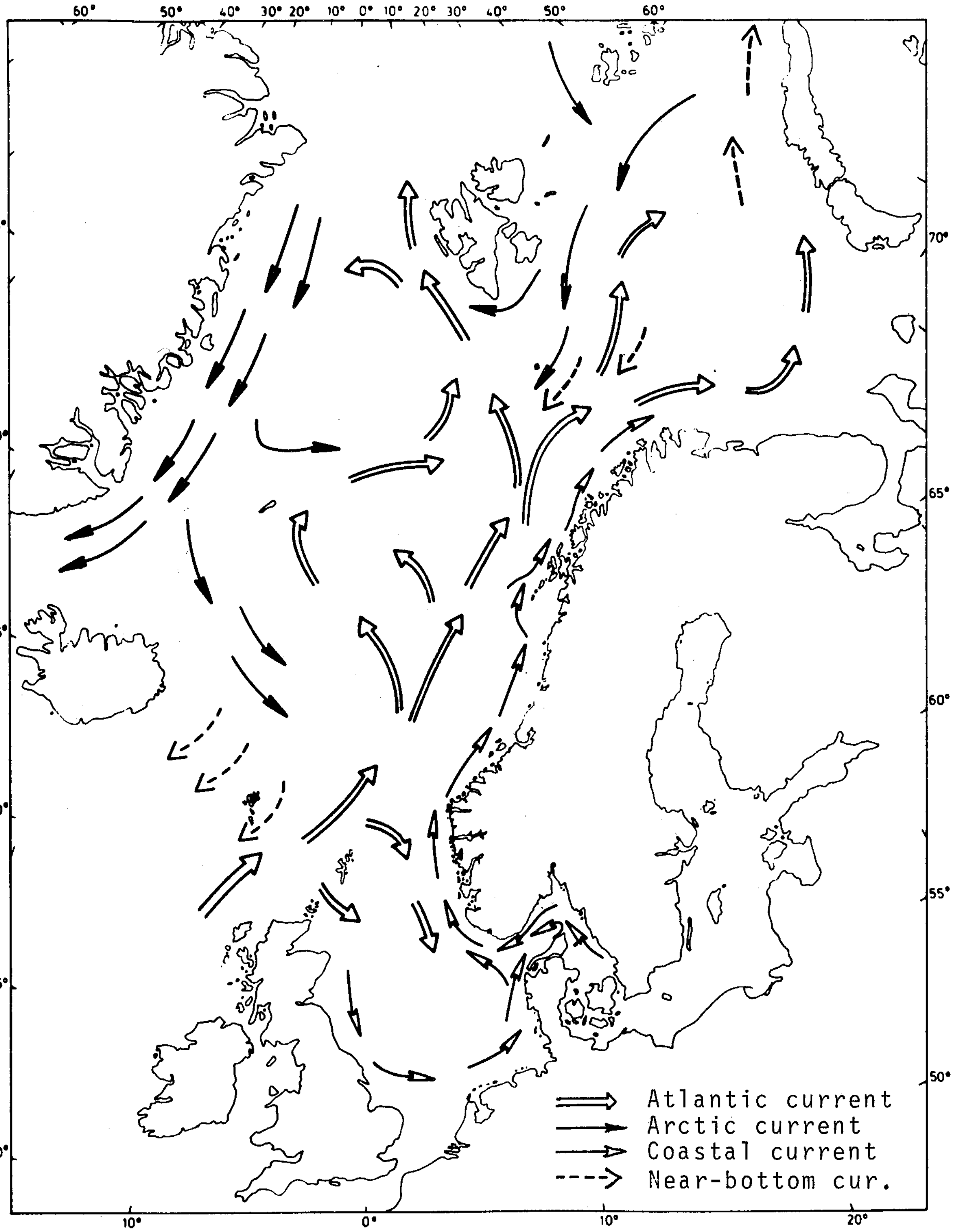

Fig. 2. Surface currents of the Norwegian and Greenland Seas (Reprinted with permission from Midttun (1986)).

The distribution and character of the Atlantic water mass and the Norwegian Sea Deep Water are of particular significance for the composition, distribution and production of the slope and outer shelf communities. A major feature of all the sections shown in Fig. 3 is the frontal zone between the warm upper strata and the cold Deep Water at moderate depths along the eastern slope. This front is found along the entire slope from the Faeroes to northern Spitsbergen, but its depth and temperature range vary geographically. The boundary layer is narrow and shallow in the southernmost area, but becomes gradually wider and deeper in a northward direction and reaches a maximum width and depth off North-Norway. The vertical extent of the Atlantic water mass is about 400-500 m in the southern part, increasing to 700 m off North-Norway, whereas off Spitsbergen it has decreased to 500 m due to gradual mixing. The temperature of the Atlantic water mass falls from around 8^0C at the entrance to the Norwegian Sea to 4-5^0C off Spitsbergen, thus the temperature range in the boundary layer decreases from 8-9^0C to some 5^0C going northwards.

Fig. 4 shows the temperature and salinity in a section crossing the ridge between the Norwegian Sea and the North Atlantic proper. There is a pronounced temperature difference between the slope water on either side which is of great zoogeographical significance.

FISH DISTRIBUTION RELATED TO DEPTH AND WATER MASSES

Somewhat surprisingly, there are very few recent and comprehensive accounts of fish distribution along the slopes of the Norwegian Sea, especially covering depths below 500-600 m. Much of the available written information dates from the pioneer exploratory surveys in the last decades of the 19th century and the first decade of this century. Based on a number of surveys, Johan Hjort (in MURRAY and HJORT 1912) listed 14 species as typical members of the community inhabiting the slopes deeper than 600-700 m and the abyssal plains. Most of these were small species, primarily belonging to the families Zoarcidae, Cyclopteridae (Liparidae) and Cottunculidae, while only a few large fishes, e.g. Greenland shark (Somniosus microcephalus) and Raja hyperborea were included. The list is clearly not complete, possibly due to gear selection, and several species, e.g. Greenland halibut (Reinhardtius hippoglossoides) and roughhead grenadier (Macrourus berglax), should be added.

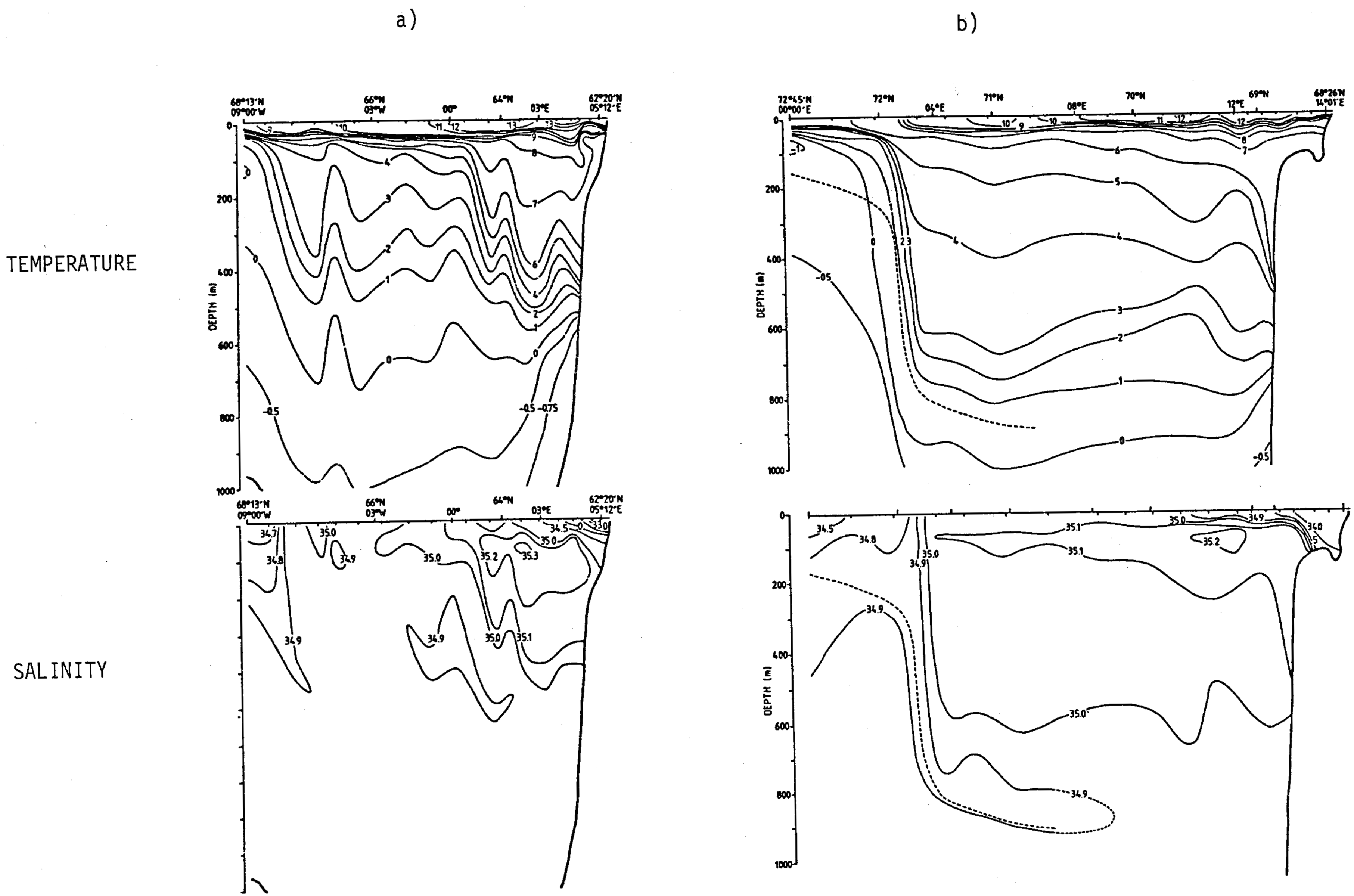

Fig. 3. Temperature and salinity in sections in a Northwesterly direction across the Norwegian Sea from the coast of Norway at a) N $62^0 20'$ and b) N $68^0 26'$ (August, 1980). (Reprinted with permission from Blindheim (1986)).

Most of these species were found along the slopes, whereas the abyssal fauna appears very poor, also from the very limited recent data. DAHL et al.(1976) caught only three species of fish (two Cyclopterids and one Zoarcid) by bottom trawl and baited traps.

