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Monitoring beaked redfish in the North Atlantic, current challenges and future prospects

Benjamin Planque, Kristján Kristinsson, Alexey Astakhov, Yuri Bakay, Matthias Bernreuther, Eckhard Bethke, Konstantin Drevetnyak, Kjell Nedreaas, Jakup Reinert, Alexey Rolskiy, Thorsteinn Sigurdsson, Christoph Stransky

Beaked redfish (*Sebastes mentella*) inhabit North Atlantic waters in the depth range 100-950 m, over the continental shelf, slope and the open ocean and can be demersal or pelagic, at various stage of their life cycle. The geographical distribution of the species extends to most of the Atlantic waters from Newfoundland and the Labrador basin in the west to the Barents Sea in the east. The wide geographical distribution and large scale migrations, associated with a deep distribution which complicates trawling and hydroacoustic measurements as well as problems with tagging makes it a particularly challenging species to observe with conventional research methods We review these key challenges and explore possibilities for the coordinated observation of *S. mentella* in the North Atlantic that would best contribute to the assessment and ecological research of this species.

Keywords: *Sebastes mentella*, survey design, trawling, hydroacoutics, tagging, assessment, management

Contact author: Benjamin Planque, Institute of Marine Research, 9294 Tromsø, Norway. E-mail: benjamin.planque@imr.no, Phone: +47 77609721, Fax: +47 77609001

1. Introduction

There are four redfish species of the genus *Sebastes* found in the North Atlantic, i.e. golden redfish (*Sebastes marinus*), beaked redfish (*S. mentella*), Acadian redfish (*S. faciatus*), and Norway redfish (*S. viviparus*). *Sebastes* spp. are ovoviviparous species, i.e. eggs are fertilized, develop and hatch internally and larvae extruded soon after they hatch from eggs. They are long-lived, slow-growing, late-maturing, and have in general low natural mortality. These unique life-history characteristics of *Sebastes* spp. influence complex population structure (Cadrin et al., 2010) and also makes them highly vulnerable to fishing.

Three of the redfish species have historically been an important fishery resource in the North Atlantic. Acadian redfish has only been exploited along the eastern coast of North America. Golden redfish and beaked redfish have, on the other hand, mainly been exploited on the continental shelves and slopes of Greenland, Iceland, the Faroe Islands, Norway, and to lesser extend Canada. In the beginning of 1980 a pelagic fishery for deep-water redfish developed (Sigurðsson et al., 2006a) and in the early 2000s in the Norwegian Sea (ICES, 2011b). Little fishery has been conducted on Norway redfish although in recent years some exploratory fishery has occurred in Icelandic waters (ICES, 2011c).

In general, the redfish catches were high in the beginning of the fishery but rapidly declined because of overfishing. Little directed fishery now occurs along the east coast of North America and in the Norwegian and Barents Seas (ICES, 2011c). Most of the redfish fishery is now on the continental slope and shelf in Icelandic waters on golden redfish and beaked redfish and in the pelagic ocean of the Irminger Sea on beaked redfish (ICES, 2011c).

The description of the pelagic fishery in the Irminger Sea and adjacent waters since the start of the fishery is thoroughly described in Sigurðson et al (2006a). The commercial fishery for pelagic *S. mentella* in the international waters of the Irminger Sea started in 1982 by the former USSR. Other nations joined the fishery and the annual landings quickly rose. The fishery at the beginning was conducted west of Reykjanes Ridge at depths between 50-250 m on pre-spawning and spawning aggregation from early April to mid-May, on post-spawning fish from late May to mid-June, and on feeding aggregations from mid-July to August. In early 1990s two distinct pelagic fisheries developed. In the northeast of the Irminger Sea, within and outside Icelandic EEZ, the fishery expanded to deeper waters (500-800 m), whereas shallower fishery (150-350 m) expanded to the southwest Irminger Sea. The northeast fishery is mainly from the spring to early summer, whereas the southwest fishery is in the later months of the summer and in the autumn.

Annual landings of pelagic deep-water redfish of the period 1982-1993 ranged between 60,000 t and 100,000 t, declining to around 30,000 t between 1989 and 1991 when the East European countries reduced their effort. Annual landings quickly rose, when the fishery expanded in to deeper waters in the northeast Irminger Sea, to a record high of 180,000 t in 1996. Since then catches have declined drastically, especially in the shallower waters of the southwest Irminger Sea and in recent years very little fishery is conducted. The main fishery is in the northeast Irminger Sea and annual landings since 2005 has ranged between 30,000 and 70,000 tonnes.

Traditionally, the main fishing grounds in the Northeast Arctic were north of Norway towards Spitsbergen. In the Northeast Arctic the highest landings were 293,000 t in 1976 followed by rapid decline to 80,000 t in 1980-1981 and in 1987 only 10,500 t were caught in the Barents Sea. At this time, the fishery expanded further south along the continental slope of Norway at approximately 500 m depth. After an increase to 49,000 t in 1991, the annual landings has since then been around 10,000 t and is mainly originated from by-catches in other trawl fisheries.

A directed pelagic fishery for deep-water redfish in the international waters of the Norwegian Sea has developed since 2004 (ICES, 2011b). The annual landings quickly rose to approximately 30,000 t, but have since then declined rapidly and in 2010 approximately 8,200 t were landed from this area.

The North East Atlantic Fisheries Commission (NEAFC) is the responsible management body of the directed pelagic *S. mentella* fisheries the international waters of the Irminger and Norwegian Seas, and ICES the advisory body. In both pelagic fisheries management of fisheries on pelagic redfish is based on setting an annual TAC. In the Irminger Sea, there has been no agreement on the TAC and allocation key between contracting parties, and some countries had set autonomous quotas. This has lead to much more catch than ICES has advised in the area. In the international waters of the Norwegian Sea NEAFC sets annual TAC for the area but it is not allocated to individual nations or vessels, i.e. the fishery is an Olympic fishery. Since January 1st 2003, all directed trawl fisheries for *S. mentella* have been forbidden in the Norwegian EEZ north of 62°N and in the Svalbard area.

Several acoustic surveys have been conducted on pelagic redfish in the Irminger Sea and adjacent waters (ICES 2011c). During the period of commercial fishery in the area, which commenced in 1982, the former Soviet Union, and later Russia, carried out acoustic surveys annually until 1993. These surveys provided valuable information on the distribution and relative abundance of oceanic redfish and on the biology of the species as well as on the oceanographic conditions of the area surveyed (e.g. Shibanov et al., 1996a). The acoustic measurements were, however, not considered sufficient for stock assessment purposes (ICES, 1991).

From 1991 to 1997, acoustic surveys were conducted annually by individual nations or in collaboration between two nations (ICES, 2011d). The survey area coverage was limited and it became obvious that two vessels were hardly enough to measure a species with such a wide distribution. In 1999, an international acoustic-trawl survey was carried out with the participation of Iceland, Germany, and Russia. In this survey, pelagic redfish measured by acoustics and also with so-called "trawl method". The reason for this is that acoustics could only measure fish down to approximately 500 m depth. Attempts have been made to measure below that depth, but without success in obtaining any reliable stock size estimate. The reason is mainly due to the "deep scattering layer" (DSL), which is a mixture of many vertebrate and invertebrate species (Magnússon, 1996) mixed with redfish. Although several attempts have been made by Russia and Iceland to map the distribution of pelagic redfish at depths below 500 m (Shibanov et al., 1996b) (Sigurðsson and Reynisson, 1998), the 1999 survey provided for the first time an estimate on the abundance of the pelagic *S. mentella* deeper than 500 m. Since then, the survey has been conducted in this manner biennially with two to five research vessels.

In the Norwegian and Barents Seas several surveys are conducted that are of relevance for *S. mentella* in the area. Most of them are bottom trawl surveys conducted by Norway and Russia. During August 2008 the horizontal and vertical distribution of pelagic *S. mentella* in the open Norwegian Sea basin was investigated by an internationally coordinated survey with three vessels from Russia, Norway and the Faroes carrying pelagic trawling and hydroacoustics. A similar survey was conducted in 2007 and 2009, but only over a restricted geographical and only by Norway (ICES, 2009a).

The main objective of these surveys has been to obtain biomass estimates pelagic redfish in the Irminger and Norwegian Seas. Other objectives have been to map the distribution and to collect biological of redfish and environmental data in the area. The results from the surveys are the basis for the ICES advice on pelagic redfish in the areas. No analytical assessment is conducted and stock statuses are based mainly on the perception of the biomass trends derived from survey indices. The Working Group on Redfish Surveys, (WGRS, formerly PGRS/SGRS) has been responsible for the planning of the international trawl/acoustic surveys of pelagic redfish in the Irminger Sea and adjacent waters since 1994 and in the Norwegian Sea since 2009 and corresponding reports on the survey results.

The objective of the paper is to provide a thorough description of the challenges involved when monitoring *S. mentella* and recommendations on how monitoring could be conducted in the future, given the importance of monitoring for the description, understanding and provision of advice on the fisheries of *S. mentella* populations across the North Atlantic ocean.

2. Geographical extent

Sebastes mentella is widely distributed in boreal waters of the North Atlantic and adjacent seas of the Arctic Ocean. Its habitat in the west covers the area from Nova Scotia to Baffin Island and Disco Island near West Greenland; in the east it covers the area from the Northern North Sea along the continental coast and extends northward and north-eastward to the Norwegian and Barents Seas. The species occurs on the Faroe-Iceland Ridge, in the waters of Iceland and East Greenland (Fig. 2.1, Andriashev, 1954, Templeman, 1959, Hureau and Litvinenko, 1986, Cadrin et al., 2010). The seasonal and ontogenetic migrations between the different areas and depths as well as the meta-population structure over the whole North Atlantic basin are further discussed in sections 3, 4, 6, 14 and 15 of this document. The area of pelagic distribution of the species is around 660,000 NM^2 for the Irminger and Norwegian Seas combined, which requires 130-150 days-at-sea to survey, in addition to effort needed to survey the demersal components on continental shelves, a situation that imposes international collaboration (ICES, 2009a). Because *S. mentella* is found demersally and pelagically and since the depth distribution of redfish extends down to ~1000m, the species is usually not well sampled by conventional demersal or pelagic fish assessment surveys, and rather requires dedicated sampling protocols.

Conclusion: The geographical and depth distribution of *S. mentella* in the North Atlantic are very extensive. Monitoring requires dedicated international effort of >150 days-at-sea to cover the species distribution.

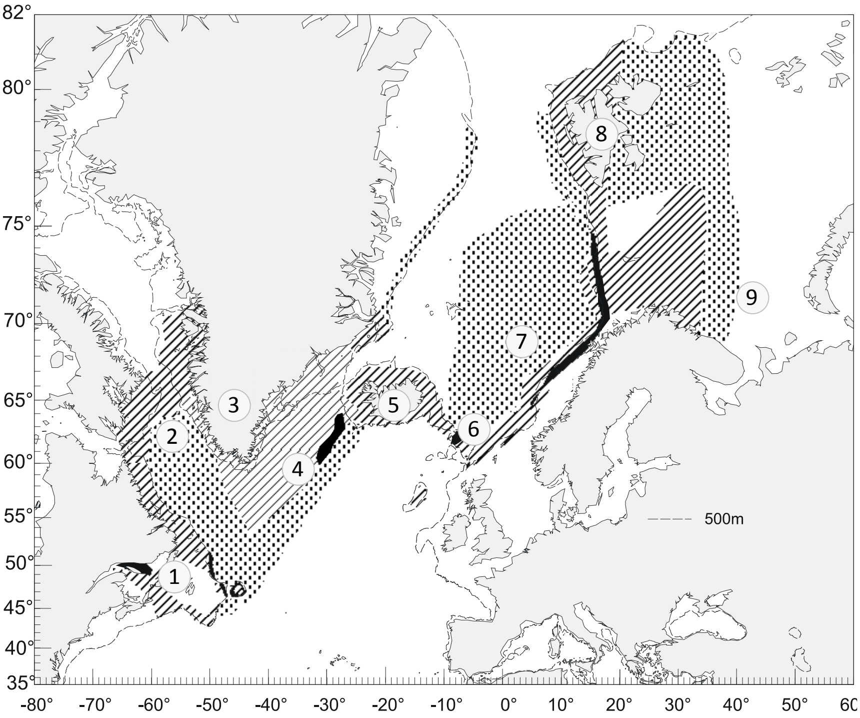

Fig. 2.1. Geographic range of Sebastes mentella*. The hatched area shows the centre of abundance. The dotted area is the outer sector of distribution range. The black area along the slope shows the main area of larvae release. The dashed line indicates the 500m depth contour. Numbers indicate geographical locations: 1: Newfoundland; 2: Davis Strait; 3: Greenland; 4: Irminger Sea; 5: Iceland; 6: Faroe Islands; 7: Norwegian Sea; 8: Svalbard; 9: Barents Sea. Reproduced from Cadrin et al (2010).*

3. Pelagic-demersal mixing

All the *Sebastes* species in the North Atlantic show various kind of pelagic and demersal behaviour during their life span. All *Sebastes* species are viviparous. Larvae extrusion takes place in late winter–late spring/early summer, but copulation occurs in autumn–early winter. Little is known about the copulation areas. The larvae ascend to the surface layers (0-60 m) as they are transported by sea currents from the larvae extrusion (“spawning ”) areas to the nursery grounds where the juveniles settle. During the first autumn and winter the 0-group redfish descend to near bottom habitats and may be captured by shrimp trawls towards the end of the year, causing some of the shrimp trawling fields to be closed, although the vast majority of this young and small redfish may live semipelagic above the bottom.

When they are 5-6 years old and more, they begin to gradually migrate against the current to locations along the continental slope, especially *S. mentella. S. marinus* and *S. viviparus* possess these migrations more within the shelf area and closer to the coast (Drevetnyak and Nedreaas, 2009).

Most of the research survey abundance time series from the continental shelf are abundance indices estimated from bottom trawling representing approximately the 10 meter bottom layer. During many of these surveys hydro acoustics are also used to scrutinize the redfish abundance in the whole water column including the bottom layer. The ratio between acoustic redfish s_A values in the pelagic water column above 10 meters from bottom and the acoustic redfish s_A values within the 10 m bottom layer could then be taken as a proxy for how much the abundance index estimated from bottom trawl catches only (which is assumed to be proportional to the 10 m bottom layer s_A value) should be multiplied to get closer to the total redfish abundance in the area. This approach is illustrated in Figure 3.1 which is taken from a North East Atlantic Fisheries Commission (NEAFC) working group collating information on the distribution of *Sebastes mentella* in ICES sub-areas I and II (Anonymous, 2009a).

