International Council for the Exploration of the Sea

ICES CM 2009/E:15

Theme Session on climate impacts on marine fishes: discovering centennial patterns and disentangling current processes

The impact of variations in oceanographic conditions on distribution, aggregation structure and fishery pattern of redfish (*Sebastes mentella* Travin) in the pelagial of the Irminger Sea and adjacent waters

by

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ABSTRACT

Analysis of data from acoustic trawl surveys of *Sebastes mentella* in the Irminger Sea pelagial suggests that extension of redfish distribution to the southwest observed since the mid-1990s was caused by migration of some aggregations from the traditional feeding areas due to an increased advection of Atlantic waters by the Irminger current and higher temperatures of the surface layer (TSL). However, the use solely of the data from surveys conducted every other year limits the possibility to study the impact of variations in oceanographic conditions on distribution, aggregation structure and fishery pattern of redfish in the long term, although such information is essential for the development of sustainable harvesting strategies for fish resources. Data on monthly mean TSL fields at the regular grid nodes for 1982-2008 were used as additional oceanographic indices. To identify and forecast TSL data, the aliquant frequency method was used. Besides, the calculations used air temperature data for 1949-2008 to derive the trend component which was applied to fill in the gaps in the basic TSL data and make a projection. Interannual spatial bathymetric variability in some population parameters of redfish in the Irminger and Labrador Sea was analysed. CPUE for the northeastern and southwestern fishing area was calculated. A statistically significant correlation between CPUE and TSL was revealed, which suggests that CPUE indices directly depend on primary production conditions during spring. CPUE forecasted for 2009-2010 shows a decreasing trend in the Labrador Sea. A strong impact of oceanographic conditions on different fishery patterns for redfish was demonstrated. It was concluded that the proposed division into the northeastern and southwestern fishing areas, as well as the use of two units in the management of the redfish stock in the pelagial of the Irminger Sea and adjacent waters are not efficient and lack scientific substantiation.

Keywords: aggregation structure, fishery pattern, the Irminger Sea, *Sebastes mentella,* oceanographic conditions.

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INTRODUCTION

Fishery on *Sebastes mentella* in the Irminger Sea pelagial has been conducted not long ago, since early 1980-s. It was started in the international waters in the north of the Irminger Sea in 0-400m layer. Fishing area was gradually expanding, including 200-miles zone of Greenland, Iceland with increasing depth of fishing to 1000m. During the last decade, a large-scale pelagic fishery on this species was carried out in the Labrador Sea pelagial as well (NAFO Divisions 1F, 2GHJ). Despite numerous studies, scientists still have no general understanding of populational structure of the species in this area of Atlantic as well as measures required for sustainable harvesting of pelagic aggregations. Since 1996 pelagic fishery on *S. mentella* was controlled on the basis of knowledge on biological identity of pelagic aggregations in all distribution area at all depths. In 2009 participants of WKREDS meeting developed recommendations for introduction of new management regime for pelagic fishery based on the hypothesis of two biological stocks of this species in the pelagial of the Irminger Sea and adjacent waters (Anon., 2009a). Additionally, it was stated that suggested boundaries of management units "...effectively delineate the pelagic fishery in the northeast Irminger Sea from the pelagic fishery in the southwest Irminger Sea, with a small portion of mixed-stock catches" (Anon., 2009b).

Suggested harvesting strategy for two supposed stocks of *S. mentella* mainly based on data on their possible genetic and geographic isolation of two fishing areas in the pelagial of the Irminger Sea and adjacent waters ,which have to be reviewed, did not consider extensive information on environmental conditions in different areas and at different depths of *S. mentella* habitat. This information was collected in the course of regular Russian and ICES trawl acoustic sureveys. However, it is a common knowledge that there is a close relationship between biological, oceanological and atmospheric processes in the World Ocean. Additionally, analysis of complex causal relations is more important than direct relationship between climate variations and various biological aspects of hydrobionts (Laevastu, Hela, 1974). Moreover, such relationship often indicates reccurency of various duration for long-term forecasts of distribution, abundance and catches of commercial fish speceis(Gershanovich, 1986).