The species listed by Hjort live in the Norwegian Sea Deep Water or in the boundary layer between this and the Atlantic water mass, hence at rather low temperatures (from 3 to 0.9^{0}C). Accordingly, the majority are Arctic or boreo-Arctic species, and rather submerged shallow-water species than true deep-water fishes (EKMAN 1967). Along the entire eastern slope of the Norwegian Sea and the slopes off northern Iceland, the frontal zone at the upper slope or shelf-break appears to act as a distributional boundary between a deep cold-water fauna and an

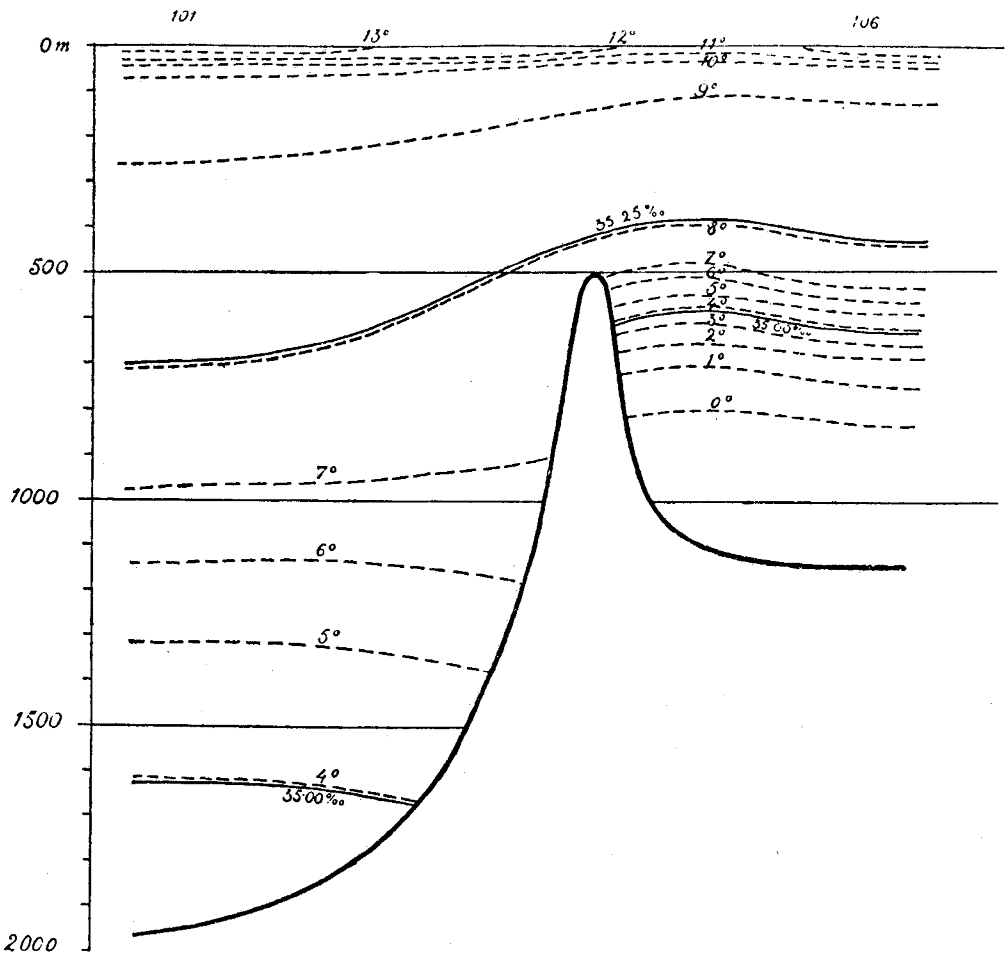

Fig. 4. Temperature and salinity in a section across the Wyville-Thomson Ridge (From Murray and Hjort (1912)).

outer shelf fauna dominated by boreal species. This is illustrated by the results from the very few ichthyofaunal studies and the somewhat more numerous and extensive scouting surveys.

BAKKEN *et al.* (1975) mapped the fish distribution in relation to depth in the interval 300 to 1000 m in three areas off Norway (Approx. N 62°30', N 65°00' and N 72°30'). Table 1 illustrates the bottom trawl species composition by numbers in the depth range 300-500 m in one of the areas. Five species, i.e. the greater argentine (*Argentina silus*), blue whiting (*Micromesistius poutassou*), silvery pout (*Gadiculus argenteus thori*) and the redfishes (*Sebastes viviparus*, *S. marinus* and probably some *S. mentella*) contribute 95% to the total catch. Moreover, at least blue whiting, redfish and greater argentine are typical benthopelagic species in this area which are probably highly underrepresented in the catches compared with their real relative abundance.

Table 1 also shows results from the same survey at depths from 700 to 1000 m and illustrates the pronounced contrast between the depth zones. The 0°C-isotherm was found at approx. 640 m, and accordingly several of the Arctic or boreo-Arctic species were abundant below 700 m, e.g. *Raja hyperborea*, roughhead grenadier, Arctic eelpouts (*Lycodes* sp.) and Greenland halibut.

In the boundary layer, there appears to be a mixture of the two species assemblages, although this remains somewhat uncertain due to the low number and wide separation of the hauls. Some data from closely spaced hauls indicate a rather abrupt change from a typical "shelf-break-Atlantic water mass" fauna to a "slope-Arctic" assemblage. An example is given in Table 2 and Fig. 5 (BERGSTAD, unpubl.) from a series of bottomtrawl hauls in the depth interval 400-630 m at approximately N 62°00' off Norway. The temperature gradient is rather steep (Fig. 5, upper), and the transition from catches dominated by shelf species to hauls with 60-80% boreo-Arctic or Arctic slope species seems to happen over a depth interval of about 50 m. (This result necessarily depends to some extent on the zoogeographical classification of the different species which may be uncertain for some species, e.g. for *Hippoglossoides*

Table 1. Catch composition (by numbers) of the bottom trawl hauls from the shelf-break and slope off Norway (N 65^{0}00'). From Bakken _et al_.(1975). Species below the broken line occurred in the lower depth interval only.

No. of hauls	7	11
Depth (m)	300-500	700-1000
Etmopterus spinax	28	
Galeus melastomus	8	
Raja oxyrinchus	1	
R. radiata	1	2
Chimaera monstrosa	99	
Argentina silus	2537	2
Brosme brosme	11	
Phycis blennoides	4	
Molva molva	2	
Molva dipterygia	41	
Pollachius virens	46	
Melanogrammus aeglefinus	22	10
Trisopterus esmarkii	1	
Micromesistius poutassou	748	18
Merlangius merlangus	1	
Gadiculus argenteus thori	975	
Sebastes marinus	241	3
Sebastes viviparus	954	1
Artediellus europeus	1	
Lepidorhombus whiffiagonis	8	
Hippoglossoides platessoides	1	
Glyptocephalus cynoglossus	4	

Raja hyperborea		9
Benthosema glaciale		13
Macrourus berglax		47
Lycodes spp.		50
Careproctus reinhardti		1
Reinhardtius hippoglossoides		134

platessoides, _Sebastes mentella_ and _S. marinus_). BAKKEN _et al_.(1975) found that the sharpness of the boundary between the two faunas depends on the steepness of the temperature gradient, and hence becomes comparatively diffuse further to the north and northwest along the slope off North-Norway and Spitsbergen.

The impression from scouting surveys and commercial fishing

Table 2. Catches by bottom trawl at the shelf-break and upper slope off mid-Norway (N 62°00'-N 62°30', E 001°00'-E 003°00'). M/S Håkon Mosby, 26-28 February 1987. (Bergstad, unpubl.). Species accepted as boreo-Arctic or Arctic are listed below the broken horizontal line.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m)	400	400	440	450	535	545	565	585	615	625	630
Squalus acanthias	1	14									
Etmopterus spinax	19	16									
Raja batis										1	
Chimaera monstrosa	10	46	54	39							
Argentina silus	31	118	33	62	2	3					
Trisopterus esmarkii	98	468		62		4					
Micromesistius *poutassou*	298	1402	9193	2418	35	31	5	20		2	
Pollachius virens	1	4	25			1					
Gadus morhua			1								
Gadiculus argenteus thori	35	186	22			1					
Molva byrkelange	1			1	1						
Brosme brosme		2		23		1					
Lycenchelus sarsii											1
Sebastes viviparus	194	256	576	1895			8		2		
S. marinus and S. mentella			9	47	223	465	46	11	1	4	9
Lophius piscatorius	1		1								
Lepidorhombus whiffiagonis	1										
Glyptocephalus cynoglossus	26	24	33	8							
- - - - - - - - - -											
Raja radiata	3				3		3	1	3	4	
Raja fyllae					6	6	7	5	5		9
Raja hyperborea					2	2	3	1			3
Breviraja spinicauda						1	8	3	2	3	2
Macrourus berglax					4	10	6	1			
Onogadus argentatus						1	1	3		1	
Lycodes esmarkii					2	3	4	1		3	2
Lycodes eu-dipleurostictus							1		1	1	2
Lycodes squamiventer										1	1
Careproctus reinhardti						1	3				1
Cottunculus microps	1					1	4			1	1
Hippoglossoides platessoides	1	10	33	8		10					
Reinhardtius hippoglossoides					1	12	9	20		4	11
Total catch (No.)	721	2546	9980	4563	279	553	108	66	14	25	42
No. species	16	12	11	10	10	17	14	10	6	11	11

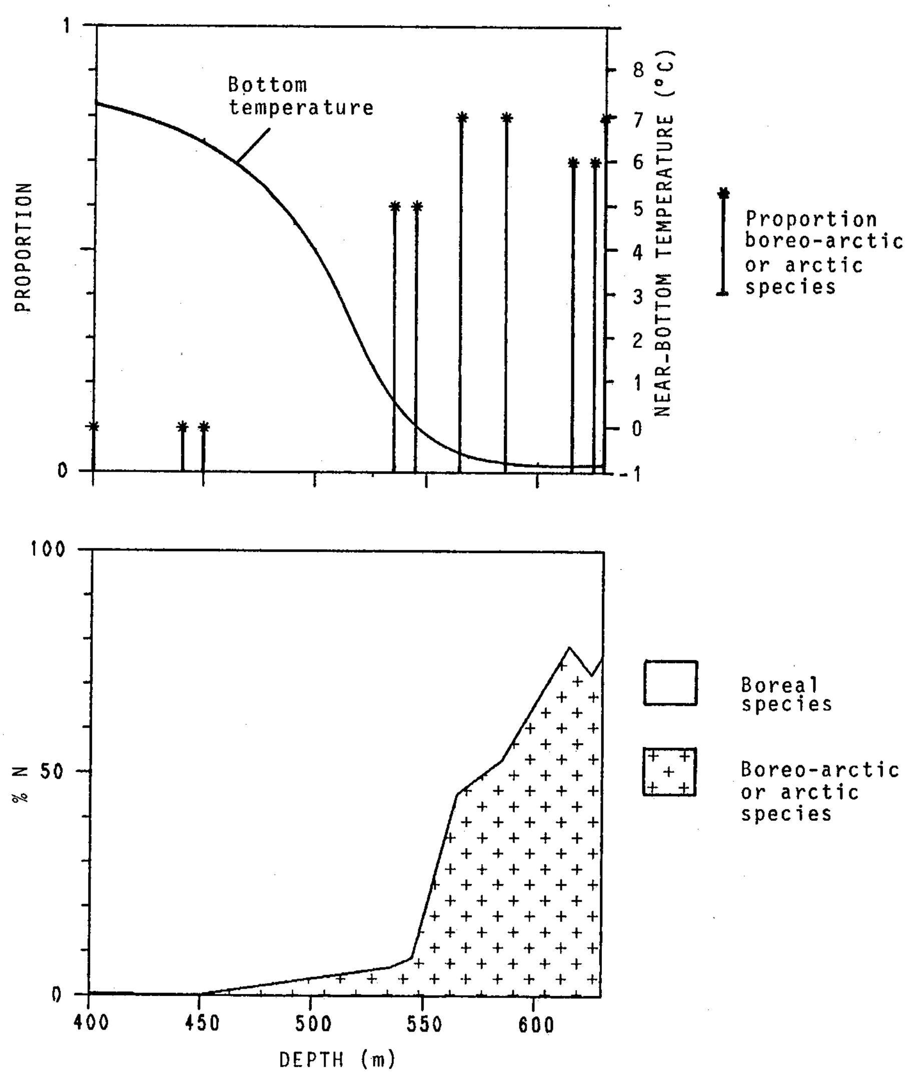

Fig. 5. Proportion of boreo-Arctic and Arctic species of the total number of species (upper) and of the total catch (by numbers, lower) in bottom trawl catches from the shelf-break and upper slope off mid-Norway (Table 2). Near-bottom temperature from a synoptic hydrographic section is shown in the upper figure.

operations is that certain species, e.g. Greenland halibut, roughhead grenadier and to some extent Sebastes mentella and S. marinus, show affinity for the hydrographic boundary layer itself in which they are particularly abundant. The abundance of all three species increases northwards and reaches high levels off North-Norway and the slope between Norway and Spitsbergen where the boundary layer is wide (PECHENIK and TROYANOVSKII 1970, ELIASSEN 1983 a, SAVVATIMSKIY 1985, NEDREAAS, K., Inst. of Marine Research, Bergen, pers. comm., 1987). Both Greenland halibut and the roughhead grenadier appear to have major spawning areas in the boundary layer, and an apparent accumulation of suitable hyperbenthic prey, primarily crustaceans, (T. BRATTEGARD, Dept. of Marine Biology, Univ. of

Bergen, pers. comm. 1986), may provide favourable food supply.