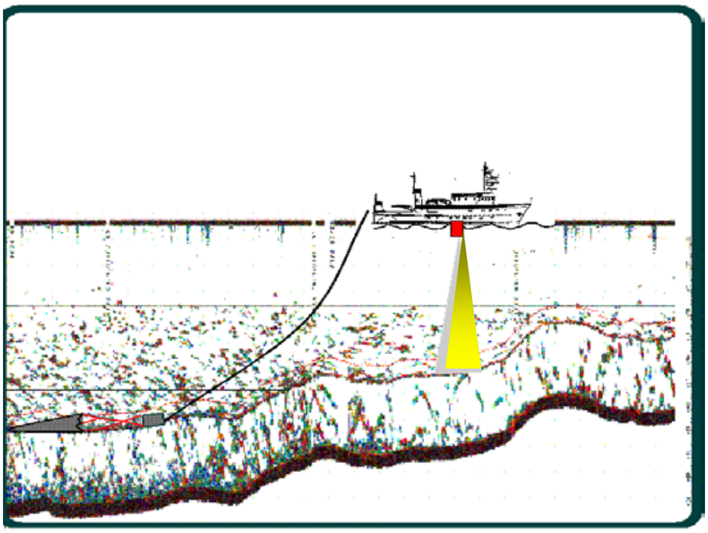

Figure 3.1. Illustration of the 10 meter bottom channel covered by a bottom trawl and the entire vertical distribution of redfish which is possible to cover by hydro acoustics.

During nine surveys (more than 12,000 nautical miles) in the Barents Sea and Svalbard (Spitsbergen Archipelago) in 2007-2009 hydro acoustic data scrutinized for redfish were analysed. The pelagic portion was very stable and varied from 72% to 85% during all those surveys, with an average of 80%. This is a likely ratio taking into account the semi pelagic behaviour of the species. There may be size or age differences in this pelagic behaviour, but the data did not allow for a more detailed analysis on this, and the Working Group decided to raise all the bottom trawl abundance indices by a factor of 5 to account for the entire water column.

Similar was done to the continental slope bottom trawl survey data. Parallel hydro acoustic estimation during the spring 2009 slope survey shows that about 10% of the redfish is within the 10 meter bottom channel. The Working Group finds it likely that a greater portion of the redfish is living pelagic above the bottom channel along the slope. A factor of 10 was hence used to raise the bottom trawl indices to total abundance along the continental slope.

Little is known about the mechanisms that trigger a pelagic or demersal behaviour, but it is related to size (age), grazing and search for food and mating/larvae extrusion. Among the *Sebastes* species, *S. mentella* is probably the species that most frequently and to the greatest extent change between a demersal and a pelagic way of living. In the Northeast Atlantic, mature *S. mentella* extend their feeding out in the Norwegian Sea (see e.g., Figure 8.1), and have inhabited the international waters in the middle of the Norwegian Sea from late May until mid November. Then they return back to a demersal or semi-pelagic way of living along the Norwegian continental slope where they extrude their larvae in March-April. Similar is seen in the Irminger Sea where mature *S. mentella* live pelagic. Different stocks of *S. mentella* in this area show different degree of pelagic behaviour.

Conclusion: In order to assess the state of the stock, it is necessary to survey the whole distribution area of *S. mentella* in Subareas I and II, both the pelagic and the demersal components (ICES, 2011a). Coordinated pelagic and demersal surveys should be continued. It is recommended that demersal trawl surveys should be supplemented by simultaneous and synoptic acoustic scrutinizing of the water column to reduce the temporal and spatial variation in total abundance estimation. It is also necessary to define a best practice on how to combine trawl swept-area estimates and acoustic estimates to derive total abundance estimate that are as accurate as possible. The works of Aglen et al. (1997) and Hjellvik et al. (2003, 2007) may be useful in this regard.

4. Seasonal migrations

Spatial distribution of *S. mentella* in the Irminger Sea and adjacent waters and in the Norwegian and Barents Seas is described in Section 2. Stocks of *S. mentella* in these areas inhabit both pelagic and bottom habitats and are distributed over wide range of depths, down to 1000 m. Spatial and seasonal migration patterns of the stocks are still largely unidentified although it is known that adult *S. mentella* undertake large migration between mating grounds, larval extrusion grounds and feeding grounds.

Males and females mature at different times. Males mature in August-November, at the time of mating. The location of copulation remains uncertain (Anonymous, 2004). Copulation and larval extrusion are believed to occur in different areas since males and females have different spatial distribution during larval extrusion (Magnússon and Magnússon, 1995). Males are generally more abundant than females outside the main extrusion areas. The females carry sperm and non-fecundated eggs for several months before fertilization occurs in January-February.

In the Irminger Sea, after larval development, females migrate to the open ocean where larval extrusion occurs from April to June with peaks in late April/early May. Larval distribution in the Irminger Sea is continuous although the main concentration area may vary between years. Pelagic fry drift to nursery areas that are found along the coast of East Greenland, and to some extend of West Greenland, where they settle to the bottom (Magnússon and Magnússon, 1995). As juveniles mature they migrate into the stocks found in deeper shelf areas and in the pelagic zone into the Irminger Sea and adjacent waters, with unknown shares. No nursery grounds have been located in Icelandic and Faroese waters.

After extrusion of larvae, adult redfish migrate northward towards the slopes of northwestern Iceland and East Greenland, and to the west and southwest towards the shelf and slopes of East Greenland. Fishing pattern reflects this geographic and depth distribution for which two distinct fisheries have developed (Sigurðsson et al., 2006a). First, a pelagic fishery in the northeast part of Irminger Sea west of Reykjanes Ridge, close to and within the Icelandic 200 nautical mile EEZ, and close to the continental shelf of Iceland, at depth from 500 m to 900 m. This fishery has mainly been conducted from mid April to end of June/beginning of July. Second, a fishery that extended to the southwest in the NEAFC area and into NAFO areas south of Greenland at depths down to 350 m. The international redfish surveys reflect this distribution of adult redfish in the area (ICES, 2009b) with redfish in the upper layer down to 500 m being mainly distributed west and south-west with the highest concentration south and south-east of Cape Farwell, Greenland, whilst the greatest abundance of pelagic *S.mentella* below 500 m is found in the northeastern part of the survey area close and within the Icelandic EEZ.

Very little is known about the adult distribution of pelagic *S. mentella* in the Irminger Sea from September to March, when the larvae extrusion starts again.

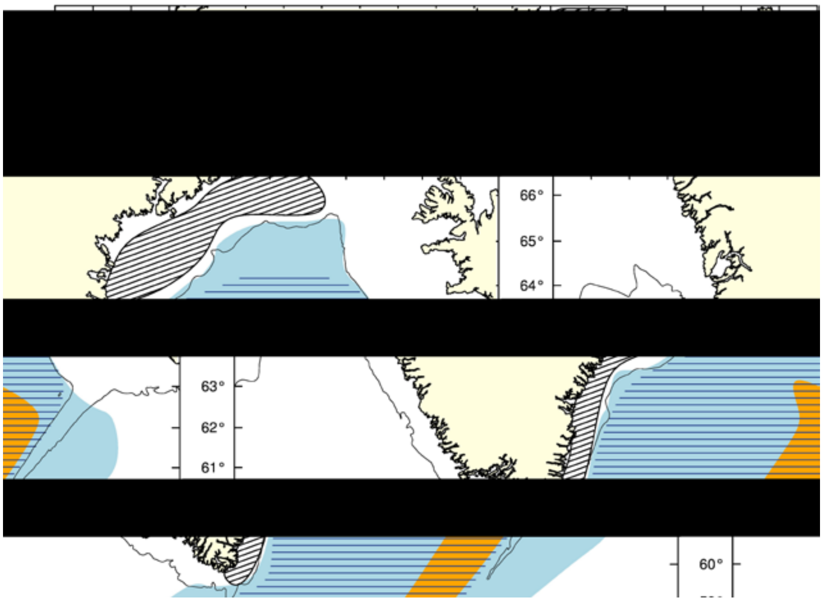

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Figure 4.1. Distribution of pelagic redfish in the Irminger Sea and adjacent waters at different stages of the life-cycle.

S. mentella in the Norwegian and Barents Seas is found on the continental slope and shelf and in the ocean (Anonymous, 2009a). *S. mentella* in this area has a similar life cycle as the stocks found in the Irminger Sea and adjacent waters, i.e. males and females mature at different times and where copulation occurs in the autumn and larval extrusion in the spring. Larval extrusion occurs along the continental shelf break from 64°N to 74°N in March-April. Larvae drift northward along the continental slope in the surface layer towards the Barents Sea and shelf waters around Spitzbergen. Juveniles are mainly distributed in the Barents Sea and along the continental slope (Drevetnyak and Nedreaas, 2009). After extrusion, adults migrate to the open Norwegian Sea where a large fraction resides during summer and autumn at depths ranging from 150 m to 800 m (Figure 4.2). This fraction of the population has been targeted by a pelagic trawling fleet operating in the international waters during summer since 2004 (ICES, 2011b).

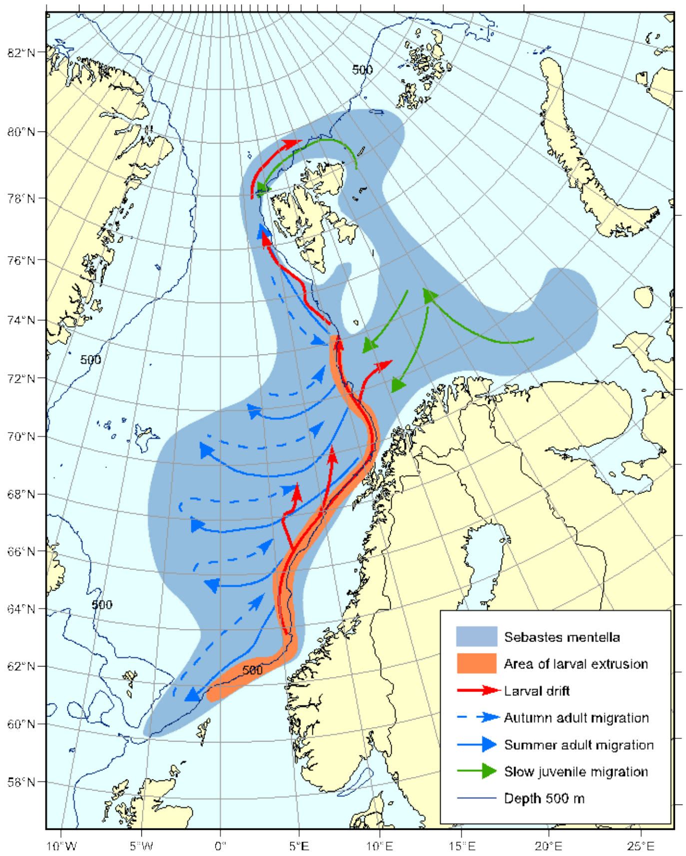


Figure 4.2. Schematic diagram of seasonal distributions and migrations patterns of Sebastes mentella in the Norwegian and Barents Seas. Reproduced from Drevetnyak et al. (in press).

Very little is known about the migration between the Norwegian and Irminger Seas, although genetic studies suggest that the individuals found in the shallow Irminger Sea and in the open Norwegian Sea belong to the same population. To date only limited genetic studies have been carried out on *S. mentella* in the Norwegian and Barents Sea and these suggest that only a single population inhabits these areas (Cadrin et al., 2010, Johansen et al., in prep).

Most of the current knowledge is derived from seasonal observations of the population through scientific surveys and by following the spatial distribution of the fishery. However, conventional tagging methods (capture, mark, release and recapture) can not be used with redfish since individual do not survive the barotrauma associated with the capture, and as a result direct observations of individual migration patterns are generally lacking. To date, only a limited number of fish have successfully been tagged and recaptured with the underwater tagging equipment (UTE, see section 9), in Icelandic waters. Attempts to use natural tags, such as otolith elemental composition to reconstruct individual histories are few and have had limited success (Stransky et al., 2005a).

Conclusion: Our current knowledge of the seasonal migration patterns of beaked redfish remains elusive and this could be substantially improved by conducting more *in situ* tagging at depths of several hundred meters on a routine basis (see Section 9). Such tagging, with special underwater tagging equipment, has been conducted in the Irminger Sea (Sigurdsson et al. 2006*a*), but has not been done since 2008. No such tagging has been conducted in the Norwegian and Barents Seas.

5. Longevity

Full analytical assessment of the stock size and development requires data segregation into cohorts (year-classes), thus correct age determination is the prerequisite for reliable age-based stock assessment. The age determination of *S. mentella* is generally difficult, time-consuming and highly variable (e.g. ICES, 2009d). For some stocks, indirect validation by following peaks in the length distributions has been attempted (e.g. Saborido-Rey et al., 2004). Only few studies, however, have been conducted for direct validation (radiometric otolith analyses by Campana et al., 1990, Stransky et al., 2005b), but these remain baseline studies due to their high methodological effort. For *S. mentella* in the Irminger Sea, a longevity of at least 40 years has been confirmed (Fig. 5.1).

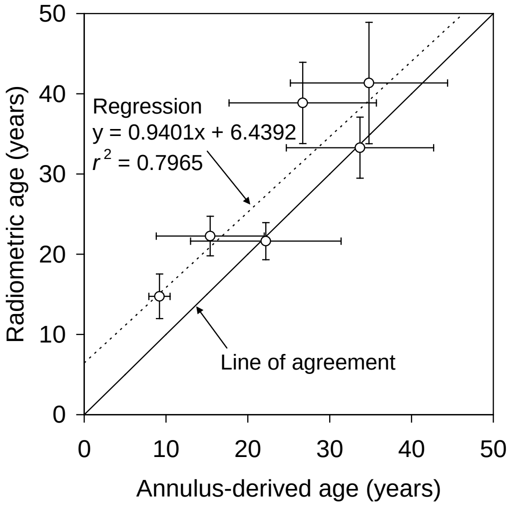


Fig. 5.1 Age estimates from otolith annulus counts for S. mentella in the Irminger Sea in relation to radiometric ages calculated from lead-radium activity ratios. Error bars represent ± 1 SD. Reproduced from Stransky et al. (2005b).

A promising validation technique that can (and should) be combined with tagging (section 9) is oxytetracycline (OTC) marking in order to follow growth increments in the otoliths from the time of marker injection (e.g. Greenland halibut: Treble et al., 2008).

Conclusion: Reliable age determination and validation efforts should be continued and combined with tagging and OTC marking of *S. mentella* otoliths.

6. Meta-population

A metapopulation is a system of discrete local populations (=stocks), each of which determines its own internal dynamics to a large extent, but with a degree of identifiable demographic influence from other local populations through dispersal of individuals (Kritzer and Sale, 2004).