MATERIAL AND METHODS

Data on monthly TSL fields at the regular grid nodes were used in the paper from the server of the International Research Institue for climate prediction (IRI) being a part of the Integrated Global Ocean Services System (IGOSS) as initial oceanographic information. Besides, data on air temperature at station Reykjavik (Iceland) and those for regular grid nodes from the server of Climate Prediction Center (CPC) were applied.

Objective use of TSL data in the analysis of oceanographic conditions in this area were proved by studies which estimated conjugation of data massive and water temperature in areas of the North Atlantic and Northern European Basin. According to the results, TSL data demonstrate well main oceanographic processes in different areas of the Northern Basin. Therefore, this base can be further applied in researches, including development of various forecasting models (Karsakov et al., 2000; Ionov, Karsakov, 2009).

IGOSS TSL data massive are mean monthly values of surface temperature in the period 1982-2008 in knots of 1-grade grid in the North Atlantic area. Estimates were made for the Irminger Sea area within 55°30'-63°30'N, 26°30'-50°30'W in April-October (Fig.1). In the studied period the domestic fishery of *S. mentella* was conducted in this area, distribution and migration behaviour of this species being dependant on oceanographic conditions. Additionally, the area was conventionally divided into two districts: northern and southern. As a result, three time lags of averaged surface temperature were formed: for the northern district, southern district and all studied area (see Fig.1).

To identify and forecast TSL data, the aliquant frequency method was used (Schiekedanz, Bowen, 1977). Applying this method, time sampling can be estimated as a summed finite number of harmonic functions with various frequency and intensity (amplitude) by expansion of time sequence into Fourier series, i.e. approximation of complicated function by weighted sum of simple functions. This estimation suggests trigonometric coefficients which approximate, to a certain extent, distinct cyclic components. Standard statistical methods were applied: correlation and regression analyses. Realized TSL forecasts were estimated according to the "Guidance for estimation of quality of methods and realized hydrological forecasts"(1965).

According to the data of Russian and international trawl-acoustic surveys of stock in summer period 1982-2007, analysis of interannual variability of boundaries and distribution of *S. mentella* aggregations was conducted. Since the stock estimated by means of the trawl method at depths over 500m has a short series of observations, and in first years was experimental, acoustic estimates above the deep scattering layer at depth under 500m were used.

Biological material was sampled in the pelagial of the Irminger Sea and adjacent waters in summer period 1995-2008, when *S. mentella* aggregations distributed in all area at wide depth range. Material was collected and processed in accordance with PINRO methods (Instructions and guidelines..., 2001). Size composition of S. mentella was analyzed applying data of Russian and international trawl-acoustic surveys, feeding - data of Russian exploratory-fishing vessels separately for north-eastern and south-western areas at depths 0-500m and over 500m. While allocating size groups of *S.metella*, fish smaller than 35cm in length were referred to undersized group, 36-40cm – group of medium size fish, over 40cm – group of large fish. The length of totally 24326 *S. mentella* individuals was estimated as well as the feeding of those 29261.

Data of Russian fishery on *S. mentella* in the pelagial of the Irminger Sea and adjacent areas in 1996-2008 were used as initial fishing information. In the course of studies, two groups of vessels were specified by fishing area and direction of fishing (northwards, over 500m and southwards, less than 500m). CPUE for these fleets were estimated. It was found that data on fishing efficiency correspond to logarithmically normal law of probability distribution. Therefore, mathematical expectations (MO) were applied as CPUE numerical characteristics for analysis of groups of vessels.

RESULTS AND DISCUSSION

Estimation of variations in oceanographic conditions

Actual data series of TSL is of small length (1982-2008, n=27). It was decided to restore available data on TSL to estimate oceanographic conditions in the area at a long time lag. With this aim, data on air temperature from Reykjavik station were used, where observations have been conducted since early XX century. Correlation rates between variations in air temperature and TSL for three studied areas comprised 0,65-0,70. Applying methods of linear regression, TSL series since 1901 has been restored. Charts describing relations and equations applied in restoring are given in figure 2.

Technical realization of restored TSL values according to the data 1982-2008 was 82-88%, and efficiency in comparison with climate forecast – 23-28%. This suggests the use of restored values of TSL in our studies (Instructions on quality assessment..., 1965).