Of obvious relevance to resource studies are the quantities caught or observed. Except in areas with apparent spawning concentrations of Greenland halibut and roughhead grenadier, there are rather consistent drops in the bottom trawl catch rates with increasing depth in the range 500-1000 m, and the density of fish below the frontal zone appears very low (BAKKEN et al. 1975, BERGSTAD, unpubl., Table 1 and 2, Fig. 6). At 1000 m the average catch rates are only about 1 % of the rates at 400-500 m.

The catch rates by trawls may of course not reflect density in

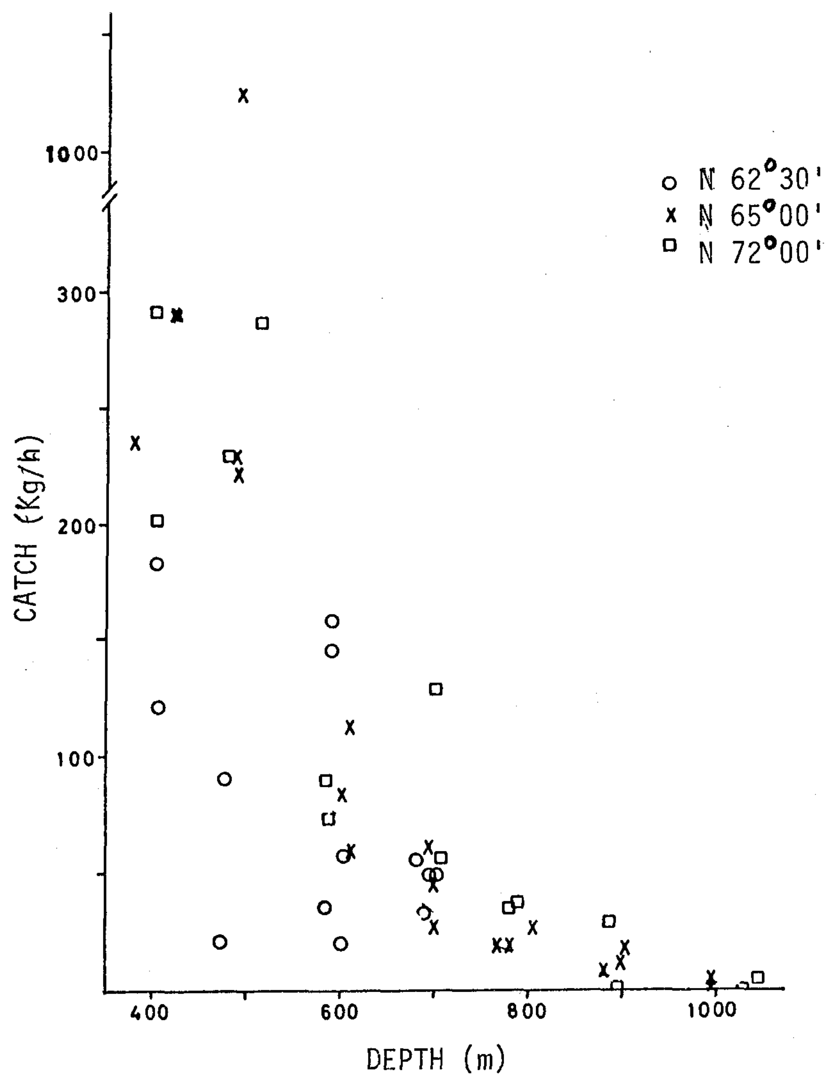

Fig. 6. Catch rates by bottom trawl related to depth at three locations along the continental slope off Norway (Modified with permission from Bakken et al. (1975)).

a consistent manner. Experience from fishing and recent _in situ_ measurements (ENGÅS and GODØ 1985) point to a significant decline in catch efficiency with increasing depth. The real density in the deeper zones may thus be somewhat higher than indicated by the trawl surveys, but probably far from equal to or above the levels at the shelf-break influenced by the Atlantic water mass. The abundance of large fish, e.g. Greenland halibut, roughhead grenadier, _Anarhichas_ sp., ling, blue ling, tusk and the skates, invariably appears very low from trawl data, again with exception of areas with major spawning concentrations. This can partly be due to the rather low sampling volume and area of the trawls and a low catch efficiency for these species.

There are no strictly comparable data from the slopes of the Norwegian Sea and areas of the Atlantic Ocean proper. The clear impression is, however, that the species composition, richness and biomass are low in the Norwegian Sea compared with similar depths along the slopes to the west of the British Isles, south of the Faeroes and Iceland and in the Northwest Atlantic. The submarine ridges between Scotland and Iceland have been accepted as a zoogeographical boundary separating the deep-sea faunas on either side (EKMAN 1967, DAHL _et al_. 1976). The Arctic and boreo-Arctic species of the Norwegian Sea Deep Water do probably not cross this boundary regularly, and several of the species which are abundant in areas to the south of the ridges, e.g. in the Rockall Trough and southeast of the Faroes (PECHENIK and TROYANOVSKII 1970, GORDON and DUNCAN 1985, EHRICH 1983), do not find suitable conditions in their preferred depth ranges in the Norwegian Sea. This may explain the virtual absence of e.g. roundnose grenadier (_Coryphaenoides rupestris_) and _Aphanopus carbo_ from the slopes of the Norwegian Sea.

On the other hand, all the deep shelf species which are abundant on both sides of the ridges are primarily restricted to areas heavily influenced by Atlantic water masses. Examples are blue whiting, greater argentine, _Chimaera monstrosa_, ling, blue ling, tusk and several others which inhabit the outer shelf, soft-bottom shelf deeps (BERGSTAD 1986) and the deeper fjords of Norway (TAMBS-LYCHE 1987). The roundnose grenadier does occur north of the ridges, but only in some coastal depressions off mid-Norway, in several of the fjord systems and in the comparatively deep basin of Skagerrak between Norway and Jutland, Denmark (ELIASSEN 1983c, 1986, BERGSTAD 1986).

Species richness seems very different between similar depths in the Atlantic and in the Norwegian Sea. BAKKEN et al.(1975) recorded some 14-15 species, while EHRICH (1983) reported some 200 species from the Rockall Trough.

Bottom trawl catch rates are minute at 800-1000 m depth in most areas which have been fished along the slopes of the Norwegian Sea. In other areas of the North Atlantic, significant concentrations of several species, e.g. grenadiers, Greenland halibut, have been located by trawling at these depths and deeper (PECHENIK and TROYANOVSKII 1970, EHRICH 1983). This can rather clearly be related to the comparatively shallow frontal zone between warm water masses and the cold Deep Water along the Norwegian Sea slopes.

The account has thus far focused on conditions along the eastern Norwegian Sea, covering the slope from the Faroe-Shetland-ridge to somewhere off Spitsbergen. Most other areas, i.e. Northern Spitsbergen, Jan Mayen, Greenland, lack the continuous influence of warm Atlantic water masses, and the slopes are most probably solely inhabited by Arctic or boreo-Arctic species. There has, however, been no systematic ichthyofaunal studies in these waters. Off northern Iceland, however, the warm Irminger Current produces a frontal zone at or somewhat below the shelf-break. As off northern Norway, appreciable concentrations of Greenland halibut are found in these areas, primarily during the feeding season (PASCHEN 1968, PECHENIK and TROYANOVSKII 1970, ERNST 1974, SIGURDSSON 1979). The conditions appear fairly similar to the ones described for the eastern slope, but no comprehensive reports on fish distribution and species composition have been found.

CONVENTIONAL DEEP-WATER RESOURCES

The previous chapter provided some information on the species assemblages available for the slope and outer shelf fisheries. Only a rather small proportion of the landings in the Northeast Atlantic come from outer shelf and slope species (Fig. 7) and, in fact, large quantities of major species, e.g. blue whiting, is taken pelagically or at moderate depths, also as bycatch in other fisheries. It should be noted that landings from areas outside the Norwegian Sea, i.e. the banks to the west of the British Isles and Ireland and south of the Faeroes and Iceland are included in Fig. 7.

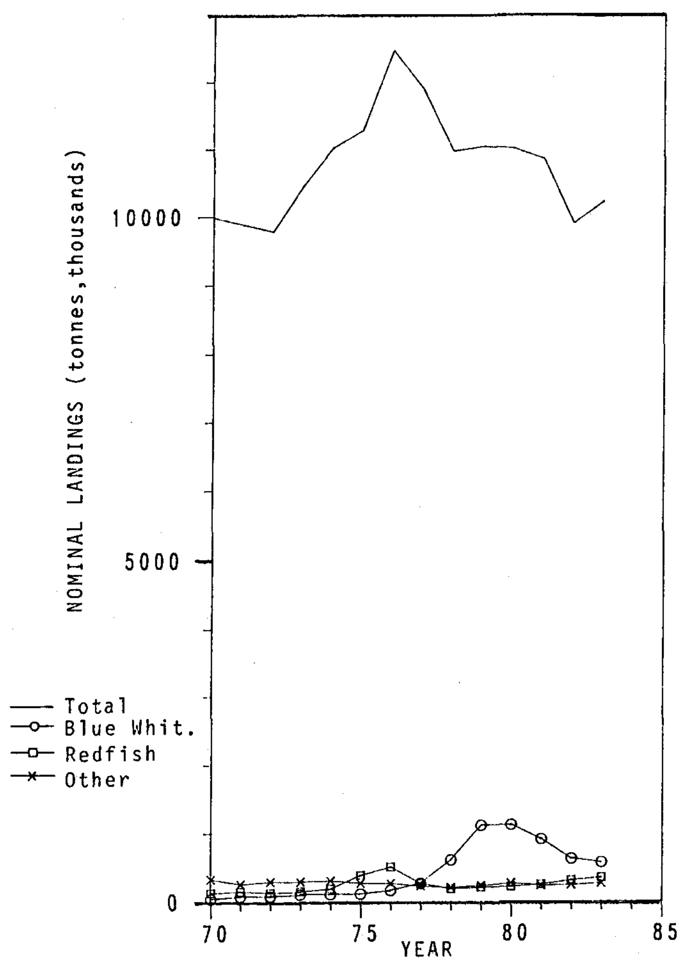

Fig. 7 Total nominal landings of fish from the entire ICES area and the landings of deep-water species. The 'other' category includes ling, tusk, blue ling, Greenland halibut, Atlantic halibut, European hake (<u>Merluccius merluccius</u>) and greater argentine. (Data from ICES <u>Bulletin Statistique</u>, Anon. (1986 a,b) and the Institute of Marine Research, Bergen (Unpubl.)).