In 2009, a workshop on Redfish Stock Structure (WKREDS) of the International Council for the Exploration of the Sea (ICES) analysed recent information on genetic stock structure of *S. mentella* in the North Atlantic in the context of existing biological information (ICES, 2009e). The main conclusions of the workshop – which were not unanimously approved by the participants - indicate that, based primarily on genetic information, four different stocks can be identified in the Irminger Sea and adjacent waters. The different stocks are separated horizontally and vertically but partly share an important nursery area, the East Greenland shelf. In contrast, the exact stock structure in the Norwegian and Barents Seas remains unresolved. Results of genetics, fatty acid analyses, morphometrics and otolith morphology (summarised in Cadrin et al., 2010) suggest that the Norwegian and Barents Sea stock, and eventually *S. mentella* dwelling east of the Faeroes, may form one distinct stock. The connectivity between the two large areas of the North Atlantic, the Irminger Sea and adjacent waters in the west and the Barents and Norwegian Seas in the east, but also between smaller areas like the shelf east and west of the Faeroes remain unknown. The exact meta-population structure remains heavily debated in the scientific community. A schematic of the different units is presented in Figure 6.1, but divergent views exist on the validity of this representation, even among the authors of the present contribution. An alternative to the schematic presented in Figure 6.1. suggests that there is only one population (stock) of beaked redfish in the Irminger Sea area (Makhrov et al., in press).

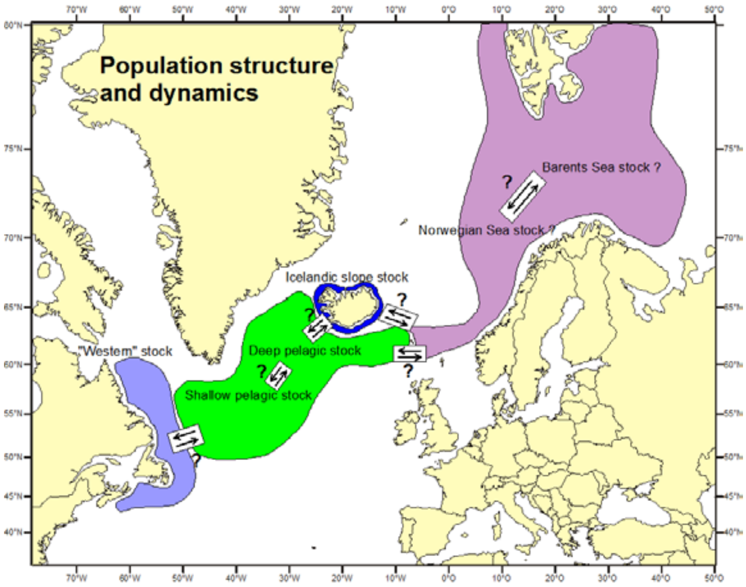


Fig. 6.1 Schematic stock distribution and connectivity of beaked redfish (S. mentella) in the North Atlantic

There are mainly three questions that arise concerning *S. mentella* in the North Atlantic: 1) Does *S. mentella* function as a metapopulation in the North Atlantic? 2) Do local populations act as sink or source of juvenile migrants in the metapopulation? And 3) to what extent does the commercial fishery affect the persistence at local and metapopulation levels? A more complete description of migration of adult fish between the habitats of the different stocks or the recruitment of juvenile fish from nursery areas into the adult stock would help in answering these questions (see section 4 and 15). This might be achieved by tagging studies, using dedicated underwater tagging equipment (section 9 and Sigurðsson et al., 2006b). Appropriate areas for tagging studies are many (Fig. 6.2); an intensive tagging effort in the Norwegian Sea and around the Faroe Islands would constitute a good starting point to investigate connectivity of *S. mentella* in the North Atlantic. Additionally, further extensive genetic studies over the whole geographical distribution area are essential for classifying the different populations into management units.

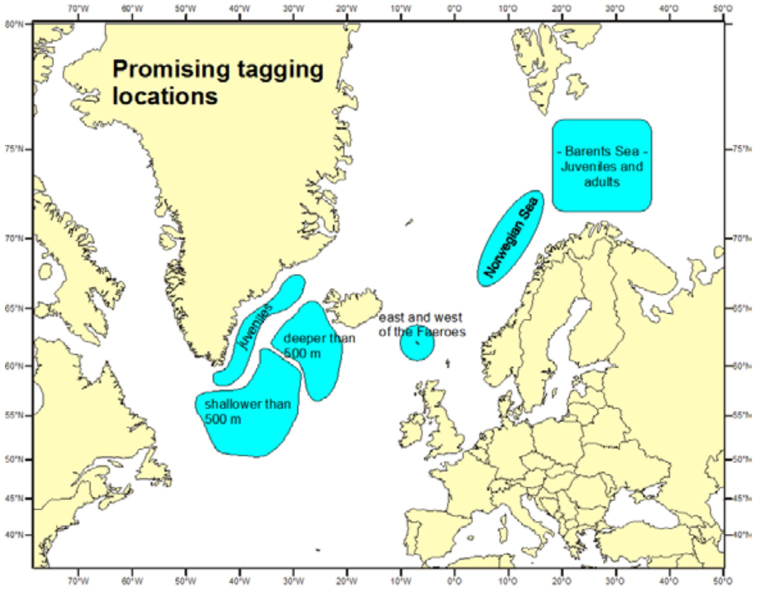
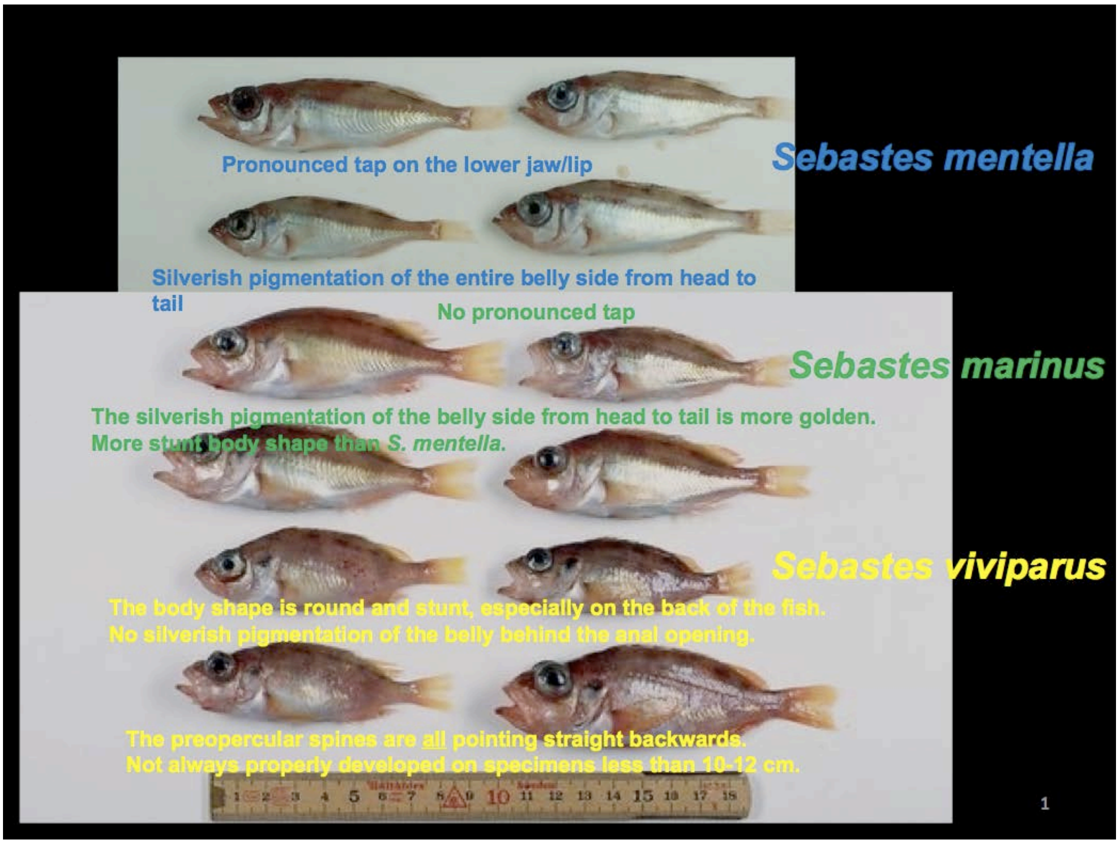


Fig. 6.2 Possible tagging locations that would help resolving meta-population structure of beaked redfish (S. mentella) in the North Atlantic.

Conclusion: Resolving the stock structure of *S. mentella* in the entire North Atlantic and identifying and quantifying the interactions between local populations (=stocks) remains a major challenge. A comprehensive genetic investigation and underwater tagging efforts in different areas will help solving this task. Although extensive genetic studies have been conducted on the adult stock of deep-sea redfish in the Irminger Sea, and some tagging studies have been conducted around Iceland, these studies remain absent or limited in other areas. Little is known about the redfish (both juveniles and adults) inhabiting the continental shelf and slope of Greenland. In the Norwegian and Barents Seas only few genetic studies have been conducted and tagging has never been attempted. It is recommended that such studies be conducted, as for example suggested in Figure 6.2.

7. Species identification

The four *Sebastes* species in the North Atlantic have very similar external features, and this make their differentiation based only on visual inspection of the external features very difficult, even for experts. An illustration of morphological characteristics for young specimen is given in Figure 7.1. Difficulties in morphological differentiation have several implications, for example, in the Northwest Atlantic *S. mentella* and *S. fasciatus* are managed together as beaked redfish, because the commercial catches cannot be split. Difficulties have been found also in some other areas between *S. marinus* and *S.mentella*, and in the Northeast Arctic many fisheries regulations are not redfish species specific in order to avoid confusion by the fishers. Morphometric studies had been previously used to distinguish *Sebastes* species and populations on both sides of the Atlantic (Misra and Ni, 1983) (Power and Ni, 1985) (Kenchington, 1986) (Saborido-Rey, 1994). The EU Redfish project (2000-2003, Anonymous, 2004) involved collaborative sampling efforts and analyses of genetics, morphometrics, reproduction and maturation, otolith shape, otolith chemistry, and growth. The overall conclusion of the results of the morphometric analyses is that the four *Sebastes* species inhabiting the North Atlantic are morphometrically distinct, but with gradients and differences within species between areas. The external features normally used to identify species have been revealed as problematic for a real identification of the species around the Faroes, and especially off Greenland. In Faroese waters, the use of the gasbladder musculature demonstrates a high proportion of correct species assignation, and being a relatively fast method, it is recommended to use it more frequently. In Greenland, pronounced problems with species assignation existed, but when used, the species assignation made by their genotype, the species become morphometrically distinct. Therefore, the species off Greenland are also perfectly distinct, but identification by the external features and the gasbladder musculature is problematic.



Pronounced tap on the lower jaw/lip

Silverish pigmentation of the entire belly side from head to tail

No pronounced tap

The silverish pigmentation of the belly side from head to tail is more golden.
More stunt body shape than *S. mentella.*

The body shape is round and stunt, especially on the back of the fish.
No silverish pigmentation of the belly behind the anal opening.

The preopercular spines are all pointing straight backwards.
Not always properly developed on specimens less than 10-12 cm.

Fig. 7.1. Photographs of young specimens of the three Sebastes species commonly found in ICES areas I and II. Key identification features are indicated in coloured text.

Several investigations on *Sebastes* species identification were made during the early 1990-ies using electrophoresis, i.e., genetic analyses of proteins (e.g. Nedreaas and Nævdal, 1989, Nedreaas and Nævdal, 1991b, Nedreaas and Nævdal, 1991a, Nedreaas et al., 1994). The investigations revealed diagnostic genetic criteria to separate the *Sebastes* species. Haemoglobin is diagnostic for *S. mentella*, while *S. marinus* and *S. viviparus* show the same haemoglobin pattern. Specimen less than about 60 mm, of all three species, had not achieved the adult haemoglobin pattern, hence making the separation of *S. marinus* and *S. mentella* specimens less than 60 mm impossible when analysing the genetic structure of proteins (this conclusion is, however, limited to the proteins analysed). The genetic structure of the enzyme malate dehydrogenase (MDH) is diagnostic for *S. viviparus*, and analyses of both haemoglobin and MDH is necessary to separate *S. marinus* from the other two species.

Genetic variation in DNA among and within species of the genus *Sebastes* (*S. viviparus, S. fasciatus, S. mentella* (including deep-sea and oceanic types) and *S. marinus* (both ordinary and giant types)) from the North Atlantic has been investigated by several researchers. The findings so far are summarized in Cadrin *et al.* (2010). Since the main focus in these works has been related to variation within species and population genetics, a protocol describing procedures and methods to use for diagnostic identification of species using DNA techniques is still lacking. It can though be mentioned that Johansen and Dahle (2004) investigated this by polymerase chain reaction (PCR)-based random amplification of polymorphic DNA (RAPD). They found that only one primer, OPA20, could be used to diagnostically distinguish among species.

Conclusion: Species identification based on morphological characteristics is uncertain and more difficult or even not possible for young and small individuals. Scientists and technician working on *Sebastes* samples must keep a high level of training in morphological identification. This should always be supplemented by additional techniques based on genetic analysis either on genotype or phenotype. A protocol describing procedures and methods to use for diagnostic identification using DNA techniques would constitute a significant advance for the identification of *Sebastes* species.

8. Deep distribution 1: hull mounted vs. deep towed hydroacoustics

Field observations of the vertical distribution of beaked redfish ranges from 100 m down to 950 m. On the continental shelves and slopes many individuals are located in the neighbourhood of the sea floor but a large fraction is also distributed pelagically. For example, an analysis hydroacoustic records in the Barents Sea from nine years of data showed that 80% of the biomass was located above the 10 m sea bottom layer that is accessible by trawling (see section 3). In the open basins of the Norwegian Sea the pelagic distribution is typically between 300 m and 600 m (Figure 6 in ICES, 2009a). In the Irminger Sea, the bulk of population biomass is located in or below the acoustic deep scattering layer (DSL) which is situated around 300 m during daylight hours (ICES, 2009b). Observations in the Norwegian Sea in spring show continuity between the continental, slope and open ocean distribution, as illustrated in Figure 8.1.

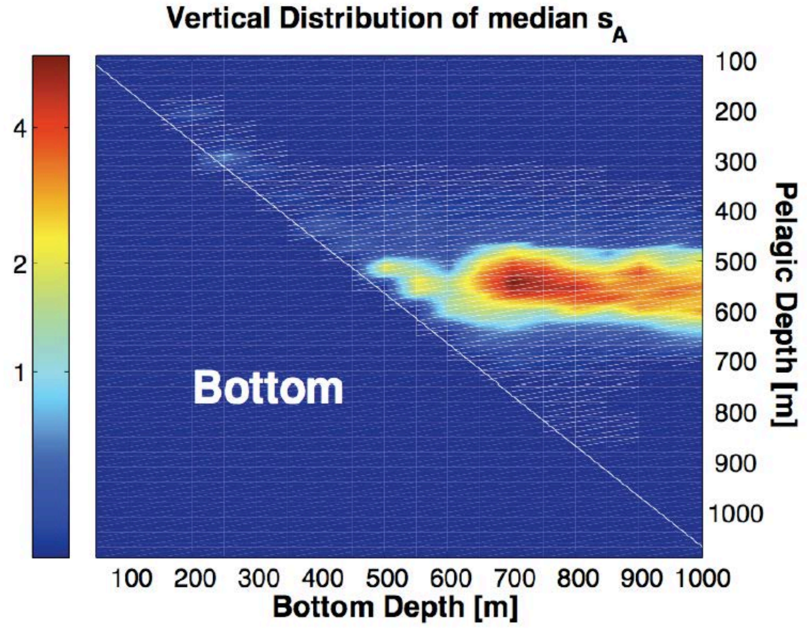


Figure 8.1. Vertical distribution of the median sA of Sebastes mentella as a function of bottom depth, as recorded during the Norwegian slope survey in spring 2009. The hydroacoustic registrations reveal a preferred depth range for S. mentella of 450-650m and dominance of pelagic vs. demersal distributions. Reproduced from ICES (2010a).

Acoustic energy echoed by a single target in inversely proportional to the 4th power of the range between the hydroacoustic source and the target, whilst acoustic noise (such as that generated by the vessel) is independent from the range. The fact that most adult redfishes are distributed at depths that exceed 300m and often below 500m therefore makes it difficult to use hull mounted hydroacoustics devices, which in such conditions unavoidably operate with poor signal-to-noise ratios. In addition, as the area of the acoustic beam increase with the power of the range, the chance of hitting simultaneously multiple targets increases with depth, therefore reducing the resolution of the detections and the ability to perform scrutinizing, echo counting or estimates of target strength. Finally, since many individual fish are located within the DSL, they are mixed with a collection of smaller animals present in great numbers (myctophid fishes, cephalopods, shrimps, jellyfishes, etc… see table 6 in ICES, 2009a) which generate acoustic reverberation. Such reverberation can hardly be separated from the individual target signal unless the resolution of the hydroacoustic signal is at a sufficiently high resolution. All of the above constitute severe difficulties for scrutinizing of echograms. In the Irminger Sea, the standard methodology adopted consist of scrutinizing echograms above the DSL whereas the abundance estimate within and below the DSL are derived from trawl catches using a regression analysis between s_A values and catches (see section 2.4 in ICES, 2011d). In the Norwegian Sea, scrutinizing has been carried out down to 800m (ICES, 2008a) and the scrutinizing methods have been reviewed (Planque et al., 2009) but international protocols and quality standards have not been adopted yet. Approaches and limitations to scrutinizing are discussed in section 12.

To solve many of these problems, John Dalen, Kjell Nedreaas and Ronald Pedersen conducted a study in the Irminger Sea during the summer 2001 with a deep towed transducer. The basic idea was to move the transducer closer to the fish targets, thereby increasing the signal to noise ratio, and increasing the resolution (Figure 8.2, Dalen et al., 2003). Not surprisingly, they found that abundance estimates using the deep towed transducer were superior to those from the hull mounted one. Below the DSL the abundance estimates could be up to 55% higher using the deep-towed transducer. Unfortunately, the experiment was never repeated and the deep towed transducer has not been implemented as standard equipment for deep-water registrations of redfish. This is probably explained by the cost of purchasing the equipment, the associated need for increased engineering capacity on board, and the reduce speed of vessel operations which directly affects survey coverage or spatial resolution.

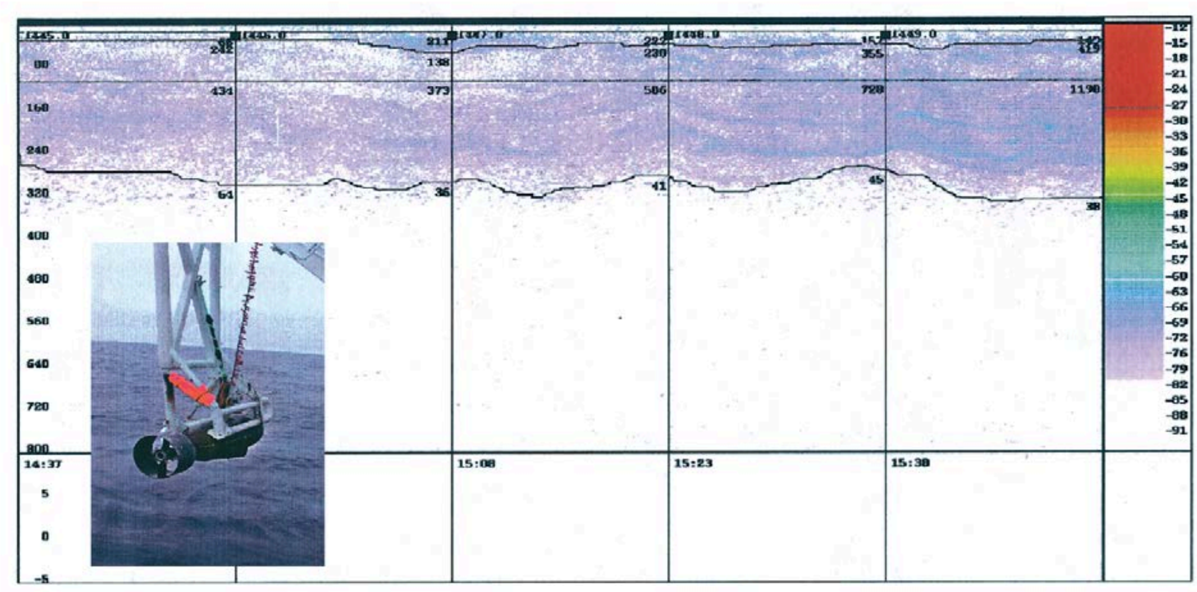


Figure 8.2. An echogram from the EK500 at 38 kHz with hull-mounted transducer. Numbers at the top indicate ship log (nmi). Numbers on the left indicate depths (m). Depth extension is 350–1100 m. Zero metre represents 350 m, which equals the depth of the vehicle. The colour bar displays the scale of the volume-backscattering strength. The insert shows the deep-towed vehicle being launched into the Irminger Sea. Reproduced from Dalen et al. (2003).

Conclusion: conducting deep-water hydroacoutic registrations on a routine basis remains a challenge because of the trade-offs between cost, time and instrumental resolution. The current situation is far from optimal and the methodology in use cannot deliver abundance or biomass estimates with a sufficient level of accuracy.

9. Deep distribution 2: tagging

Tagging has been used in fisheries research since the late 19th century (Petersen, 1896) and is a fundamental tool for studying the behaviour of commercial fish, especially after the advent of electronic tags (Arnold and Dewar, 2000). Tagging methods have generally involved bringing fish to the surface by various types of fishing gear and hauling them aboard, where the live fish are transferred to containers with seawater from which the survivors are tagged and released back into the sea. Although some improvements have been made in the capture and handling of fish, many species are very sensitive to this type of handling. The trip to the surface remains a major hazard for the survival of fish in tagging experiments (Jakobsson, 1970, Jones, 1979). This is especially true for a physoclistous fish with a closed swimbladder.

The redfish species have been considered almost impossible to tag by the conventional methods as the fish is unable to release the air of the swimbladder fast enough when it travels up from the high pressure deep waters to lesser depths. As a result, the swimbladder may expand and rupture and the expanded air can push the internal organs out through the oesophagus and mouth. Many attempts have been made to overcome this obstacle although not always well reported. Hislop (1969) described a method where a underwater tagging bench was used by four divers to tag fish caught by trawl or Danish seine (Jones, 1979). Fish have also been tagged in deep waters with baited tags (Priede and Smith, 1986, Armstrong et al., 1992). Such method depends on the ability of the fish to swallow the tag hidden in the bait. Manned submarines capable of shooting darts with acoustic transmitters have also been successful and given results in certain circumstances (Schauer et al., 1997).

Redfish is an important species in the deep-water ecosystem. Successful tagging of these animals may substantially improve understanding of the function of these ecosystems. Tagging can also reveal the growth of tagged fish and could, with sufficient effort, be used to estimate mortality rates.

The Marine Research Institute in Reykjavík, Iceland in collaboration with Star-Oddi Ltd. have approached the problem of tagging with redfish by constructing and building the Underwater Tagging Equipment (UTE) which makes it possible to tag redfish by a robot (Figure 9.1), in the fishes own environment, thus avoiding the hazardous trip to the surface (Sigurðsson et al., 2006b). This system allows redfish to be tagged in their natural environment without subjecting them to the journey from deep water to the surface. The main interest of the MRI in the UTE is to obtain more precise information on vertical and horizontal migration patterns of the various stocks of redfish, but also to obtain biological information such as growth.

Figure 9.1. The Underwater Tagging Equipment (UTE).

Since 2003, five cruises have been conducted to tag redfish, both in the Irminger Sea as well as on the shelves southwest and west of Iceland. During these cruises more than 2,400 redfish have been tagged, whereof 55 with electronic tags. In total, 52 recaptures have been reported to MRI (Figure 9.2) with fish having been in the sea for up to 4 years from tagging. None of the recaptures were electronic tags.

Although the tagging equipment has proven to be successful only Iceland has used it for tagging redfish. The reason is that the tagging needs to be performed on relatively large vessels. Also, tagging fish with this method is slow compared to conventional tagging and only around 100-150 fishes can be tagged per day. However, with current technology this is the only known successful method of tagging redfish at great depths. Since the knowledge of the life cycle and migration of different deep-sea redfish stocks is limited, greater tagging effort with joint effort of several institutes is needed in order to gain knowledge on important biological questions such as juvenile areas of different stocks, mating grounds, vertical and horizontal migration, and mixing between management units.

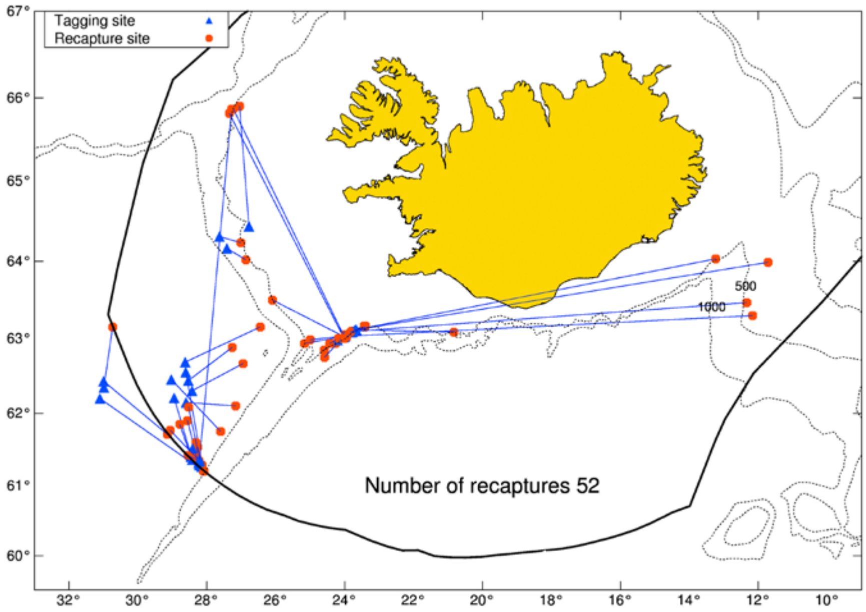


Figure 9.2. Tagging and recapture locations for deep-sea redfish tagged since October 2003. Red circles indicates recaptures and blue triangles indicates the tagging site. The lines between the two points indicate the shortest distance between the two positions. Updated figure from Sigurðsson et al. (2006b).

Conclusion: Tagging programs using the UTE could significantly contribute to resolve key questions related to migration (section 4), stock structure (section 6), age determination (section 7), recruitment (section 15), habitat (section 14) and diet (section 10). It is recommended that that such surveys be applied for in an internationally coordinated manner in the future.

10. Deep distribution 3: stomach content

Information on trophic relationships of *S. mentella* in the Irminger and Norwegian Seas are scarce. Observations show that deep-sea redfish in the Irminger Sea are opportunistic feeders that graze within the deep scattering layers mostly at 300-800 m depth and feed on invertebrate species and small fish (Magnússon, 1996). The most important food items are Copepoda, Euphausiacea, Mollusca, Decapoda and Myctophidae (Magnússon, 1996, González et al., 2000, Pétursdóttir et al., 2008, ICES, 2009b). Stomach content analyses are however rather difficult because a high proportion of redfish have everted stomachs when hauled to the surface. In the international redfish survey in 2009, 87% of fishes caught at shallower water than 500 m had either everted or empty stomachs and this was true for over 90% of those that were caught deeper than 500 m (ICES, 2009b). Similar results were reported in other studies (e.g. González et al., 2000). Due to this, it is difficult to evaluate feeding condition and food composition and therefore it is difficult to investigate tropic interactions in the area.

Although the main feeding items of redfish are known, more effort is needed to improve the knowledge of tropic interactions in the Irminger Sea and adjacent waters. Such research requires that representative samples to be taken and the main obstacle is the above-mentioned fact that most of stomachs are everted when the fish is hauled to the surface. In order to improve the sampling, the Unterwater Tagging Equipment (UTE, section 9) could be a tool for sampling whole fish *in situ*. With relatively minor changes of the equipment it should be possible to collect whole fish into bags which will be closed after the fish has entered into the bag and the stomach content can be analyzed although the fish comes everted onboard the sampling platform. Other method to investigate trophic relationship and feeding of redfish is using fatty acid and stable isotope analyses can also be envisaged (Pétursdóttir et al., 2008), although these can not provide detailed taxonomic resolution of the diet composition.

Conclusion: conventional stomach content analysis can hardly be performed on S. mentella, and at best provide very biased results, because of the high proportion of individuals with everted stomachs when hauled to the surface. This could be resolved through the use of a modified version of the UTE and by stable isotope and fatty acid analyses.

11. Target Strength

The measurement of the target strength of *S. mentella* is still an unsolved problem. The main problem has a biological origin – in contrast to other species, it is almost impossible to catch beaked redfish alive, which excludes traditional TS measurements as e.g. direct measurements of caged fish (e.g. Gauthier and Rose, 2001). The use of a TS probe (Ona and Svellingen, 2001) is also problematic because *S. mentella* redfish generally occur as single targets and it is difficult to get individuals for measurement into the TS probe. A practicable alternative seems to be *in situ* measurements, comparing the distribution of the cross-section of targets, computed from the length distribution of the catch, with the cross-section distribution obtained from the measured TS distribution (e.g. Ermolchev, 2009). A direct comparison of the echoes of *S. mentella* with echoes of the calibration is always useful in order to exclude calibration errors (Figure 11.1). The acoustical interaction between fish and calibration sphere (MacLennan, 2011) and the depth-dependency of TS-value of calibration sphere (Pedersen et al., 2005) can be neglected. The error introduced by this negligence is at present much below the overall measurement error.