Blue whiting, redfish, greater argentine, tusk, ling, blue ling, Atlantic halibut, Greenland halibut and pink shrimp (Pandalus borealis) support fisheries along the upper slope, in deep shelf areas or in the mesopelagial. Each of these will be treated briefly in the following, and information on distribution, the fishery, abundance and potential and topics for further research are summarized in Table 3. The landings are given in Fig. 8. This overview is based on the literature referred to in Table 3, and the references will as a rule not be included in the text.

Blue whiting

The blue whiting is not really a typical deep-water fish, rather an outer shelf species which partly utilizes mesopelagic oceanic habitats. Aimed midwater trawl fisheries started in the early seventies in the Norwegian Sea and to the west of Scotland, increasing to a record landing of 1.1 million tons in 1979. The oceanic fishery in the Norwegian Sea, primarily by eastern European fleets, has decreased, and there is some basis for expansion in this area. Unfortunately, recent attempts to produce "surimi"-products or filets from blue whiting from the Norwegian Sea did not prove very successful. Minor stocks of blue whiting in the fjords of Norway may support small-scale consumption fisheries. Among the listed deep-water species, blue whiting is probably the one with greatest potential for increased exploitation.

Separation of stocks, improvement of the quality of the abundance estimates and development of strategies for pre-recruit assessment are present research topics of high priority. The hydroacoustic abundance estimates are thought to be underestimates today, and improvement of the technology for deepwater acoustics appears necessary.

Redfish

The stocks of Sebastes marinus and S. mentella appear underexploited, and the fishery is expanding in areas previously considered uninteresting or inaccessible due to rough sub-

Table 3. Conventional deep-water fishery resources of the Northeast Atlantic. Distribution, major fishing areas and gears, abundance estimates, potential, topics for future research and relevant references.

Species	Distribution: Geographical SA: spawning area and period	Distribution: Bathymetrical	Major fishing area and gears	Abundance	Supposed potential and areas of possible expansion of fishery	Topics for future research	References
Blue whiting, <u>Micromesistius poutassou</u>	Northern stock: Ireland to Spitsbergen, incl. SE Iceland and North Sea. SA: Bks. W of Scotland and N. Ireland March-April	200-700 m, mesopelagic in oceanic areas and benthopelagic along upper slopes and in deep shelf areas.	Bks. and slopes W of British Isl. Norwegian Sea Midwater trawls	Hydroacoust. estimates, 1983-86: 2.8-4.9 mill.t	1.0 mill. t (?) Oceanic consumption fisheries, util. of fjord resources.	Stock identification, improved acoust. abundance estimation, larval and juvenile biology and distr., resource sharing with other pelagics, e.g. herring of the Norw. Sea.	Sahrhage and Schöne, 1980 Bailey, 1982 Zilanov, 1984 Schulz <u>et al</u>.,1984 Anon., 1986 a,b Monstad and Blindheim, 1986
Redfish <u>Sebastes marinus</u>	Rel. warm parts of Barents Sea, outer and deeper shelf areas from S. Spitsbergen to Faroe-Shetl. ridge. N. and E. Iceland. Pelagically in Norw. Sea ? SA: Outer shelf, upper slope off N-Norway (Vesterålen). April-June	100-350 m, primarily benthopelagic, but also pelagic.	Barents Sea and outer shelf off N. Norway and further south. Iceland. Bottom trawl.	Unknown	Unknown potential, but probably underexploited. Fishing in rough-bottom areas. Pelagic fisheries ? Further development of human consumption fisheries.	Abundance estimation, species ident., ageing techniques, recruitment studies, exploration of pelagic conc., dev. of gear for rough-bottom fishing (setnets, trawls)	Maslov, 1944 Sorokin, 1961 Trout, 1961 Shestova and Lukmanov, 1983 Haunschild and Vaske, 1985 Ernst, 1985 Shestova, 1986 Godø and Nedreaas, 1986

Table 3. Continued

Species	Distribution Geographical SA:spawning area and period	 Bathymetrical	Major fishing area and gears	Abundance	Supposed potential and areas of possible expansion of fishery	Topics for future research	References
S. mentella	Overlaps with S. marinus, but in colder waterm. and further north Pelagically in Norw. Sea ? SA: Off Bear Isl., Bear Isl. Channel.	300-700 m, benthopelagic and pelagic.	Deeper parts of Barents Sea, outer shelf off Spitsbergen and N. Norway. 300-700 m Bottom trawl	VPA estimates: 1965-85: 0.3-1.05 mill.t 1980-85:approx. 0.7 mill.t	Same as for S. marinus.	Same as for S. marinus.	
Greater argentine, Argentina silus	S. Spitsbergen to Bay of Biscay. In Norwegian Sea: Deep shelf areas from N. Norway to Faeroe-Shetl., incl. Northern North Sea and Skagerrak and Norw. fjords. SA: Skagerrak and deeps off mid-Norway. March-June, but apparently protracted.	200-600 (100-900) m. Benthopelagic along shelf-edge or in shelf deeps. Juveniles in upper part of depth range.	Shelf deeps off mid-Norway, N. North Sea and Skagerrak (The Norwegian Deeps) Bottom trawl.	Unknown	Unknown potential, probably approx. 20,000 t. Expansion of fishing area to incl. outer shelf areas and perhaps fjords may increase yield. Util. of bycatch in shrimp- and reduction fisheries.	Abundance estimation, target strength estimation, recruitment studies, det. of long-term stability and yield given that the stocks are dominated by very old fish, stock identification.	Borodulina, 1964, 1968 Wood and Raitt, 1963, 1968 Keysler, 1968 Thorsen, 1979 Westhaus, 1982 Johansen and Monstad, 1982 Ehrich, 1983 Johannessen and Monstad, 1984 Bergstad, 1986

Table 3. Continued

Species	Distribution: Geographical (SA: spawning area and period)	Distribution: Bathymetrical	Major fishing area and gears	Abundance	Supposed potential and areas of possible expansion of fishery	Topics for future research	References
Tusk, <u>Brosme brosme</u>	Shelf off Spitsbergen and W. Barents Sea to Bks. off Ireland, incl. North Sea, Skagerrak, shelf off Iceland, Norw. fjords. SA: Rockall Bk., the Faeroes and probably locally in entire range (Not well known) April-July	100-1000 m, various substrates, supposedly benthic. Main conc. shallower than 500 m in Norw. Sea. Atl. watermasses, but in lower part of temp. range.	Barents Sea and slope off N. Norway, bks. W. of Scotland, Iceland. Long-lines, Bottom trawl (as bycatch)	Unknown	Probably fully exploited in main fishing areas, and potential for expansion appears limited except on minor local conc. Basis for det. of exploit. level and potential is poor.	Further studies of biology (Age, growth, reproduction, recruitment, migrations etc.). Developm. of management strat. based on improved data base from the fisheries.	Damas, 1909 Schmidt, 1909 Andriyashev, 1954 Rahardjo-Joenoes, 1961 Anon., 1977 Anon., 1987
Ling, <u>Molva molva</u>	W. Barents Sea to Bay of Biscay, incl. S. and SW Iceland, North Sea, Skagerrak and Norw. fjords SA: W of Scotland, Rockall, Shetlands, Faeroes, S. of Iceland, Norway coast N. to N 67^0. Slopes, 100-200 (60-400 m). march-july	Juveniles in relatively shallow bk. areas and coastal waters. After 3-4 yrs. at 150-800 m, in Norwegian Sea mostly shallower than 250 m. Supposedly benthic. Atlantic waterm., upper temperature range.	W. of Scotland and Ireland bks., Rockall, Iceland, North Sea, Norway Coast, Faeroes Long-lines, bottom trawl (primarily as bycatch)	Unknown	Same as for tusk	Same as for tusk	Damas, 1909 Schmidt, 1909 Molander, 1956 Rahardjo-Joenoes, 1961 Anon., 1977, 1979, 1987

Table 3. Continued

Species	Distribution: Geographical (SA: spawning area and period)	Distribution: Bathymetrical	Major fishing area and gears	Abundance	Supposed potential and areas of possible expansion of fishery	Topics for future research	References
Blue ling, Molva dypterygia	W. Barents Sea to Morocco and W. Mediterranean, incl. Iceland, North Sea, Skagerrak and Norw. fjords. SA: W. of Scotl., S. of Iceland, Faeroes. (Probably several unknown areas). Slopes: 500-1000 m February-July	200-1500 m, mostly 350-600 m in Norw. Sea. Benthic and benthopelagic. Atlantic waterm., upper temp. range	W. of Scotl. bks., Faeroes, Rockall, Iceland. Bottom Trawl Long-lines Set-nets (In local Norw. slope fishery off mid-Norway)	Unknown	Same as for tusk and ling	Same as for tusk and ling	Rahardjo Joenoes, 1961 Koch and Lambert, 1976 Thomas, 1980 Magnusson, 1982 Engås, 1983 Ehrich, 1983 Ehrich and Reinsch, 1985 Anon., 1979, 1987
Atlantic halibut, Hippoglossus hippoglossus	Spitsbergen and Barents Sea to Bay of Biscay, incl. North Sea, Skagerrak and Norw. fjords. SA: Numerous minor areas, muddy substr. at 300-700 m. In Norway, several fjords N. to Sørøy, Finnmark. November-April (Desember-February)	Juveniles in shallow water, gradually moving deeper after 3-5 yrs. After this, variable depth range, 300-2000 m. Benthic and (bentho-)pelagic.	Entire range, but major traditional fisheries in N. Norw. fjords and deep shelf areas north to Spitsbergen. Also off the Faeroes and Shetlands. Set-nets, long-lines, danish seine, bottom trawl (as bycatch)	Unknown, but stock evidently significantly reduced.	Overexploited in entire N.E. Atlantic. Potential cannot be utilized. At present no basis for expansion of fishery.	Local scale mapping of juvenile distribution to be able to reduce exploitation in areas of high abundance.	Devold, 1938 Joensen, 1954 Sigurdsson, 1956 Rae, 1959 Mathiesen and Olsen, 1968 Anon., 1979 Haug et al., 1984 Haug, 1984 Godø and Haug, 1987c

Table 3. Continued

Species	Distribution: Geographical (SA: spawning area and period)	Distribution: Bathymetrical	Major fishing area and gears	Abundance	Supposed potential and areas of possible expansion of fishery	Topics for future research	References
Greenland halibut, <u>Reinhardtius hippoglossoides</u>	N. Spitsbergen and S.E. Barents Sea to Faeroe-Shetland Ridge and Iceland. SA: Slope off Bear Isl. to N. Norway (N68^{0}), W. Iceland. Possibly several unknown areas. Soft substr., 600-900 m, 0-3^{0}C. October-January and March-July.	150-1200 m, juv. coastal or at moderate depths in fjords and bank areas. Bentho-pelagic and possibly pelagic.	Slopes off Bear Isl. - N. Norway. Iceland. As bycatch in Barents Sea. Bottom trawl, long-lines.	Barents Sea and N. Norway: Virgin stock: 0.5 mill. t 1972-86: 0.1-0.2 mill.t	Stock in trad. areas assumed to be fully exploited or over-exploited. Possibly a certain potential from new areas to the south and north along eastern slope.	Exploration of new areas, recruitment studies, mapping of migration patterns, trophic ecology.	Milinskii, 1944 Lahn-Johannesen, 1965 Sorokin, 1967 Fedorov, 1968, 1971 Nizovtsev, 1969 Hognestad, 1969 Pechenik and Troyanovskii, 1970 Rørvik, 1977 Sigurdsson, 1979,1981 Haug og Gulliksen, 1982 Kovtsova and Nizovtsev, 1985 Anon., 1986 b Godø and Haug, 1987a,b