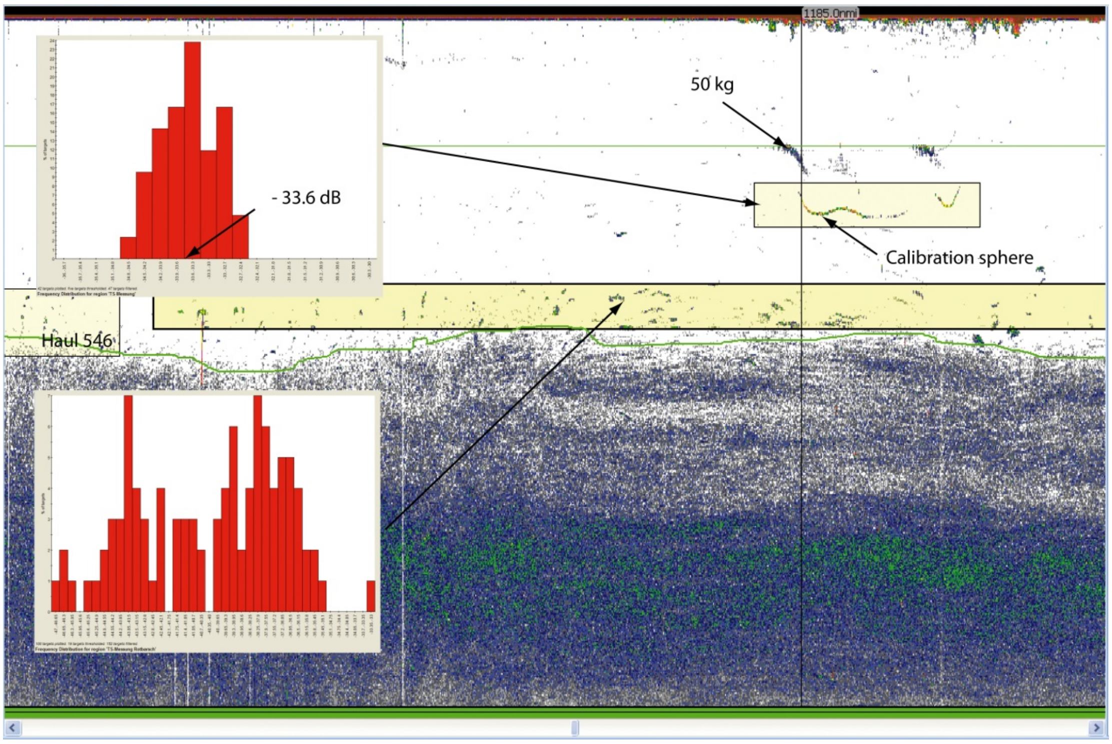


Figure 11.1. TS-measurements of S. mentella in the Irminger Sea during summer 2011. Direct comparison between the calibration sphere and redfish close to the sphere (depth of the calibration sphere about 150 m, trawl depth – headrope 207 m).

Here an extension to the method of Ermolchev (2009) can be proposed. From Figure 11.1 we can read that the measured TS-value of the calibration sphere is not a single value but a distribution of measured values. Fitting a Gaussian distribution function to the measured values for σ (cross section of the target) we can estimate the measurement error (σ_{sphere} = 0.0056±0.0009m^2). The same relative error we can expect for the measurement of σ_{TS} of redfish. In addition, a much larger uncertainty is added as a result of variation in acoustic response between individuals. Therefore, also due to the different position in space and the directivity of the fish body, we have to expect a wider TS- and σ_{TS} -distribution. However, computing the expected cross-section σ_{Length} from the length distribution results in one value for each certain length group. To introduce the stochastic character due to measurement errors and directivity variability, the σ_{Length} - distribution has to be convoluted with the probability density distribution of the variability. Here we assume again a Gaussian distribution. For symmetrical functions the convolution and the weighted moving average are identical procedures. The weighting function is given by Equation (1):

$$w_i = \frac{\Delta\sigma}{STD\sqrt{2\,\pi}}\; e^{-\frac{(i\,\Delta\sigma)^2}{2\,STD^2}}$$

$$with \sum_{i=-5}^{5} w_i \approx 1 \qquad (1)$$

Where *STD* is the standard deviation of the Gaussian distribution, $\Delta\sigma$ is the class width of the σ-distribution and *i* is the index of the neighbourhood (For illustration: the convolution of a distribution where only in one class is the value 1 with the weighting function according Eq (1) results in the given Gaussian distribution). After convolution both distributions, the σ_{Length}-distribution, computed from the length distribution of the catch, and the σ_{TS}-distribution measured with the echo sounder include the stochastic properties of the backscattering of sound and are therefore now directly comparable. The parameters *K* (intercept of the *TS*-Equation) and *STD* can be computed by e.g. a least square procedure

The data presented in Figure 11.1 were collected during trawl–acoustic redfish survey in the Irminger Sea and adjacent waters in 2011. Unfortunately due to the low number of trawl hauls it was not possible to collect enough data for the computation of reliable results. The obtained results were ambiguous, however, the computed values were within the expected range, which suggest that the method is appropriate.

Therefore, the state of the art data are still the results obtained by Reynisson and Sigurdsson (1996) and Pedersen *et al.* (2005). These Icelandic data, however, were reanalysed with a focus on the problem of multiple echoes by Reynisson and presented at the workshop WKTAR in 2010 in Tromsø (ICES, 2010c). A TS-value of -39 dB was estimated for *S. mentella* observed during daytime at a depth below 300 m with a mean length of 36.9 cm. Night-time data can not be used during the survey because in this time the deep scattering layer disturbs the measurements. For the standard–TS–Equation $TS=10log(L^2)-K$, a value of K=70.3 is estimated.

Norway carried out TS measurements during the EU-redfish project in June-July 2001 also in the Irminger Sea applying a hull mounted transducer and a transducer mounted in a towed body; both connected to an EK60. The Data were collected during day-time, however, for trawls at a depth of all but one of about 600 m, well below the DSL. The mean length of the redfish was larger than in the measurements of Reynisson and Sigurdsson (1996), but computing the intercept *K* results in a maximum value of K_{max}=71.0, a minimum value of K_{min}=69.1 and a mean value of K_{mean}=70.2 for eight TS measurements with 500 to 1800 targets.

The measurements of Reynisson & Sigurdsson (1996) and Pedersen *et al.* (2005) are in a good agreement, however, both measurements are based on the usage of mean TS values measured with the sounder. In measuring these TS values small-targets TS-values have to be excluded. An arbitrary threshold changes of course the average of the measured values. This effect can be mitigated by the new method described above. Here it is sufficient to recognize the σ-peaks in the distribution caused by the peaks in the length distribution a value for a mean TS is not needed.

The most recent synthesis of target strength measurements across the whole North Atlantic is provided in the report of the workshop on the Determination of Acoustic Target Strength of Redfish (WKTAR, ICES, 2010c). This was achieved through an extensive review of published and ongoing studies, from which data were evaluated, ranked, and served as input to a meta-analysis. The meta-analysis results indicated that the best candidate for a general model of *S. mentella* TS-length equation at 38 kHz is the free slope model: $TS = 10.6\ log(L) - 55.4$ (Figure 11.2). The fixed slope model resulting from this analysis has a K value of 69.7. However, the meta-analysis revealed important departures from this equation in individual studies and the reasons for such discrepancies are generally undetermined or at best very poorly documented. To address this problem the following three actions were recommended: 1) ensure that high quality acoustic/biological data for TS determination are collected during redfish surveys, 2) per-form simultaneous comparative measurements between EK500 & EK60 echosounders for Target Strength determination and 3) pursue the joint meta-analysis of TS measurements in further workshops.

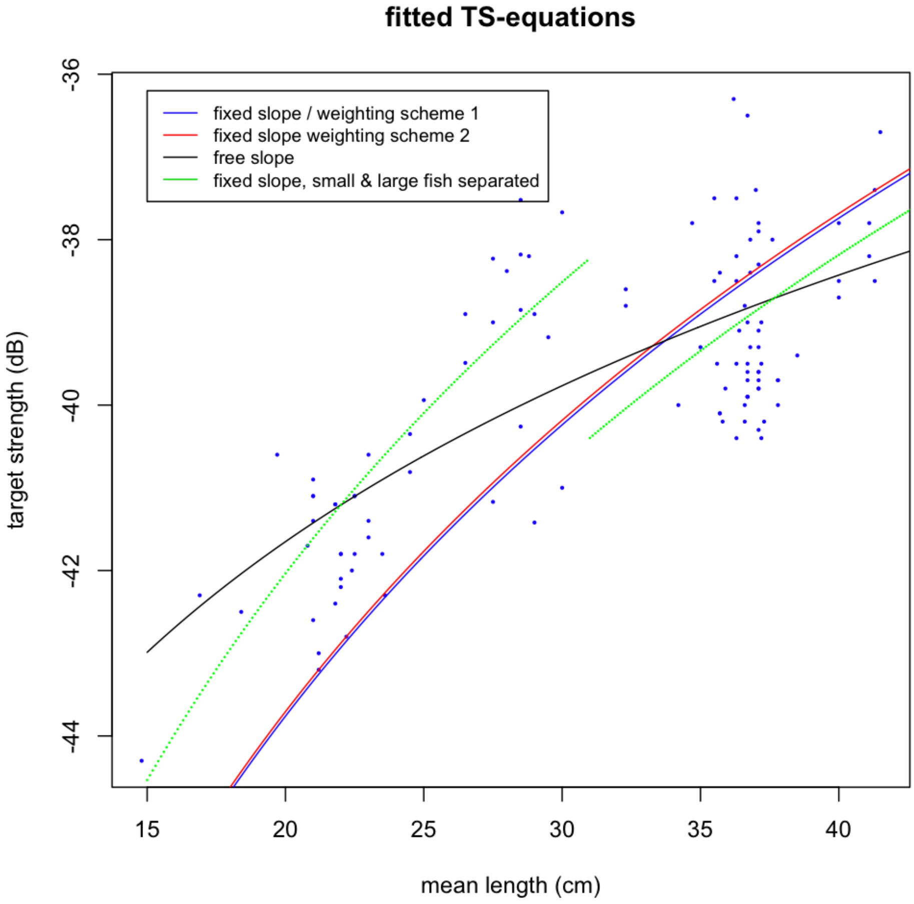


Figure 11.2. Fit of TS-length equations based on a meta-analysis of past records of Sebastes target strength. Blue dots: individual data points. Red and blue lines show fit of the fixed-slope model (20log(L)) (with 2 different weighting schemes) and black line show the fit of the free slope model. The green line shows the fit of a piecewise model with fixed slope and different intercepts for small (<31cm) and large (>=31cm) fish. Reproduced from (ICES, 2010c).

Conclusion: There is yet no commonly agreed general TS equation for *S. mentella*. The most recent estimates are converging towards a intercept (*K*) value in the range [69.7-70.3] for the fixed slope equation (20Log(*L*)-*K*) model. Specific additional data acquisition at sea combined with new numerical analyses will help in obtaining precise TS estimate and understand the factors modulating target strength (day-night cycles, developmental stages, regional differences, etc.).

12. Scrutinizing of echograms

In the open ocean, the distribution of *S. mentella* is scattered and a large proportion of the redfish biomass is vertically mixed with the DSL (see section 16). In the Irminger Sea, hydro-acoustics registrations have been used to derive biomass estimation above the DSL whereas abundance estimate within and below the DSL have been derived using a conversion of the catches into equivalent acoustic values named $s_{A.tr}$. In the Norwegian Sea, hydroacoustics registrations have been used to derive biomass estimates above, within and below the DSL, with varying degrees of success.

The methodology applied in the Irminger Sea (i.e. scrutinizing above the DSL and applying a conversion within and below the DSL) is justified by 1) the difficulty to acquire hydroacoustics registration of sufficient quality using a hull mounted transducer (section 8) and 2) the high acoustic reverberation in the DSL produced by many organisms of unknown target strength (section 16). The methodology has been developed and proposed by Victor Mamylov (Mamylov, 1999), and is used as an alternative to the more expensive and technologically challenging use of deep towed transducers.

The scrutinizing of the echogram data is done with post-processing system such as EchoView or FAMAS. The hydroacoustic measuring system (FAMAS/EchoView) provides nautical area backscattering coefficients (NASC), expressed as s_A values, which are converted by means of the length distribution from the catches to fish density. The scrutinizing method is showed in Figure 12.1. The figure shows that the upper part of DSL is at about 350 m depth. Above the DSL, *S. mentella* is found in the depth range 100-350 m where hydroacoustics is little disturbed by vessel noises under good weather conditions.

To be able to make a comparable "detailed report" in the post-processing, the height of the layers is set to 25 m, and the registrations is scrutinized and presented for every 5 NM. The data is, however, stored for every 1 NM.

During surveys the acoustic data obtained when the mixing of the target fish with the components of the DSL is greatest (during the night) is discarded in the biomass estimation. On sections along the survey tracks, where the available acoustic data are not satisfactory due to mixing, the integrator values will be estimated by interpolation (from values in the nearest vicinity, ICES, 2011d).

Trawling is done regularly when pure redfish aggregation is observed for species identification and biological sampling (to obtain length distribution). To obtain a correlation between catches and s_A values (calibration), the hydroacoustic measurements are carried out at the same time and depth as trawling shallower than the DSL. A drawing tool of the scrutinizing software is used to draw the path of the trawl directly on the echogram according to the log readings obtained during trawling and taking into account the lag of the trawl from vessel.

For the biomass and abundance estimation of redfish in the Irminger Sea, a length-based target strength model of:

$TS = 20 \log L - 71.3$ dB

is used. Alternative target strength models can be used (see section 11 and the WKTAR workshop, ICES, 2010c).

To calculate abundance of redfish within and below the DSL a "trawl method" is used. The method is based on a combination of standardized survey catches and the acoustic data, where the correlation between catch and acoustic values shallower than the DSL is used to obtain acoustic values for the deeper layer, based on catches in the deeper layer. To be able to make the calculations, trawl hauls at different depth intervals are carried out, evenly distributed over the survey area. In general, the catches in numbers per standardized tow are converted to s_A values expected using trawl calibration results (geometric mean linear regression analysis between s_A values – dependent variable and catches in standardized hauls performed within and below DSL – independent variable in the layer shallower than DSL). Thereafter, the estimated total-s_A values will be converted to absolute fish numbers and fish biomass.

For all types of trawling, standardized catches (catch in kg per 1 NM) are converted to equivalent acoustic estimates by predicting the s_A values using the obtained correlation for each vessel. Further, the obtained s_A values were then adjusted for the vertical coverage of the trawls and the depth range of each haul ($\Delta D/H_{tr}$; where ΔD is the difference between maximum and minimum depth of each haul, and H_{tr} is the vertical opening during each tow). The s_A value for each trawl ($s_{A\ tr}$) is:

$s_{A.tr} = C * K * K_H$

where C is the catch in kg per NM of trawl, K is the coefficient of the trawl obtained from the linear regression of type 1 trawls for each vessel, and K_H is the width of the depth range towed defined as:

$K_H = (H_{MAX} – H_{MIN} + dH_{TR}) / dH_{TR}$

where H_{MAX} and H_{MIN} are the maximum and minimum depths of the trawl headline during the tow and dH_{TR} is mean vertical opening of the trawl. For both vessels dH_{TR} was 50 m. For type 3 trawls H_{MIN} was 550 m and H_{MAX} was 850 m. For type 2 trawls H_{MAX} was 400 or 450 m but H_{MIN} varied and was dependent on the minimum depth of the DSL layer. Based on the regressions, confidence limits for the estimates are also calculated.