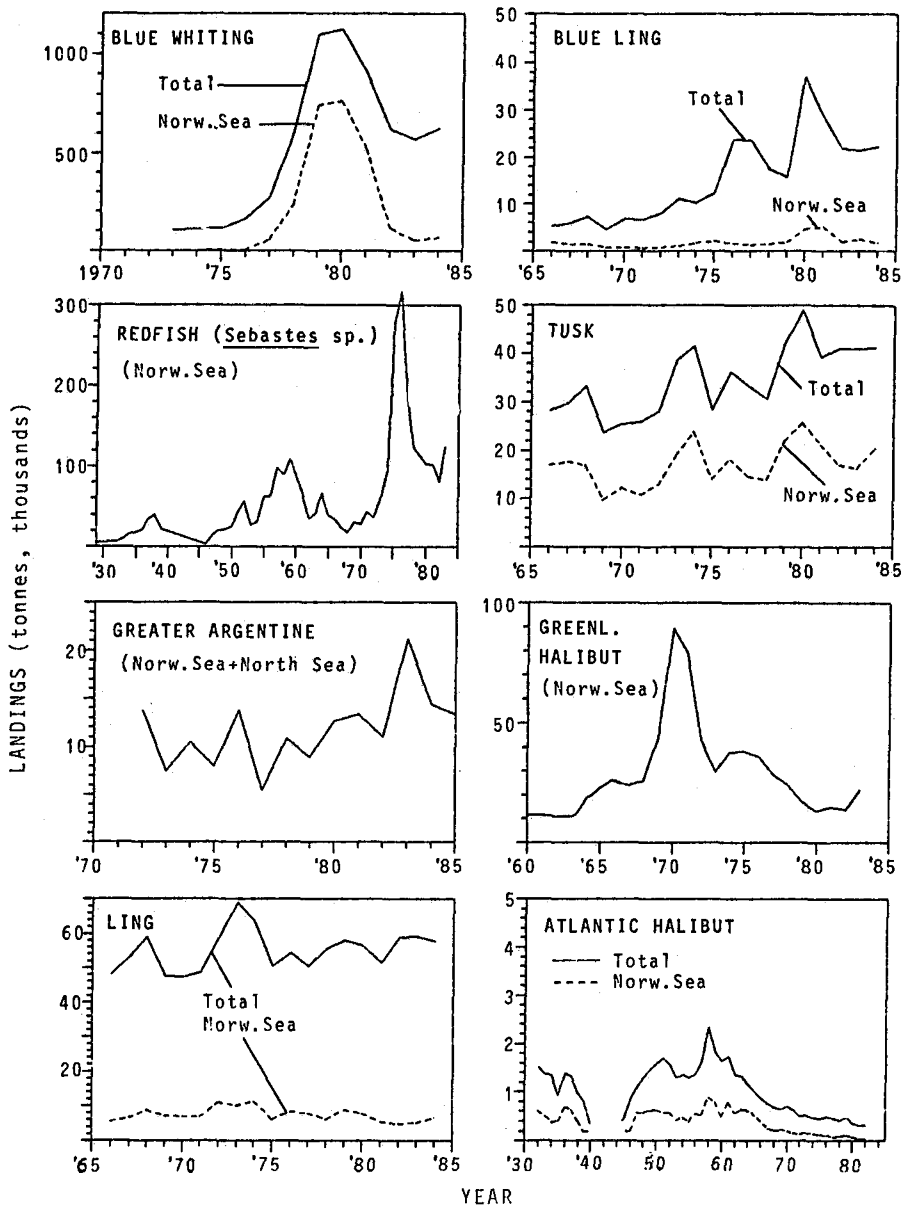

Fig. 8. Annual landings of various fish species from the entire ICES-area ('Total') and/or from the Norwegian Sea (ICES-regions I and II). (Data from ICES Bulletin Statistique, Anon. (1986 a,b) and the Institute of Marine Research, Bergen (Unpubl.)).

strates. There is also a certain potential for fishing on *S. viviparus* at moderate depths of the deeper shelf areas, but at present the demand seems low for this rather small fish.

The research and management suffer from the problems with lack of reliable species separation of the catches, poor effort data, unsatisfactory ageing techniques and the lack of fishery-independent abundance estimates. Thus, significant improvement of the data base on biology, abundance and fishery is needed.

Major oceanic pelagic redfish concentrations have never been found in the Norwegian Sea, although HJORT (1909) caught redfish by floating long lines in the open ocean. Unidentified scattering layers at mesopelagic depths are often observed, however, and some of these may be redfish. Identification of such layers would thus be of some interest.

Greater argentine

Until the late seventies, when an aimed trawl fishery for human consumption started off Norway, the greater argentine was only landed as bycatch in the multispecies industrial fisheries in the Norwegian Deeps (North Sea) and off Møre (mid-Norway). Presently there are direct fisheries in deep shelf areas off mid-Norway and in the Skagerrak which utilize concentrations of adult and very old fish (50-70% > 20 years old) in and around the principal spawning season from March to June. The fishery depends on large fish, hence on the preservation of a high fraction of old fish in the stock.

There has been no significant change in the age composition since the direct fisheries started, but it must be assumed that the stock is rather vulnerable to exploitation, and that the potential for further exploitation is rather limited. There are, however, rather large unexploited concentrations near the shelf-break off mid-Norway which can be fished successfully by midwater trawls. The potential in the Skagerrak is uncertain, as is the basis for fishing in the deeper fjords of Norway.

Future research goals include reliable direct abundance estimates and recruitment indices. Hydroacoustic mapping is done for greater argentine, but satisfactory target strength values are needed, as is technology for observation of concentrations at relevant depths and close to steep slopes. Moreover, an important source of error is the separation of argentine from other species in multispecies scattering layers. Information on mixing rates between the concentrations off mid-Norway, in the North Sea and in the areas north of the Shetlands and to the west of Scotland is also clearly needed.

Tusk, ling and blue ling

Tusk and ling, and to some extent, blue ling support long line fisheries to the west of Scotland, north of the Shetlands, at the Faeroes, at Iceland and along the slope off Norway. Tusk and ling occur as bycatch in the trawl fisheries, whereas a direct trawl fishery for blue ling has developed to the west of Scotland.

All the three species are distributed significantly deeper on the Atlantic side of the Faeroe-Shetland ridge than in the Norwegian Sea, most probably reflecting the distribution of the preferred rather warm water masses. The tusk tolerates lower temperatures and is found further northwards in the Norwegian Sea than ling and especially blue ling. The deep fjords of Norway are inhabited by all three species.

There is a definite need for more documented information on biology, ecology, distribution, migrations and abundance for tusk, ling and blue ling. The knowledge of spawning areas and times, on growth, reproductive biology and migrations is with few exceptions supported by a very limited amount of data or, at least for tusk and ling, by rather old data. Information from the Norwegian Sea is particularly poor. Some data on population structure have been collected, but the basis for calculating mortality and recruitment rates is limited since there are no continuous time series. Information on abundance and density can only be collected from fishing operations, not by any more direct means such as hydroacoustics, thus the quality of the observations becomes rather poor. The fishery itself, however, is a valuable, but seemingly underutilized source of information, and improved reports on landings, effort and age compositions would provide a significantly better basis for the assessments.

Due to the lack of basic data and, to some extent, inadequate information about fishing effort and landings, it is virtually impossible to determine what state the stocks are in or to manage the stocks rationally. It seems probable, however, that the exploitation rate is rather high in the traditional fishing areas and that the potential for expansion outside these grounds is limited.

Atlantic halibut

The Atlantic halibut has been highly priced for centuries in the Northeast Atlantic, being fished by handlines, long lines and, since 1936, by large-meshed gillnets. The development of the Norwegian fishery was reviewed by HAUG (1984). Traditionally the winter gillnet fishery in the deep fjords and shelf areas exploited the mature fish, while both mature and immature fish were caught by long lines in shallower bank and coastal areas. The gillnet fishery on the comparatively dense concentrations of spawners proved surprisingly efficient, and the catch rates soon declined from the initial high levels of the late thirties. Despite an almost immediate introduction of protective regulations, i.e. minimum landing size, minimum mesh size and a closed season, it has proven impossible to avoid an evidently rather severe depletion of the stocks. At present, the bulk of the halibut landings are bycatches in trawl, Danish seine and long line fisheries for other species rather than from direct halibut fisheries, since these have proven largely unprofitable.

The potential of the Atlantic halibut stocks is clearly not utilized as long as the stock is left at a very low level of abundance. Since the halibut remains merely a bycatch species, it appears difficult to develop effective protective measures which would allow the stocks to grow. Minimum landing size is clearly not sufficient, and one alternative is to localize and close areas with consistent dense concentrations of juveniles.

A future research goal is hence to collect and improve the information on behavior and local distribution of the different life stages, particularly the ones vulnerable to towed gears. Recent studies of the halibut in North-Norway may fill some gaps in the knowledge of the biology and ecology of larvae and juveniles and improve the basis for a more rational management (HAUG 1984, HAUG and TJEMSLAND 1986, HAUG and SUNDBY 1987, KJØRSVIK et al. 1987, GODØ and HAUG 1987c.). In addition, however, a major effort on mapping of local distribution is required to make a closed area regulation feasible.

Greenland halibut

There remains little to add to the comprehensive reviews presented by and GODØ and HAUG (1987b) on biology, exploitation and management of Greenland halibut (*Reinhardtius hippoglossoides*) in the Northeast Atlantic. The Greenland halibut supports a true slope fishery in the Northeast Atlantic, but is also caught in fisheries for a mixture of species (redfish, cod, haddock, tusk, ling), mainly by bottom trawls and long lines. The trawl fishery developed in the latter half of the sixties, and from fishery-based assessments it appears that the Barents Sea-Norway Coast stock has been fully or quite heavily exploited since then. The potential for immediate increased yields is hence limited. It is unknown whether expansion by fishing deeper or along the eastern slope further southwards and northwards is profitable since rather few fishing trials have been made in these areas.

Future research goals are improved estimates of recruitment at an early stage, more documented information on migrations and distribution, spawning times and areas and on the variability in population parameters of growth and maturation. Very little is known about the interactions between Greenland halibut and other species e.g. Atlantic cod. GODØ and HAUG (1987b) assumes that cod is an important predator on the 0-, I- and II-group and found indications of an inverse relationship between the recruitment of the two species.

Pink shrimp (*Pandalus borealis*)

Most of the available literature on pink shrimp in the Northeast Atlantic is referred to by SHUMWAY *et al*. (1985) in a recent synopsis of biology, ecology and exploitation. The pink shrimp has a wide depth range; from about 50 to 1450 m, but in the Northeast Atlantic most fishable grounds are found from 80 to 500 m. STRØM and ØYNES (1973) offer the most recent maps of the numerous shrimp grounds along the Norwegian coast and in the Barents Sea, but several recently discovered areas in northern regions (even north of Spitsbergen) and the traditional North Sea grounds are not included.

Fig. 9 shows the Norwegian landings of pink shrimp from 1908 to 1986 and reflects the gradual expansion from an initial exploitation of the Skagerrak grounds and southern fjord grounds to the inclusion of numerous coastal grounds along the entire coastline and finally to an immense increase in the landings in the seventies as the offshore grounds in the Barents Sea - Spitsbergen region were discovered (RASMUSSEN and ØYNES 1970). Since the expansion into the offshore areas started, the scientific effort on pink shrimp increased and resulted in several reports (BRYAZGIN 1970, 1973, BERENBOIM 1978, TEIGSMARK 1983). The USSR and Norway conduct annual shrimp surveys in the Barents Sea-Spitsbergen region as part of the assessments (BERENBOIM et al. 1986, HYLEN and ØYNES 1986).

There is most probably no potential for expansion of the fisheries in traditional areas. On the contrary, the biomass of shrimp in the more profitable offshore grounds appears to be significantly reduced in the recent years (1985-), and the short-term prospects are not promising. The resources in the North Sea and the fjords and coastal areas are fully utilized. This has made the fleet search for new areas further north and in deeper waters. Although the chances of finding major unexploited concentrations may be limited, some vessels have made successful trials, also at depths exceeding 1000 m off Spitsbergen. This shows that going deeper may be possible, although the long-term return from deep-water shrimp fishing is uncertain.

The management of the shrimp resources relies almost entirely on swept-area indices from surveys and on fishery-based statistics. Thus, the development of more reliable methods for absolute abundance estimation should be given priority in the future. Further scouting in deep-water areas along the Spitsbergen shelf may be necessary to show whether a basis for fishing there really exists, but a more long-term aim must be to improve the basis for a rational management of the resources to

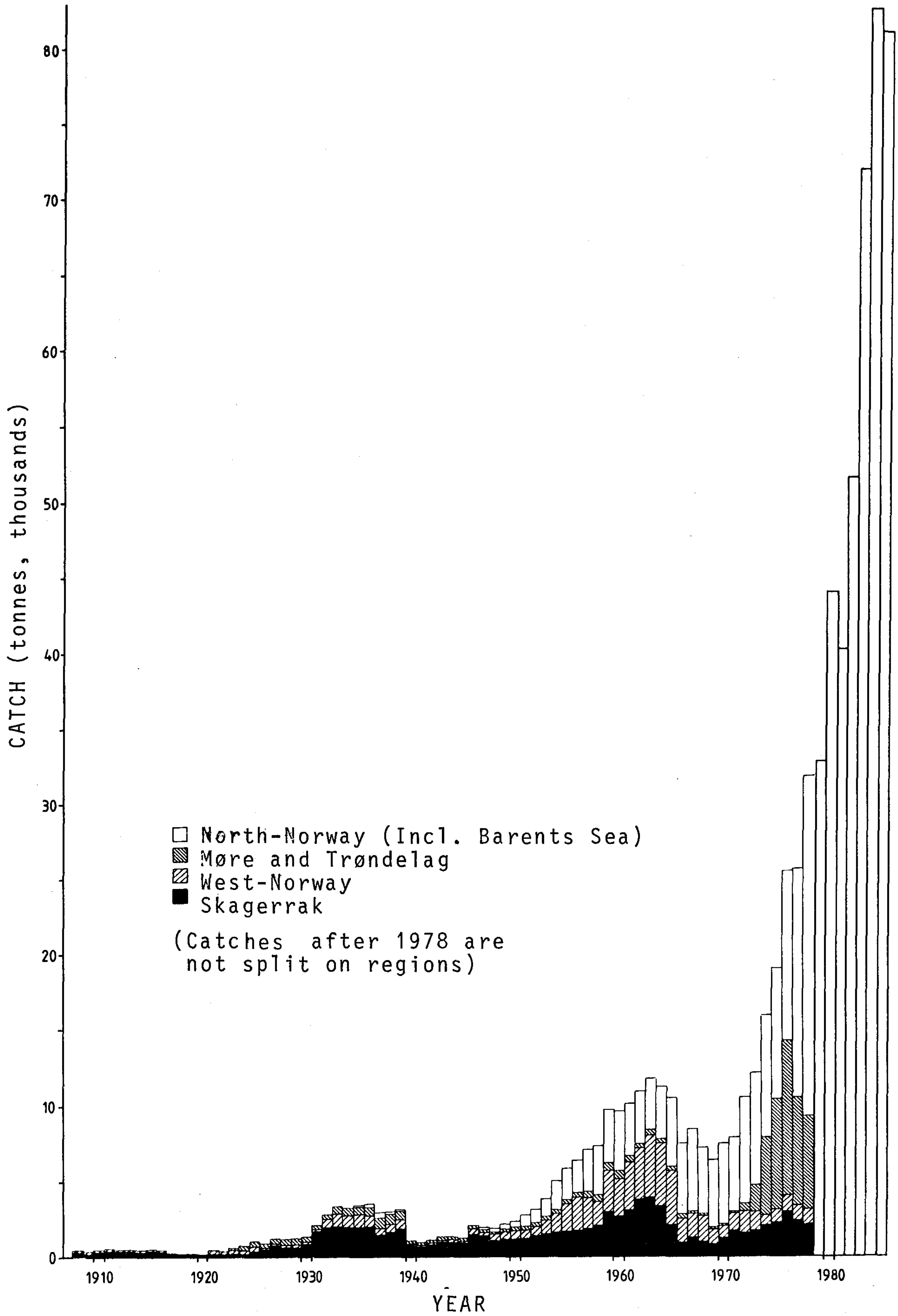

Fig. 9. Norwegian landings of pink shrimp (Pandalus borealis) in the period 1908-1985 from various areas. The landings from the districts of Møre and Trøndelag include shrimp from East Greenland. (Modified with permission from Teigsmark 1983)).

secure a reasonably steady return from the traditional areas.

It is frequently assumed that there exists a very close relationship between the dynamics of the major fish populations and the pink shrimp abundance variations. Hence an objective must be to include the pink shrimp in a multispecies management model, particularly in the Barents Sea where the pink shrimp is a major prey for Atlantic cod and other fish species. This requires a significant research effort on the feeding patterns of the predators as well as on the dynamics of the shrimp populations.

UNCONVENTIONAL DEEP-WATER RESOURCES

The few studies referred to earlier of fish distribution and species composition along the eastern slope of the Norwegian Sea did not leave any great hopes of finding new really abundant marketable fishery resources below the upper slope waters. This remains of course a conclusion drawn from a very limited amount of data sampled by gears which may have been poorly adjusted to slope fishing or inapropriate for the species present, a fact which underlines the need for improved techniques for observation and fishing at these depths and deeper.

The only demersal deep-water species which are virtually unexploited and locally abundant and which should be relatively easily marketable are the roundnose and roughhead grenadiers. Some other upper slope and outer shelf species are not immediately marketable, but may be rather abundant and widespread, e.g. velvet belly (Etmopterus spinax), rabbit fish (Chimaera monstrosa), silvery pout (Gadiculus argenteus thori), rosefish (Sebastes viviparus), four-bearded rockling (Rhinonemus cimbrius), Vahl's eelpout (Lycodes vahlii) and others. Some interest has been focused on mesopelagic fishes and squids as potential resources, and these will be treated very briefly following sections on the Macrourids.

Roughhead grenadier

The roughhead grenadier has not been extensively studied in the

Northeast Atlantic prior to the late seventies, and the information on biology, ecology, distribution and abundance is still rather limited. Most of the literature has been contributed recently by ELIASSEN and coworkers (ELIASSEN 1983 a, b, ELIASSEN and FALK-PETERSEN 1985, ELIASSEN and JOBLING 1985) and SAVVATIMSKIY (1986).

The distributional area includes the eastern slope from Spitsbergen southwards to the Faeroe-Shetland ridge and the slopes to the west, north and east of Iceland and the Faeroes (ANDRIYASHEV 1954, YANULOV 1962, PECHENIK and TROYANOVSKII 1970, BAKKEN _et al_. 1975, ELIASSEN 1983 a,b, SAVVATIMSKIY 1985, MAGNUSSON 1977, 1978). Although the relatively cool water masses in and below the boundary layer between the Atlantic water mass and the Norwegian Sea Deep Water appears to be its primary habitat, the roughhead grenadier also occurs in the deeper parts of the Barents Sea and in some North-Norwegian fjords (ELIASSEN 1983 a, HOGNESTAD and VADER 1979). The lower depth range in the Norwegian Sea is somewhat uncertain, but off North-Norway the catches seem normally to decline from a maximum at 600-700 m towards deeper areas (ELIASSEN 1983 b, SAVVATIMSKIY 1986).

Most of the catches off Norway by trawls, long lines and gillnets consist of relatively large fish (BAKKEN _et al_. 1975, ELIASSEN 1983 a, b, SAVVATIMSKY 1986), and the distribution of the younger juveniles remains largely unknown. Probable spawning areas have been located along the slope from about N 66^0 to N 72^0, with areas of particular concentration off the Røst and Træna Banks (N 67^0 - N 68^{0}30') (SAVVATIMSKIY 1986, ELIASSEN 1983 a, b, ELIASSEN and FALK-PETERSEN 1985). The temperature range appears to be 1 to 4^{0}C. There may well be undetected spawning areas further south or north of these areas.

ELIASSEN and FALK-PETERSEN (1985) found clear indications of a major spawning season from December to early February, with peak spawning in January. This is supported by SAVVATIMSKIY's (1986) findings of concentrations of prespawning and spawning fish off the Røst and Træna Banks in December and January. The existence of a secondary late summer spawning period is however not excluded.

The abundance of roughhead grenadier has never been estimated, and there are no ways to calculate with any certainty the potential for exploitation. The only information available are catch rates from scouting surveys or fishing experiments with different gears (SAVVATIMSKIY 1985, 1986, ELIASSEN 1983 a). (Quite detailed reports on Norwegian commercial-scale fishing trials are available in Norwegian (ELIASSEN 1982, ELIASSEN and LORENTSEN 1982, ELIASSEN and BREIBY 1983, BREIBY and ELIASSEN 1984)). SAVVATIMSKIY (1986) reports trawl catches of 500 to 1440 kg/h in the best areas off North-Norway in December-January. These are the highest rates reported, probably obtained from spawning concentrations. In most of the surveyed areas the catch rates were from 100-500 kg/h or less. From May to October, on average 24 % of the gillnet and long line catches in the Norwegian experiments were roughhead grenadier, the rest mainly Greenland halibut, but at certain localities also tusk. A general conclusion from the gillnet and longline experiments was that the basis for a summer fishery solely for roughhead grenadier was weak. The combination of the three species gave however an acceptable return. It is unclear whether fishing by passive gears would be more profitable in other seasons. Shrimp trawl catches in April and September were very small (less than 30 fish/h).

The results seem to indicate that the roughhead grenadier is at times moderately abundant, and that a certain potential for fishing exists. It is probable, however, that it will remain an additional species in other fisheries, and that the greatest economical return will come from higher prices due to further stimulation of the demand on the human consumption market.

There is clearly a need for improved information on abundance and seasonal distributional changes. The density to the south and north of the areas so far investigated should be determined. Roughhead grenadier should be detectable with improved hydroacoustic equipment for observation close to slopes and at relevant depths. Despite recent research efforts on biology and ecology there are major areas of interest for further research e.g., the distribution of eggs, larvae and the juveniles, recruitment variation and migration patterns.

Roundnose grenadier.

As the roughhead grenadier, the roundnose grenadier (Coryphaenoides rupestris) remains among the poorly studied species in the Northeast Atlantic. There is no aimed fishery for the species, and it appears only in minor quantities as a bycatch in the trawl fisheries, mainly on the Skagerrak shrimp grounds.