After having calculated the s_A values from the catches of each haul, the estimation of the abundance and biomass was calculated using the same target strength equation for redfish (20Lg (L) – 71.3) and the same algorithm as used for the acoustic estimation.

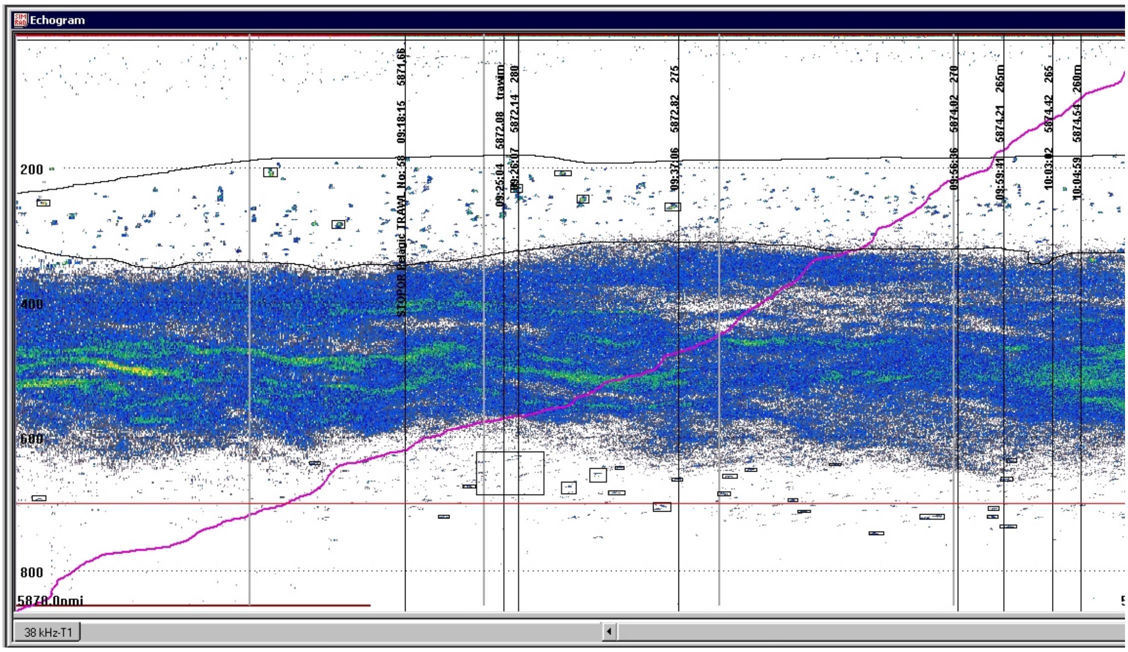


Figure 12.1. Echogram recorded by Russian RV "Smolensk" over 5 nautical miles during the summer 2007 survey in the Irminger Sea (38KHz, pulse length 2 ms). The dense layer is the deep scattering layer (DSL) in which redfish are mixed with other small organisms. Pure redfish aggregations distinctly visible above DSL in the acoustic layer (contoured by layer tool of scrutinizing software). Single targets of redfish below DSL are also visible (contoured by rectangles). Reproduced from ICES (2007).

The scrutinizing methodology used in the Norwegian Sea was reviewed during a workshop held in Tromsø on the 25-27 November 2008 and attended by 9 participants from Norway, Russia, Germany and the Faroes (Planque et al., 2009). During this workshop participants reviewed the scrutinizing procedures used by each participants, conducted parallel analysis of the hydroacoustic data on selected registrations, and advised on "good practice" for scrutinizing hydroacoustic data collected in the Norwegian Sea. The results of the comparative analysis clearly showed that differences in scrutinizing methods had a very large impact on the abundance estimate of redfish and probably constitute the major source of uncertainty for any quantitative estimate. A series of recommendation for the conduction of future international redfish surveys were provided, these include:

- Hydroacoustics should be used as a complement to trawl based estimates. For that purpose, the number of trawl hauls should be maximized. The use of the multisampler by all participants is recommended.
- All vessels/nation should use the same equipment for trawling (Gloria 2048), hydroacoustic registrering (EK60) and scrutinizing.
- Individual trawl hauls should be conducted horizontally, in single vertical layers (e.g. above, within or below DSL)
- Additional hydroacoustic observation methods should be considered (e.g. deep towed transducer, multiple frequencies)
- All vessels/nations should use a common set of acoustics categories
- Species partition based on TS distribution should be avoided
- 1-2 days should be allocated to inter-vessel comparison of acoustic systems and joint parallel trawls.
- The scrutinizing cross-comparison (as conducted during the workshop) should be conducted systematically, as a measure of data qualification
- Methods for automatic removal of noise should be implemented in the scrutinizing process
- All vessels should start and end the survey simultaneously.

Conclusion: differences in scrutinizing methods had a very large impact on the abundance estimate of redfish and probably constitute the major source of uncertainty for any quantitative estimate. Complete descriptions of scrutinizing protocols as well as continuous and rigorous evaluation and cross-validation of scrutinizing techniques are needed to ensure the highest possible accuracy of hydroacoustic estimates of *S. mentella* abundance and distribution.

13. Clumped distribution on shelves

The distribution of animals and plants in the wild is rarely random but typically follows 'clumped' distributions, i.e. spatial patterns with small regions of high animal density and large regions of low animal density. This is typically described in statistical terms as spatial autocorrelation (Legendre, 1993) and is deeply rooted in ecological theory (McGill, 2010).

Over the oceanic regions, the pelagic distribution of redfish is rather smooth and animal densities vary smoothly over fairly large regions (hundreds of kms). This can be observed from the acoustically derived spatial distribution map *S. mentella* in the Irminger Sea (ICES, 2009b) and northern Norwegian Sea (ICES, 2009a). In such conditions, regular acoustic survey designs with sufficiently small distances between transects, are usually suitable to derive accurate abundance and biomass estimates for the entire area surveyed. The situation over the continental shelves and slopes can be rather different with high variation in the density of fish over relatively small distances. This has clearly been observed over the Norwegian Sea slope in spring where and when individuals can form dense aggregations, likely in relation to larval extrusion (Figure 13.1). Such clumped distribution is common for many fish species and well described for most small pelagic fishes, which assemble in dense schools of sometimes very large size (herring, sardines, anchovies, and others). It has also been reported for *Sebastes* species in the Pacific Ocean (Spencer et al., 2009).

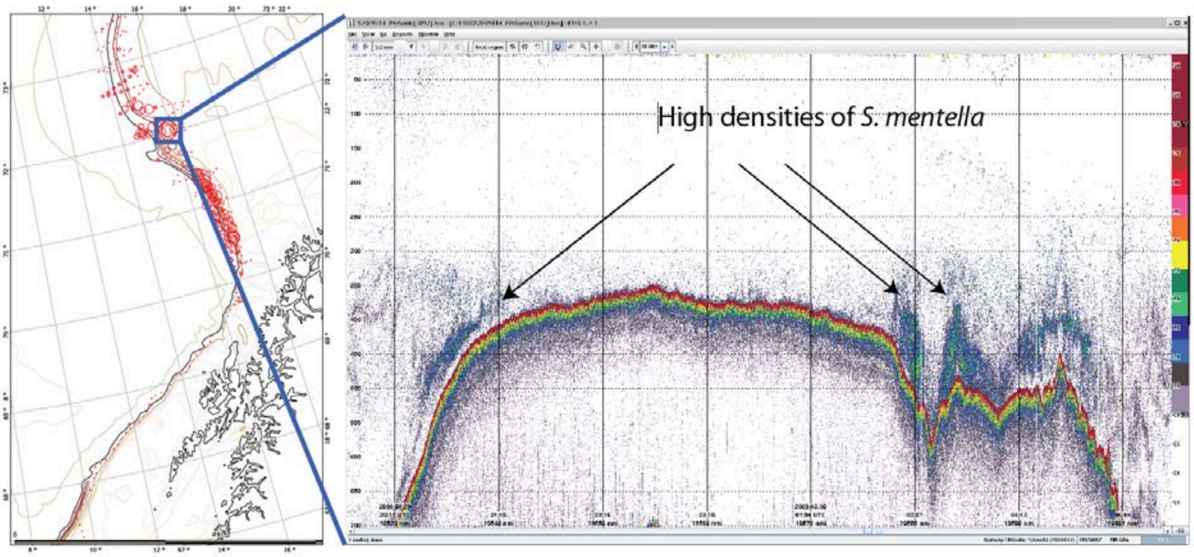


Figure 13.1. Left: the spatial distribution of redfish along the continental slope off Norway in spring 2009, as recorded with hydroacoustics. The neighbouring large circles (high abundance) and small circles (low abundance) indicate clumped distributions at small spatial scales, in addition to large scale gradients (e.g. higher abundance to the North of 70N than to the south). Right: hydroacoustics

registrations over the shelf and slope at 72N showing dense aggregations of redfish over regions of few nautical miles. Total transect distance is 70 nmi.

Highly clumped distribution poses particular challenges for surveys that are designed to estimate abundance or biomass, mainly because the uncertainty in these estimates increases as the degree of clumpiness (or patchiness) increases. In such situations, conventional survey designs, such as regular transects for hydroacoustics or random stratified design for bottom trawl surveys have poor performance, i.e. results in high uncertainties. Adaptive survey design (Thompson and Seber, 1996) has been suggested as an efficient solution to this problem and recent examples can be found in the work of Alf Harbitz, Egil Ona and Michael Pennington, who investigated adaptive acoustic survey designs for the abundance estimation of herring (Harbitz et al., 2009) or in the study by Paul Spencer, Dana Hanselman and Denise McKelvey who evaluated the use of the Trawl and Acoustic Presence/Absence Survey design (TAPAS) for the abundance estimate of Alaskan rockfish (Spencer et al., 2009). In both cases, two phases define the survey strategy. The first phase consists of a conventional observation protocol using hydroacoustics along predefined tracks. When hydroacoustics registrations are above a set threshold, the second phase is implemented, which consists of supplementary observations, either by acoustics or trawling in the area where the threshold was exceeded. The result of such approach is to substantially reduce abundance/biomass uncertainties at a relatively low cost of increased observations intensity.

Adaptive sampling schemes might efficiently improve any survey design for redfish on the shelves and slopes where clumped distributions are obvious. To date, such designs have not been considered for redfish surveys and probably more worrying, uncertainties in abundance estimates are still poorly considered.

Conclusion: The spatial distribution of *S. mentella* on the shelves and slopes is highly clumped which results in abundance estimates that are highly uncertain. Estimation of uncertainty and development of suitable sampling strategies such as adaptive sampling designs must be considered in the future.

14. Link to hydrological features, spatial range & climate change

As described in other sections of this document (e.g sections 2 and 4), *S. mentella* has a very wide distribution in the North Atlantic (both vertically and horizontally) and therefore it is difficult and expensive to monitor the stocks; adding to this comes that that the distribution (especially the horizontal) is not the same every year. This is illustrated in the pelagic fishery for *S. mentella* in the Irminger sea where the shallow (<500m) and the deep (>500m) components in the first years of the fishery had a similar horizontal distribution, whereas the two stocks/fisheries have been widely separated since the late 1990s. The spatial distribution of *S. mentella* in the Irminger Sea seem to be related to water temperature distribution, with a preferred thermal range of 4-5°C, as illustrated in Figure 14.1 (ICES, 2009b).

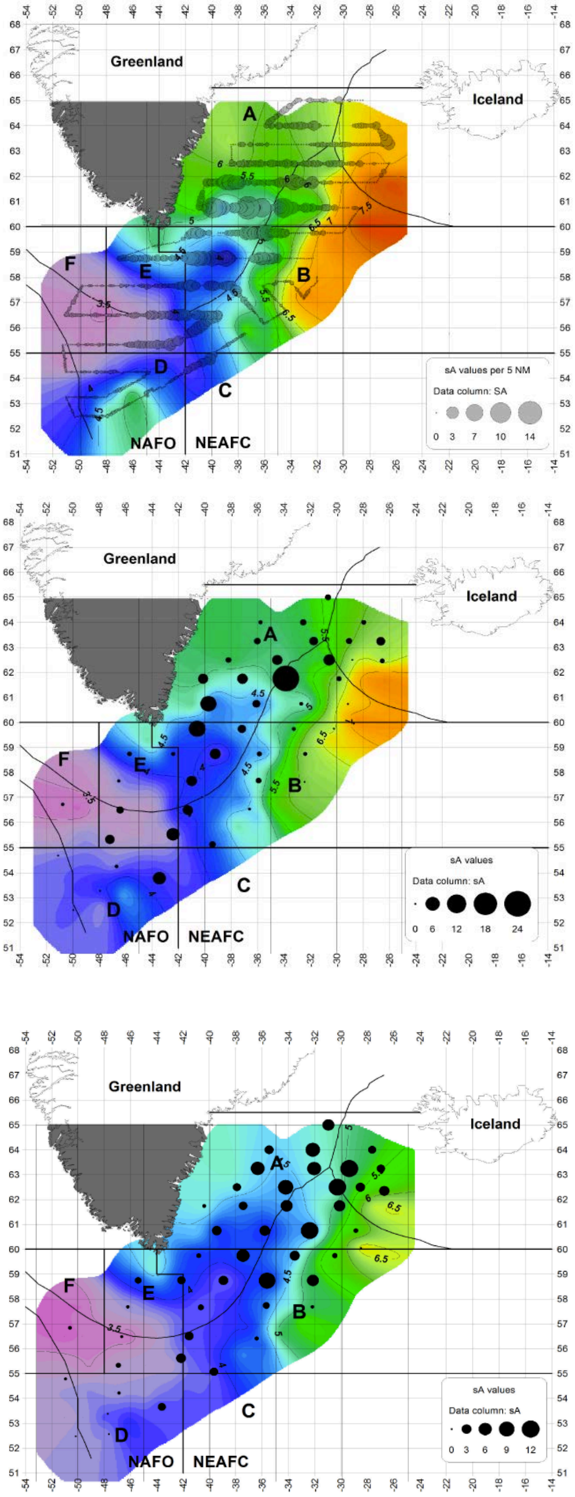


Figure 14.1. Temperature distribution (colour) and redfish distribution (bubbles) as recorded during the international redfish survey in the Irminger Sea and adjacent waters in June/July 2009. Top-left: temperature at 200m depth and redfish distribution derived from hydroacoustics. Top-right: temperature at 400m depth and trawl-catches shallower than 500m. Bottom-left: temperature at 600m depth and trawl-catches deeper than 500m.