The roundnose grenadier is not a slope species in the Norwegian Sea, rather a fish typical for rather deep (deeper than 300 m) and comparatively warm (above 5^0C) shelf basins or fjords. There are major concentrations in the deeper parts of the Norwegian Deeps in Skagerrak (HAMRE and NAKKEN 1970, 1971, BERGSTAD 1986), in the deep coastal basins off the district of Trøndelag, mid-Norway (ELIASSEN 1986), in the Vestfjord, North-Norway (ELIASSEN 1983c) and apparently sometimes in significant densities in several fjords, of which the Foldenfjord (N $64^0$45') and Trondheimsfjord (N $63^0$30') have been comparatively well studied (ELIASSEN 1983c, 1986). The species also occurs in all the major fjords of western Norway in which some bottom trawling has been done, i.e. Romsdalsfjord, Storfjord, Nordfjord, Sognefjord, Hardangerfjord (BAKKEN, E., Inst. of Marine Research, Bergen, unpubl. data, 1987). In all the areas studied hydroacoustically, the roundnose grenadier occurs as near-bottom scattering layers, but also to some extent pelagically up to 300 m above the bottom, mainly as single-fish traces (ELIASSEN 1986, BERGSTAD 1986, unpubl.).

The biomass of roundnose grenadier has been estimated hydroacoustically and by bottom trawl surveys in some areas. Some 15.000 tons were found in Trondheimsfjord, Foldenfjord and the shelf basins off the District of Trøndelag (ELIASSEN 1986), while the first and rather uncertain estimates indicate around 40.000 tons in the Skagerrak (BERGSTAD unpubl.). A potential annual yield of 15% of the standing stock would be around 2000 tons from Trøndelag and 6000 tons from the Skagerrak. In addition, there may be concentrations in other areas which would further enhance the potential. Despite the uncertainty of these calculations, there is no doubt that the roundnose grenadier is a locally abundant and significant unexploited resource in Norway and in the Skagerrak.

Recent research has resulted in data on size, age and sex composition of the major concentrations in northern and mid-Norway as well as information on growth, maturation and mortality (ELIASSEN 1986). There are indications of a late fall and winter spawning season (ELIASSEN 1986, BERGSTAD unpubl.), and the mean (scale-) age at first maturity is 8 and 10 years for males and females respectively. Small juveniles are often underrepresented in the trawl catches and may be distributed in other areas or somehow avoid the trawl. The average age in catches from Trøndelag was around 15 years, with 10-18 year old fish being most frequent (ELIASSEN 1986).

Future research should establish a better basis for the management of the roundnose grenadier by bringing forward improved abundance estimates, population parameters and data on spawning times and areas, also from the more promising unstudied areas. Specific topics of interest are the distributional patterns of the juveniles and recruitment variation.

Mesopelagic fish and squids

The lanternfishes *Benthosema glaciale* and *Notoscopelus kroyeri* and the Müllers pearlside (*Maurolicus muelleri*) have due to their overall high abundance been considered as potential fishery resources. Of the three, the *Maurolicus* is the one which occurs in considerable densities, e.g. in the northeastern North Sea and in the more open fjords of Norway. (GJØSÆTER 1978, GJØSÆTER and KAWAGUCHI 1980). The lanternfishes are abundant, but do not form very dense concentrations and are accordingly not considered to be of commercial interest. Based on a considerable research effort in the seventies and a few fishing trials, the impression is that even *Maurolicus* in the North Sea seldom form sufficient densities to support a commercial fishery (OLSEN 1972, GJØSÆTER 1978, DAHL 1985, BERGSTAD, unpubl.). The abundance appears to be highly variable seasonally and between years, and the hydroacoustic estimates in the seventies ranges from 20.000 tons to 1.6 million tons. A potential problem is also the characteristic cooccurrence of Maurolicus and euphausids (Meganyctiphanes norvegica) which makes trawl catches consist of a variable mixture of the two, often dominated by the latter.

Hence, at present there is no commercial fishery for the mesopelagic fishes, and the basis for future exploitation appears rather uncertain. An alternative would be deep-water squid fishing based on the presumed mesopelagic or benthopelagic spawning concentrations or overwintering stages of Todarodes sagittatus and Gonatus fabricii. Although both species have been recorded occasionally in considerable numbers in trawl catches and in stomachs of slope fishes, no regular areas of concentration have been localized. There is thus a need for further mapping of distribution and migrations to determine whether commercial utilization is at all feasible. A considerable amount of information on biology and distribution of the shallow-water and coastal life stages of both species has, however, been published in recent years. (WIBORG 1979, 1980, 1984, WIBORG et al. 1982, 1984, SUNDET 1985). A fishery by small one-manned boats in fjords and coastal waters for Todarodes sagittatus for bait and human consumption is the only present squid fishery in the Northeast Atlantic.

Among the almost entirely unexplored features of the mesopelagial of the Norwegian Sea are frequently observed and widely distributed scattering layers at 300 - 400 m depth. These are consistently present in the northern and western areas during the extensive hydroacoustic surveys for herring and blue whiting (DRAGESUND, O., Dept. of fisheries biology, Univ. of Bergen, pers. comm. 1987), but, surprisingly, very little pelagic trawling has been done to identify these scatterers. Hence, further identification is of some interest and needed to decide whether these are of commercial interest.

TECHNOLOGY FOR OBSERVATION AND ABUNDANCE ESTIMATION

The lack of adequate or satisfactory technology for observing, identifying and counting marine organisms is even more frustrating during deep-water studies than in shelf or coastal studies. The reliance on catch indices from a variety of gears, but mostly bottom trawls, is highly unsatisfactory due to the variable species- and size-selectivity of the gears which makes any conversion factors between catch rates and abundance uncertain, if not questionable. This is especially true when using gears which are likely to show depth-related changes in function.

Hydroacoustic technology must be considered as the most promising for future deep-water studies. The strongest motivation for the further development or modification of such equipment is that the combination of hydroacoustic surveys, applying echo integration systems, and trawl surveys most probably will remain the more useful approach for large-scale mapping of distribution and abundance and for various behavioral studies. The use of conventional hullmounted transducers for fish studies is at present limited by the loss of intensity being proportional to the fourth power of the distance between the transducer face and the target. In practice, this means that observation of fish echoes below 500-600 m becomes difficult. Reducing the transmitter frequency would increase this range, but the necessary increase of the pulse duration would make the resolution very poor and usually unsatisfactory. An additional problem when trying to observe fish near slopes is the rapid and depth-dependent elevation of the near-bottom zone in which fish echoes cannot be separated from the bottom echo.

The most reasonable way to extend the depth range of the echosounder is to use towed transducers, preferably with mechanisms which permits automatic tilting or rolling when working close to steep slopes. Tilting and rolling is required to make the beam axis stay normal to the surface of the bottom at any time, thereby securing acceptable near-bottom resolution.

Considering the normal area of distribution of commercial resources, other techniques suffer from limitations on the area coverage per unit of time or from being too costly for routine use or both. Conventional photography or video systems normally fall in the first category, although they have proven useful for mapping of benthic or bentho-pelagic organisms, i.e. bivalves and shrimp, normally in combination with traditional sampling gear. Video cameras on the headline of trawls have been applied with success, and towed bodies with cameras and other attached equipment, including transducers, may similarly increase the area coverage to an extent which would satisfy the requirements for large-scale studies. Despite their elegance and great potential for small-scale studies, manned submersibles or even today's remotely controlled vehicles are, however, much to expensive for studies of large areas. Unmanned cable-free vehicles with hydroacoustic equipment, cameras and various sensors may prove useful in the somewhat distant future.

The dependence on some kind of sampling gear will exist despite new technology for observation. Further sophistication of existing gear to remove or minimize the effects of selectivity and variable fishing efficiency should be stimulated, and a closer cooperation with commercial gear designers and people with practical experience might be fruitful. Application of technology for continuous monitoring of the gear performance is clearly beneficial.

TECHNOLOGY FOR DEEP-WATER FISHING

In the following, practical and economical aspects of deep-water fishing will be treated briefly along with some future demands for gear improvements.

Practical aspects

Bottom trawling

When the United Kingdom in 1973 (McDIARMID and HATFIELD 1975, BRIDGER 1978) and Germany (FDR) in 1974 (FREYTAG 1976) started their exploratory trawl fishery on the banks and continental slope to the west of the British Isles, the Russians had fished both exploratory and commercially for grenadiers for years (MAKLAKOV 1965), mainly in the western Atlantic.

The common experience from these investigations was that traditional bottom trawls could be used down to 700-800 m without encountering problems of any kind. Beyond this depth ordinary floats had to be replaced by special deep-water floats, of which most would withstand the pressure down to 1200 m. To maintain headline lift on greater depths, the floats had to be replaced by kites (flotation doors) (FREYTAG 1976). In order to increase the sinking speed and keep the gear on the bottom, it turned out to be necessary to add some extra weight on the doors (10-40%), depending on available length of the towing wire. Good bottom contact was moreover provided by using a heavy ground gear with spherical rubber bobbins, alloy chain and steel spacers. In addition, some attention had to be paid when shooting away these extra long warplengths. Thus one of the deepest tows ever reported, was done with the well equipped R/V "Walter Herwig" down to 2120 m (BOHL 1973).

Both McDIARMID and HATFIELD (1975) and FREYTAG (1976) found the usual echosounder useless for bottom fish finding on greater depths than 500-600 m, but the fish finders could still be used for navigational purposes. By using a low frequency oceanographic echosounder with bottom expansion it was possible to avoid rough bottom and coral banks (FREYTAG 1976).

In the Northeast Atlantic deep-water trawling is done in fisheries for Greenland halibut and pink shrimp off the coast of North-Norway and Spitsbergen. There is a demand in these fisheries for floats which can withstand pressures down to 1500 m together with rough treatment on deck (strokes). Headline floatation by kites is probably useless in the shrimp fishery, where the towing speed seldom exceeds 2.5 knots. A further improvement would be modifications which would permit trawling on more uneven and rough bottom than today. Bottom gear made of wornout tyres (Fig. 10) has for some time been used on rough bottom in the Bering Sea (WEST, B., N.E.T. systems, Bainbridge Island, USA, pers. comm., 1987) and on the Faroe Bank (JAKUPSSTOVU, S. H. i., Fiskirannsoknarstovan, Faroe Island, pers.

comm., 1987) with some success and further improvement of this bottom gear would most likely extend trawlable areas both in shallow and deep-water areas.

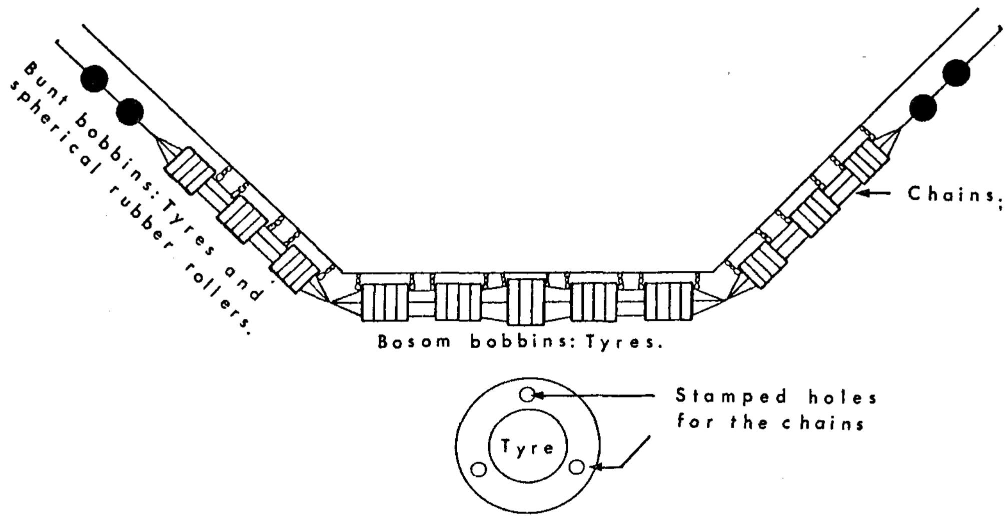

Fig. 10. Principal layout of a rough-bottom "rockhopper" gear.