The physical oceanography in this region is, however, very variable (Hátún et al. 2009). It is dominated by the dynamics of the North Atlantic subpolar gyre, a large counter-clock rotating body of relatively cold and low-saline subarctic water in the central northern North Atlantic (Figure 14.2). The distribution of *S. mentella* is confined within the subpolar gyre (Pedchenko, 2005). During the early 1990s the circulation of the gyre was intense, but declined substantially after 1995 leading to a rapid warming and salinification (Hátún et al., 2009). The subpolar gyre is characterized by the so-called gyre index, which has been used to explain variations in the distribution of variety of organisms including plankton, fish and pilot whales. It is not unlikely that the upper and lower water masses in the Irminger Sea are influenced differently by the gyre which could therefore explain the different horizontal distribution of *S. mentella* in the shallow and the deep Irminger Sea since the late 1990s (Pedchenko, 2005). Such knowledge could be used in planning of future surveys in the area and in the management of the stocks.

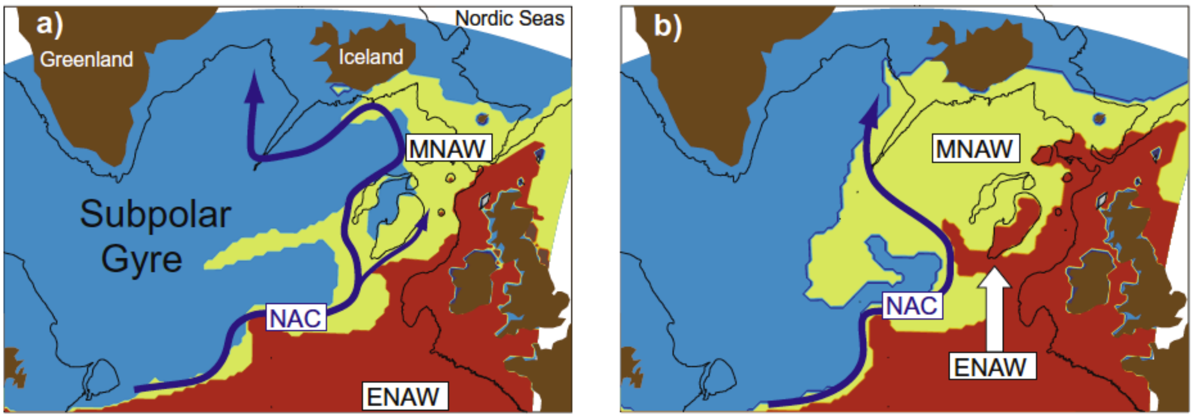


Figure 14.2. Water masses. Simulated upper layer temperatures in the northern North Atlantic Ocean. Annual averages for a cold period (a, 1993) and a warm period (b, 1998) are presented to highlight the large shift taking place. Red and blue colours represent temperatures above 9°C and below 7°C, respectively. The green colour represents intermediate temperatures, which in the region south of Iceland illustrates the distribution of Modified North Atlantic Water (MNAW). Reproduced from Hátún et al. (2009).

Very little work has been done to relate the distribution of *S. mentella* to oceanographic conditions in the Norwegian and Barents Sea. However, the distribution of *S. mentella* in the northeast Atlantic seems confined within Altlantic waters, in a similar way to the confinement of the species in the subpolar gyre in the Irminger Sea. Investigations conducted in the Norwegian Sea in 2008 indicated high catches rates between -0.5 and 5.0°C (Figure 14.3), a wider thermal range than observed in the Irminger Sea. It is yet unknown if and how fluctuations in the oceanic circulation of the Norwegian Sea and in particular the inflow of North Atlantic waters into the Barents Sea have affected the distribution and abundance of *S. mentella*. Possible effects of climate change related warming on the northward extension of *S. mentella* into the high Barents Sea and the Arctic Ocean are uncertain.

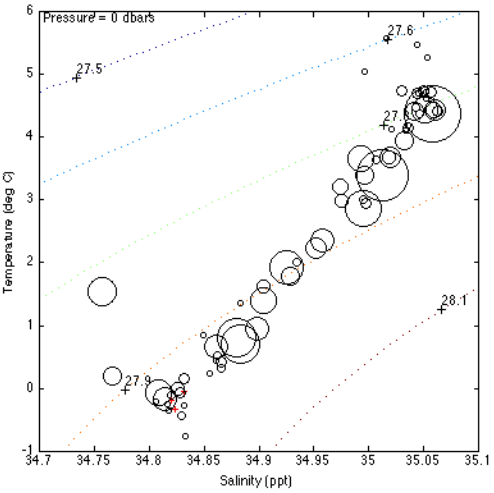


Figure 14.3. Catch rates (numbers per hour trawling, circles) in the Temperature/Salinity space, during the Norwegian Sea pelagic survey in summer 2008. Medium to high catches rates are observed between -0.5 and 5.0°C and for all of the range of salinity covered.

Conclusion: The effects of variability in oceanic conditions on the abundance and distribution of *S. mentella* have been little studied and are therefore largely unknown. The analysis of hydrographical data collected during *S. mentella* surveys should help is resolving this issue. A first attempt is planned through the *workshop on redfish and oceanographic conditions* (WKREDOCE), which will be run by ICES in 2011-2012.

15. Recruitment

As for many fish populations, the processes driving the year-to-year fluctuations in the recruitment of redfish are still poorly known. Larval extrusion occurs over two main areas:

over the Reykjanes Ridge in the Irminger Sea and along the continental shelf break off Norway (from 62°N to 74°N, Fig. 15.1). The released larvae drift to their nursery grounds (Fig. 15.2) on the shelf of eastern and western Greenland and into the Barents Sea and the adjacent continental slope, respectively (section 4).

Genetic analyses of redfish samples from the East Greenland shelf are currently undertaken to investigate the stock structure of *S. mentella* in this important nursery area. If technically feasible, tagging juvenile redfish (see section 9) on their nursery grounds would give valuable insight into the migration pattern of the juveniles, when recruiting to the adult stock(s). Ideally, tagging before the period of internal fertilization (i.e. late autumn/early winter) would be accompanied by injecting a traceable marker into the females in order to "mass-mark" larvae (e.g. Kuroki et al., 2010). Another possible method for investigating the pattern and quantity of recruitment into the adult stock is by following peaks in prominent length classes over the years, observed on the shelf in standard surveys like the annual German groundfish survey off West and East Greenland (Stransky, 2000). A detection of these length classes (as a proxy for age classes) in certain areas or depths of adjacent waters would identify the recruitment patterns and eventually help quantifying the recruitment. For a complete coverage of the area, combined surveys of the pelagic and demersal habitats would be the necessary, but difficult to accomplish.

There are several open questions regarding the recruitment (e.g. causes for variability, environmental factors, and natural mortality). The causes of the often observed variability are mainly unknown and the quantification of a potential recruitment based on scientific surveys in the nursery areas like the Greenland shelf are impaired by difficulties in reliably discriminating the different *Sebastes* species for small size individuals (17 cm and below, section 7). Species identification is a pre-requisite for understanding the population dynamics of *S. mentella* in the Irminger Sea and adjacent waters since the different stocks share the same nursery ground.

In the Norwegian and Barents Seas, the situation is somehow similar but *S. mentella* juveniles generally occurs over a wider area and in larger numbers than the other two species (*S. marinus* and *S. viviparus*), so that the total number of *Sebastes spp*. juveniles is a good proxy for the abundance of juveniles of *S. mentella* proper. Recent reconstruction of the year-class strength of *S. mentella* indicate that there is little connection between fluctuations in abundances of age-0 fish and their abundance in subsequent years. Rather, it appears that the strength of the year-classes is determined later on, at the latest at the age of 2y (Fig. 15.3, Planque et al., 2011). During the period 1996-2003, recruitment in this area was extremely reduced whilst the mature stock biomass was not particularly low, which indicates that there are no obvious connection between the size of mature stock in a given year and the level of recruitment for the associated year-class. Recruitment time-series are not available for the Irminger Sea stock(s).

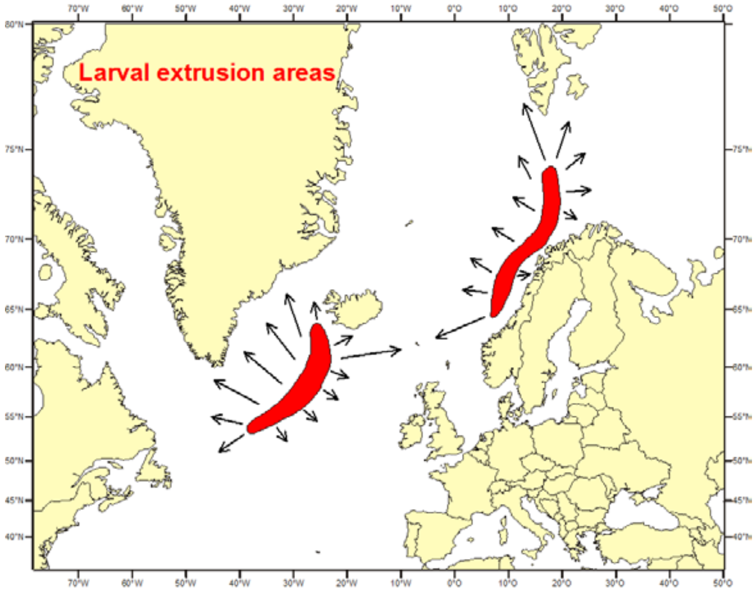


Fig. 15.1 Larval extrusion areas of beaked redfish (S. mentella) in the North Atlantic. Arrows indicate possible dispertion of larvae from the larval extrusion areas.

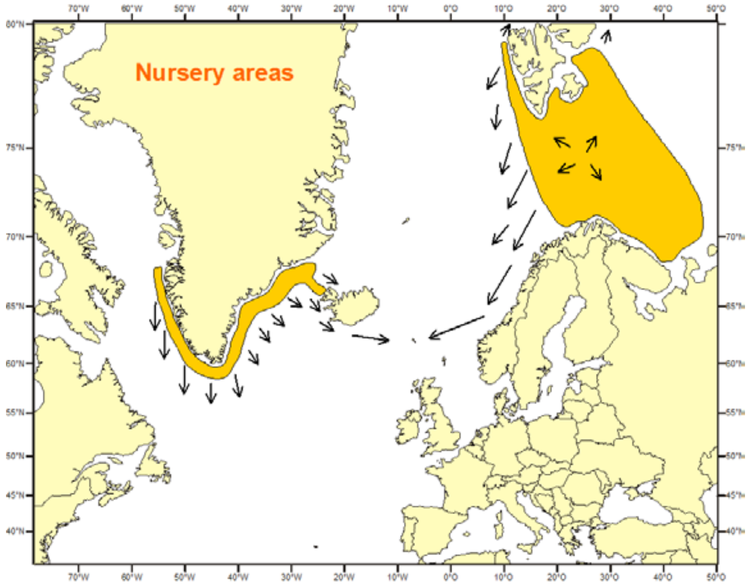


Fig. 15.2 Important nursery areas of beaked redfish (S. mentella) in the North Atlantic. Arrows indicate possible dispertion of juveniles from the nursery areas.

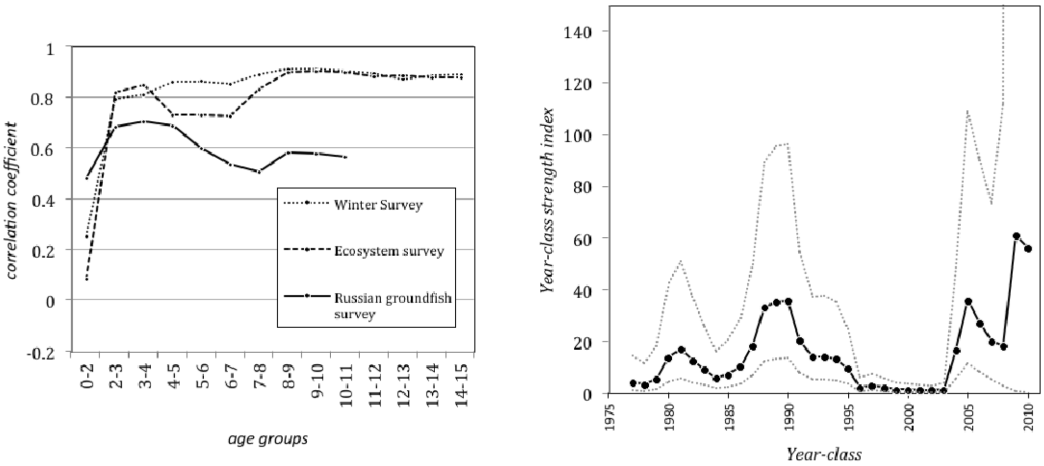


Figure 15.3: S. mentella in the Norwegian/Barents Sea. Left: correlation between time series of number-at-age for consecutive age groups for the winter (dotted line), ecosystem (dashed line) and autumn groundfish (plain line) surveys. The first point of each series (on the left) represent the correlation between age-2 fish and the 0-group index recorded 2 years previously. Right: Modelled index of year-class strength (in billions) for the period 1977-2010. The median estimate is indicated in bold black and the 95% confidence interval is indicated by the 2.5 and 97.5 percentile thin dotted lines. Reproduced from Planque et al. (2011).

Conclusion: The processes controlling recruitment of *S. mentella* into the adult stocks are not well known, but tagging and genetic studies on juvenile fish will be useful in resolving this issue, as well as statistical reconstruction of year-class strength historical time series.

16. Beyond single species surveys

As seen from sections 2, 3 and 4, beaked redfish occupies a wide range of depths, regions and habitats and therefore interacts with many components of the North Atlantic ecosystems. The monitoring of beaked redfish on shelves and slopes has generally been part of multispecies monitoring efforts, i.e. surveys designed to assess the size of multiple fish stocks sometimes including non-commercial species or even higher and lower trophic levels such as phyto- and zooplankton, birds and marine mammals (e.g. Anonymous, 2009b).

In the open oceanic basins of the North Atlantic, redfish surveys have been rather dissociated from the monitoring of other species or biological groups. Commercially important pelagic species, such as herring, blue whiting, or mackerel, are found in shallower waters (typically in the first 200m) and are monitored by dedicated surveys, which do not consider redfish. Investigations of the many fish, cephalopods, jellyfishes and crustaceans that inhabit the Deep Scattering Layers are conventionally conducted with observation tools (nets, cameras, acoustics) that cannot adequately sample redfish because the observations volumes are too small. On the other hand, redfish surveys poorly sample other fishes and biological groups because the typical trawl used (e.g. the Gloria 1024 or equivalent) is so large that it cannot capture quantitatively animals with lengths of 10cm or less or with fragile bodies such as jellyfishes. As a result, most scientific investigations on redfish and on the Deep Scattering Layer are uncoupled, despite the fact that redfish in the open ocean is tightly coupled to the DSL, as illustrated in figure 16.1.