Pelagic trawling

The fishery for blue whiting around the Faroe Islands and to the west of the British Isles is perhaps one of the best illustrations of deep-water pelagic trawling. The blue whiting is often caught quite close to the bottom at 300-500 m depth, especially during and after the spawning season. The trawls used in this fishery have no depth-limiting components like floats, the trawl mouth being simply forced up by weights on the bottom bridle. Hence, pelagic deep-water trawling is only dependent on specialized deck machinery to handle big quantities of wire and netsonde cable.

Gillnetting

Deep-water fishing with gillnets takes place off western and northern Norway in depths between 400 and 1000 m, mainly for blue ling, Greenland halibut and roughhead grenadiers. Strong currents combined with great depth require well dimensioned danline and hauling equipment. When fishing close to rocks or coral bottom, gear damage can be considerable. The commercial gillnet floats (rings) can be used down to 550-600 only. At greater depths these floats have to be replaced by spherical old-fashioned glas floats which will survive to 1000 m depth. Apart from this, there are no technical problems associated with deep-water gillnetting. ENGÅS (1983) mentioned several factors which may increase the gillnet catch of blue ling, for instance hanging ratio, soaking time and mixing of meshsizes within the gillnet chain. Moreover, experiments with odour (bait) attraction have shown positive effect on gillnet catches of cod and Greenland halibut (ANGELSEN and ENGÅS 1983), and may as well be beneficial for typical long line resources as ling and tusk.

Longlining

Longlining for ling, tusk and Greenland halibut takes place to the west and north of Norway down to 900 m. Bottom set long line has no depth limiting components like gillnets, and it should therefore be possible to operate this gear at much greater depths without problems as long as the danline and hauling equipment are properly dimensioned. In this manner, BOURNE and POPE (1969) reported experimental long line fishing to 2800 m without encountering any problems.

A topic for future research is the effect of hauling speed of long lines when fishing in deep-water. Catch loss, especially in rough weather, could turn out to be significant. Thus, recently some long line skippers have reduced the hauling speed when fishing for tusk, and claim that this does not affect catch per unit time, i.e. the catch loss during hauling is reduced (LØKKEBORG, S., Inst. of Fish. Techn. Res., Bergen, pers. comm., 1987).

Pot fishing

Various fish species are traditionally caught by pots around the world, one typical deep-water fishery has been the one for black-cod on the Pacific coast of the USA and Canada. In Norway, pots have mostly been used to catch shallow-water crustaceans and fish like lobster, crab, eel and cod. Exploratory fishing down to 500 m has however indicated that deep-water species like ling and especially tusk are caught by pots

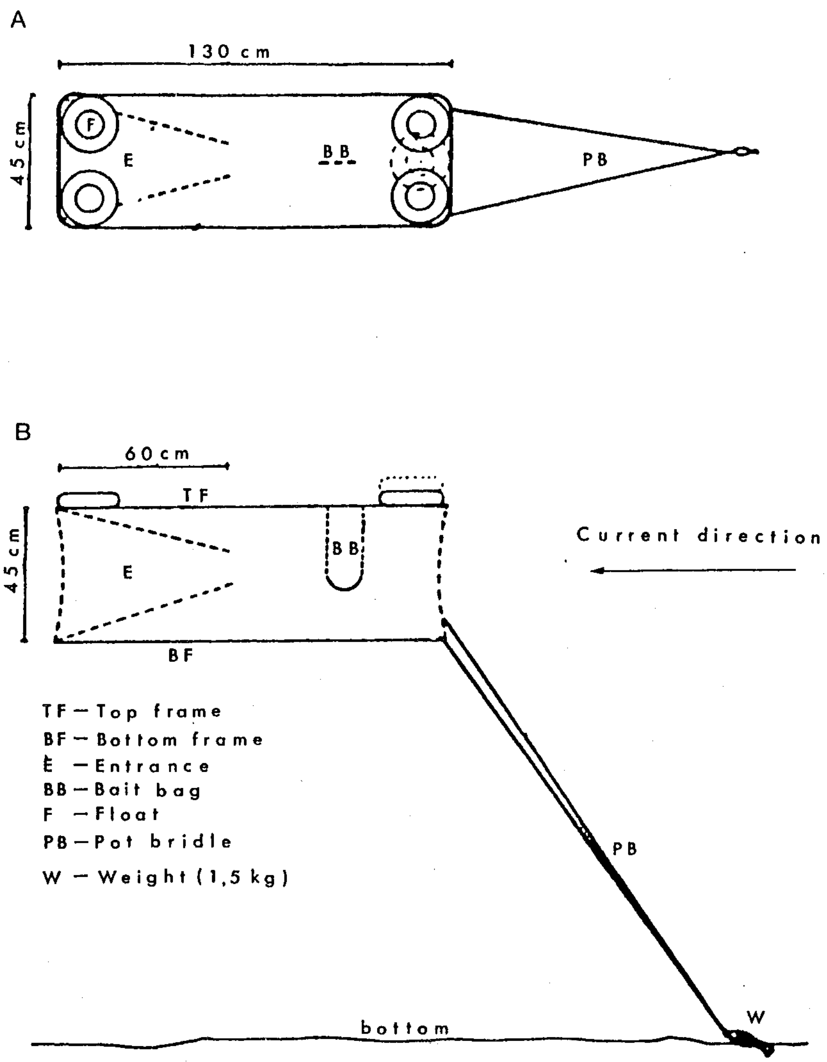

Fig. 11. Collapsible, buoyant pot for demersal fish (After Bjordal (1985)).

(VALDEMARSEN 1975). Studies of fish behaviour in relation to pots have shown that the orientation of the trap entrance relative to the current is of crucial importance (VALDEMARSEN 1977). Exploratory fishing with slightly buoyant pots (Fig. 11) has given maximum catches of 10 ling or tusk per pot (BJORDAL 1985).

Economical aspects

Deep-water fishing (beyond 600 m) differs from more traditional fishing in two main respects. The distance between boat and fishing gear is increased considerably, and the gear is more exposed to wear and tear, due to the weights (warps), the pressure (floats) and the often unknown bottom conditions.

Both McDIARMID and HATFIELD (1975) and FREYTAG (1976) mention lost fishing time as the most distinct disadvantage in deep-water trawling. At depths between 200-400 m a commercial trawler would normally carry out about five four-hour tows per day. When fishing at 1100-1200 m only four tows of the same duration would be possible, that is, an income loss of 20 % compared with shallow water fishery with the same catch rate and fish price. Including increased wear and tear on warps and gear, and possibilities of gear loss, at least in new fishing areas, it is reasonable to assume that deep-water trawling for instance at 1200 m has to give nearly 30 % greater income per tow to give a return comparable with shallow-water trawling.

Lost fishing time will also be a disadvantage when fishing with gillnets, long lines or pots. Hauling of 2000-3000 m of danline takes considerable time, also the distance to the deep-water fishing areas is often longer than to traditional grounds. The effective fishing time, that is, hauling of the fishing gear itself, is reduced and has to be compensated for by a higher catch value per gillnet, tub (long line) or pot.

However, from time to time deep-water fishing (500-1000 m) has proven profitable, for instance gillnetting for blue ling, Greenland halibut and roughhead grenadiers. Similarly, deep-water trawling may be an acceptable alternative, as for a part of the Norwegian trawler fleet, for which the only alternative to being laid up was to go deep-water fishing for Greenland halibut, or fishing on rough bottom for redfish.

CONCLUSIONS

In general, the amount of documented information on biology, distribution and abundance of the Northeast Atlantic resources becomes less with increasing depth and with decreasing actual or potential commercial value. The primary reason is that the allocation of funds and effort has depended, and still depends, to a considerable extent on the demand for information from fishermen and administrators who are mostly concerned with the major shallow-water resources. The interest of the majority of scientists appears heavily influenced by this, and by the conviction that the low production rates at slope depths leaves no basis for major biological resources. A secondary reason is the rather frustrating observational problems at great depths. The demand for further research on deep-water resources has increased somewhat in recent years, and some of the research referred to earlier is a direct consequence of this.

We chose to separate this overview in sections on conventional and unconventional resources. The impression remains that, even for the conventional resources, there are rather major gaps in the documented knowledge of biology and ecology. Indeed, the quality of the data from which population parameters are estimated is poor for several species, and their use in conventional assessment models becomes unsatisfactory. The estimation of abundance or potential is either not attempted or virtually impossible with present effort or methodology. It is probable, although the quantitative evidence is lacking, that significant benefits in terms of more rational exploitation patterns and thereby, at least in the long-term, increased yields could result from further improvement of the data base for the assessment and management. At present it is very difficult to give sound advice concerning regulations, a situation which may lead to overexploitation or excessive protection.

Apart from benefits in terms of long-term increased landings from a more rational management, there seems to be no major immediate potential for increased exploitation of the conventional species. Some exceptions have been mentioned, such as an increased oceanic fishery for blue whiting, deep-water shrimp concentrations and redfish, Greenland halibut and greater argentine in unexplored areas etc., but most of the stocks appear fully or heavily exploited and the fishing pressure should rather be reduced than increased in most areas.

This situation has of course stimulated the interest for alternative species which are immediately catchable and marketable. The few studies which are relevant have not increased the hopes of finding major unexploited resources along the continental slopes of the Northeast Atlantic below 600 - 1000 m. The most likely reason is the existence of the comparatively shallow boundary layer between the warm Atlantic water mass and the Norwegian Sea Deep Water with prevailing negative temperature, combined with the general decreasing productivity with depth and distance from the shelf waters. Accordingly, future slope fisheries may not benefit greatly from fishing deeper, rather from utilizing the resources of easily marketable species at moderate depths. The more promising species is the roughhead grenadier, although it appears likely that even this will remain an additional species in fisheries for other species.

In the deep shelf areas and the fjord systems of Norway, there are several abundant species, but presently few of these are marketable. Rather significant concentrations of roundnose grenadier have been found in several areas, and this species ought to be easily marketable. The true potential for fishing for this and other species is uncertain and further studies of biology, distribution and abundance should be stimulated.

The development of a fishery based on mesopelagic fish must at least await further fishing trials in order to determine whether actual densities are sufficient for commercial exploitation. Deep-water squid fishing is not feasible unless future research can detect areas with dense overwintering or spawning concentrations. Further research on the deep-water stages is, however, highly relevant for the utilization of the shallow-water stages. Unidentified oceanic mesopelagic scattering layers in the Norwegian Sea should be explored, not necessarily because they are promising targets of a fishery, but to fill a gap in the knowledge of the areas fauna and ecology.

Indeed, there is much to be learned about the deep-water ecosystems of the Norwegian Sea. The introductory paragraph on species composition and hydrography should illustrate the need for further basic studies. We find, however, again reason to stress the opinion that there remains a great need for more adequate technology and methodology, both for sampling of organisms and for observation in a direct or indirect manner. This is true for basic research as well as for the applied resource-oriented science. For observation and abundance estimation of slope fishes, further development of hydroacoustic equipment is recommended, more specifically the development of towable transducers with tilting and rolling mechanisms. Indeed, it is recommended that major slope surveys should await further developments along this and other lines. This is required to move forward beyond the stage of mere catch records and semi-quantitative data on distribution and abundance.

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