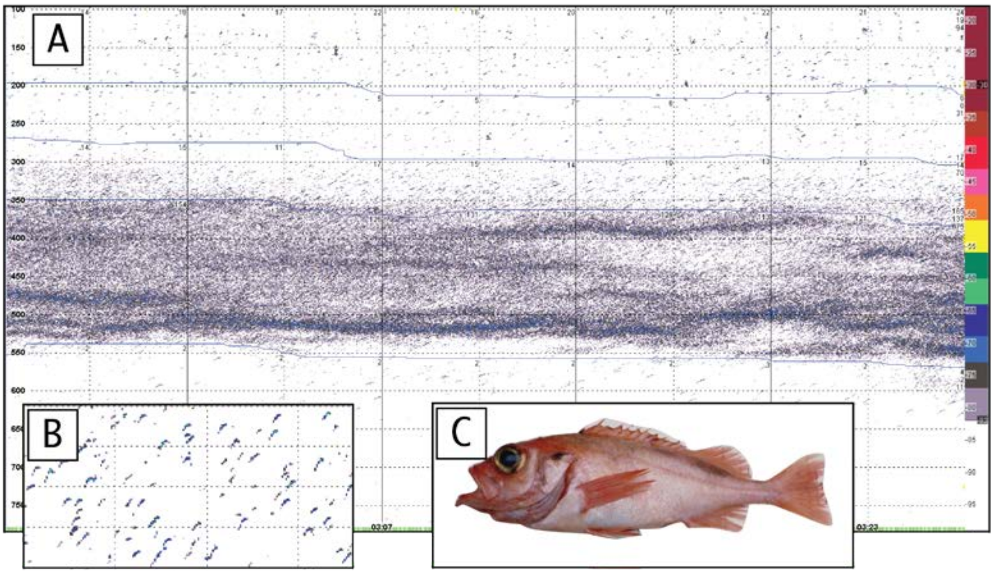


Figure 16.1. Hydroacoustic recording during the summer 2008 survey in the Norwegian Sea. A: Five nautical miles of hydroacoustic registrations from 100 to 750m depth. The dense grey layer is the deep scattering layer (DSL) in which redfish are mixed with other small species. B: Zoom on the hydroacoustic registration below the DSL where echo-traces of individual fish can be seen. C: photograph of the beaked redfish Sebastes mentella. Reproduced from Planque (2008).

Deep Scattering Layers are ubiquitous features of the world ocean, and are believed to host a very substantial fraction of the world fish biomass (the total biomass of mesopelagic fish estimated to 1 billion tons, i.e. 10 times world's total fish catches, Gjøsæter and Kawaguchi, 1980) in addition to many other groups (cephalopods, crustaceans, jellyfishes). In the North Atlantic the horizontal distribution of the DSL overlaps with most of the distribution of pelagic *S. mentella*. This is illustrated in Figure 16.2 for the Irminger Sea. Despite limitations in diet studies of redfish (see section 10), current observations indicate that *S. mentella* is predating on food items predominantly found in the DSL. Given this, the DSL appears as the essential habitat and food support for pelagic redfish in the North Atlantic and it seems therefore evident that studies of the biology and ecology of the DSL must be conducted jointly with biological and ecological studies on redfish, and vice-versa.

The ecology within the DSL is still largely unknown and fundamental questions such as the trophic importance of the DSL for commercial fish species, higher in the water column, or for marine mammals as well as for the retention of material sedimenting from the upper layers are still unanswered. The degree of interannual or interdecadal variations in biomass and production is unknown, although this may strongly influence the dynamics fish and mammal predators. With most species in the DSL having short life histories and low swimming capabilities (Salvanes, 2004), their biological dynamics is expected to be highly coupled to changes in the ocean hydrography and circulation, but this has not even been investigated yet and most studies on climate-ecosystem coupling in the open North Atlantic have only considered the upper layer of the ocean (e.g. Hátún et al., 2009).

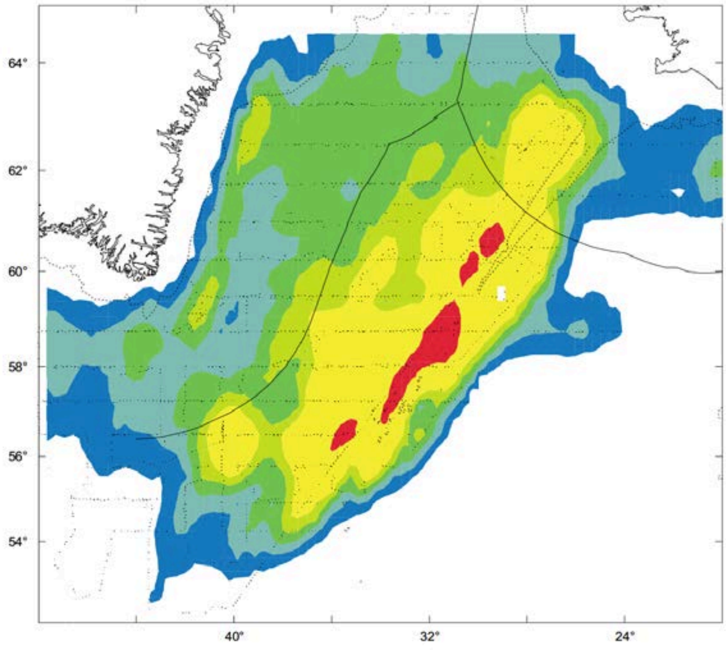


Figure 16.2. Relative distribution of the deep scattering layer in the Irminger Sea in summer 2001. When scrutinising the echosounder data, all scatter from organisms that were not judged as redfish were grouped as scattering layer. The dotted lines on the figure show the cruise tracks. Reproduced from Sigurðsson et al. (2002)

Redfish surveys in the open North Atlantic Ocean have the potential to initiate and support ecological work of a much wider scope, within one of the least known but biological significant component of the ecosystem. Such approach would require adaptation of sampling strategies and observation methods. Interestingly, a recent report on *Fishery and utilisation of mesopelagic fishes and krill in the North Atlantic* (Lamhauge et al., 2008) has identified the pelagic surveys for herring and blue whiting in the Norwegian Sea (PGNAPES, ICES, 2008b) as good candidates to promote research on mesopelagic fishes, but makes no mention of the redfish surveys as a potential platform for such research. Modifying existing redfish surveys towards deep pelagic ecosystem surveys might be efficient in raising interdisciplinary and international scientific interest and opening for research funding applications at institutional, national and international levels.

Conclusion: The biology and ecology of *S. mentella* is tightly coupled to the biological community of the deep scattering layer, but the two things have not been studied jointly and very little is known of the basic properties of the DSL (productivity, species composition, year-to-year variability, etc.). *S. mentella* surveys constitute unique platforms to study the ecology of the DSL and such joint studies would help securing the necessary funding.

17. Databases

Since the beginning of the international redfish survey in the Irminger Sea and adjacent waters in 1999 and the survey in the Norwegian Sea in 2008 various data have been collected on redfish distribution, biology, and environmental condition. This includes hydroacoustic data, trawl data, biological data on redfish, including parasite and diet data, and oceanographic data. Table 17.1 gives an overview of data collected in the redfish surveys in the Irminger Sea and adjacent waters 1999-2011.

The redfish survey data is stored by individual nations and to date, no common database system is used for coordinated archiving and extraction of the data. Participants of WGRS (previously PGRS and SGRS) have discussed the need of such common database system for several years (ICES, 2009c, ICES, 2011d).

ICES is the natural host for data collected during ICES/coordinated surveys. ICES offer the required international context and computing facilities. The data will be hosted in several data bases:

- ICES Oceanographic Database and Services (OCEAN - http://www.ices.dk/Ocean/index.asp) is the database where the oceanographic data would be hosted.
- DATRAS (http://datras.ices.dk/Home/Default.aspx) is the database where the trawl data would be held. In this database information on each trawl, catch data, and biological information on redfish (length, age (if available), sex, and maturity) would be stored.
- DOME (http://dome.ices.dk/) for hosting the redfish parasite data.
- STOMACH (http://ecosystemdata.ices.dk/stomachdata/) for hosting the stomach content data.

At present, hydroacoustic data cannot be hosted by ICES databases.

In 2006, ICES adopted an open access data policy (http://www.ices.dk/datacentre/datapolicy.asp) where the goal is to make scientific data publicly available and free. This means that "*all data submitted to ICES are considered to be in the public domain unless otherwise explicitly specified and agreed*". However, there are concerns about the ICES data policy that possibly conflicts with some nation's data policy (ICES, 2011d).

At the WGRS meeting in February 2011 it was decided that the data collected during the redfish surveys coordinated by the group will be send to ICES on individual country basis. The first step was to send hydrographical and trawl data collected in 2009 in the Norwegian and Irminger Seas.

It is also recommended that WGDIM (Working Group on Data and Information Management) provides advice on the data management to WGRS. The goal of WGDIM is to provide "*ICES with advice on all aspects of data management including data policy, data strategy, data quality, technical issues and user-oriented guidance*" (ICES, 2010b).

Table 1. Available data from the international acoustic/trawl redfish survey in the Irminger and Norwegian Seas. Also shown is the appropriate ICES database for hosting various data.

	Irminger Sea							**Norwegian Sea**		**Database**
Data	1999	2001	2003	2005*	2007*	2009	2011	2008	2009	

Nations	Ger / Ice / Rus	Ger / Ice / Rus / Nor	Ger / Ice / Rus	Ger / Ice / Rus	Ice / Rus	Ice / Ger	Ger / Ice / Rus	Nor / Rus / Far	Nor	
CTD	119	155	146	146	124	79	133	24	-	OCEAN
Tows	107	166	148	104	85	111	203	118	82	DATRAS
Distance sailed for acoustic registration (NM)			8,666	8,682	8,579**	6,120	7,590	4,679	1,738	Not Available
# Fish	7,342	6,646	1,588	6,240	6,792	3,260	4,427	10,878	2,365	DATRAS / DOME / STOMACH

Conclusion: The extensive data sets collected during redfish surveys are still not hosted by international databases. ICES DB system is willing to host such data and can accommodate most of the information collected during the surveys (with the exception of the hydroacoustics data). The transfer to ICES DB will secure archiving and data quality of redfish surveys in the future.

18. Interannual variability and survey frequency

For a long-lived species inter-annual variability in the biomass of the stock is expected to be little given moderate fishing. It might therefore not be necessary to survey the stock on an annual basis, and surveys conducted at lower frequency may be sufficient to track changes with sufficient accuracy and response time. This has raised the question whether the survey frequency of pelagic redfish, especially in the Irminger Sea and adjacent waters, should be conducted every third year instead of every second year, as it is today.

Since 1999, the international trawl-acoustic survey in the Irminger Sea and adjacent water has been conducted every second year. The redfish surveys are considered important in monitoring the pelagic redfish stocks and are the basis for the ICES advice. There are lot of uncertainties regarding the results, and monitoring the stock only every third year only adds to the uncertainties about the state of the pelagic redfish. If, for example, a survey is cancelled, the time between surveys will be six years instead of four years.

The pelagic survey in the Norwegian Sea was conducted in 2007-2009 and only in 2008 was the spatial coverage considered adequate. In 2007 and 2009 only Norway participated in the survey and the biomass measurements were not considered sufficient for stock assessment purposes. In 2008 the survey conducted in the Norwegian Sea was a joint effort between Norway, Russia and the Faroe Islands. No survey was planned in 2011 because of insufficient participation. At least five years will therefore be between the surveys and this frequency of surveys is considered insufficient in monitoring commercially important fish species.

One issue that adds to the uncertainties of the survey is a large spacing between hydroacoustic survey tracks and between trawl hauls due to the large survey area (about 400,000 square nautical miles) that has to be covered with only two or three vessels currently participating in the survey. In order to reach a sufficient density of survey tracks and trawls, WGRS recommended that "as many vessels as possible (at least four) should participate to improve the quality of the derived estimates. Thus, the efforts directed at involving other nations in the survey should be continued." This request was repeated in 2008 and 2011 without success (ICES, 2011d). In 2007 and 2009, only 2 vessels participated in the survey, which is insufficient in terms of data quality for the assessment.

The observed drastic changes in abundance and biomass estimates of pelagic redfish in the Irminger Sea and adjacent waters since 1994 and considerable changes in environmental conditions in recent years confirm the need for precise monitoring of the redfish in the distribution area at time intervals that do not exceed two years.

Conclusion: It is important to continue to conduct the international trawl-acoustic surveys on pelagic *S. mentella* in the Irminger and Norwegian Seas every second year to monitor the redfish in the distribution areas. Furthermore, it is important to involve as many nations as possible in the survey to ensure data quality for the assessment.

19. Summary and conclusions

In the present contribution we have reviewed many aspects of redfish biology, ecology, fishery that motivate and affect the way the species can be monitored in the North Atlantic. The key difficulties include the basin-wide geographical distribution, the occupation of demersal and benthic habitats at different stages of the life cycle, poorly described seasonal and ontogenetic large scale migrations, difficulties in species identification, stock identification and ageing, a deep distribution which imply remote access to hydroacoustic devices and difficulties to conduct tagging or diet studies, unknown recruitment controls and generally poor knowledge of *S. mentella* interactions with the pelagic ecosystems of the Irminger and Norwegian Seas. Although this could appear as a bleak picture of the current state of the art in *S. mentella* monitoring, solutions exist for most of the above challenges and have even been tried in several instances. Future monitoring of *S. mentella* can therefore be achieved with higher success and could even serve as a pilot for a number of fish species displaying similar monitoring challenges. The list of recommendation below should serve as guidelines for the development of *S. mentella* monitoring in the future:

1. Monitoring the entire distribution area of *S. mentella* in the North Atlantic requires stronger international support than currently available and sustained coordination effort by ICES. At least 150 days-at-sea are needed to survey the pelagic distribution area (> 650,000 NM^2). Such survey can be operated every second year.
2. Over shelf areas, surveys should consider the demersal and pelagic components of the populations, using combined trawl and hydro-acoustic surveys and appropriate survey designs.
3. The Underwater Tagging Equipment (UTE) provides a unique opportunity to resolve key scientific issues related to age determination, trophic ecology, migration and stock identification. The use of the UTE should be promoted and supported internationally.
4. Hydroacoustic observations from hull mounted echo-sounders should be complemented by observations using deep-towed transducers. Efforts to standardise hydroacoustic interpretation methods and target strength equations should be pursued through dedicated international workshops.
5. Hydrographic measurements should be pursued and improved during *S. mentella* surveys and additional observations of the species community in the Deep Scattering Layer should be initiated.
6. Stock identification work should be pursued and extended in areas where little work has been done up to present (e.g. Faroes, Norwegian and Barents Sea).
7. The reliability of species identification should be improved by internationally agreed procedures on morphological and genetic identification techniques

8. Data collected by several nations should be standardised, compiled and archived at ICES. Hydroacoustic data, for which no data-base repository has yet been identified, deserve particular attention.

20. Acknowledgements

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