Resulted from restoration, series of TSL for 1901-2008 were obtained. Preliminary analysis of water temperature in this period revealed significant interannual variations in temperature condition of surface waters. Method by V.V. Tereschenko (Tereschenko et al., 1985) was chosen for quantitative estimation of temperature condition in TSL. In this method mean-square deviation of water temperature was used as a quantitative index (σ_T). Such criterion has been successfully practiced in PINRO studies. The temperature water level was estimated by five-grade scale:

1 — anomalous cold year	$-\Delta T\ °C > 1{,}5\sigma_T$;
2 — cold year	$0{,}5\sigma_T < -\Delta T\ °C \leq 1{,}5\sigma_T$;
3 — normal year	$\pm\ \Delta T\ °C \leq 0{,}5\sigma_T$;
4 — warm year	$0{,}5\sigma_T < \Delta T\ °C \leq 1{,}5\sigma_T$;
5 – anomalously warm year	$\Delta T\ °C > 1{,}5\sigma_T$.

Normalized anomalies and classification of years by V.V. Tereschenko method are given in Figure 3.

It should be noted that the temperature level during the period 1901-2008 is similar for all three areas. From 1901 to 1916 there were hardly any tendencies to warming or cooling. Water temperature was close to normal, increasing to the level of warm years (1912 and 1915) and decreasing to the level of cold years (1903 and 1914).

The period of cooling was observed from 1917 to 1927, when TSL in the Irminger Sea corresponded to the category of cold and anomalous cold years (1921 and 1922).

1928-1966 was a long-term period of TSL warming with a local cooling in 1948-1949. In some years water temperature was equal to the level of anomalously warm years. In 1939 and 1941 TSL was the highest for all studied period (1901-2008).

The period of warming was changed by cooling in 1967-1995. Periods with the coldest temperature were 1983-1984 and 1989-1990, when water temperature corresponded to anomalous cold years.

Next period of warming, started in 1996, has been presently continued. The highest TSL was observed in 2005 and 2007. In recent years there is a trend to decrease in TSL in this area. Water temperature decreased from anomalous warm to warm. These variations were mostly distinct in the southern part of the area (see Fig.3c).

It is difficult to estimate duration of the current period of warming. On this ground, authors try to forecast TSL for the nearest two years. With this aim, the aliquant frequency method was used. Based on this method, frequency content of primary samples was found. Main local energy-carrying maximums exceeding significance threshold for all three areas (see Fig.1) are: 14-15 and 8-9 years. Additionally, the trend component estimated by air temperature with a period of 53 years was used for forecast. These summed recurrences describe around 60% of TSL variability.

Applying autoforecasting, i.e. extrapolation of found quasi-frequencies, the forecast for two steps ahead was made, i.e. for the period 2009-2010. According to the forecast, TSL in the studied area of the Irminger Sea in the nearest two years will correspond to the level of warm years having a tendency to decrease.

Variation of oceanographic conditions and distribution of *S. mentella* aggregations

Data analysis of Russian and international trawl acoustic surveys permits studying relationship between climatic processes in the area and spatial distribution of *S. mentella* aggregations in the upper 500m layer of the Irminger Sea and adjacent waters during summer 1982-2007.

During the studied period the interannual variability in geographic boundaries of pelagic aggregations of *S. mentella* with various density was revealed. In the period of anomalous cold years 1982-1984 most aggregations distributed in the north of the Irminger Sea, which southern boundary was on the level of 58°N. As negative anomalies were decreasing, the southern boundary of aggregations gradually moved and by 1992 it had reached 54°N. By that period, dense concentrations of *S. mentella* had moved to the central and southern parts of the Irminger Sea and Eastern Greenland (Pavlov, 1992a; Pedchenko et al., 1996). Since 1994 dense concentrations of *S. mentella* started moving from the Irminger Sea to the NAFO area. In the period of medium and warm years in 1999-2001 the south-western boundary of *S. mentella* area reached 52°N, 50°W, and fish dense concentrations distributed mainly in the NAFO area and, partly, in the southern part of the Irminger Sea (Fig. 4, 5, 6).

It should be noted that location of the north-eastern boundary of the area was constant from 1982 on. Resulted from our studies, it was found that increased advection of Atlantic waters by the Irminger current and the rise of water temperature in open areas of the North Atlantic observed since 1990-s, were main reasons of migrating *S. mentella* aggregations from the Irminger Sea area to the NAFO area (Melnikov et al., 2001; Melnikov, 2008; Melnikov, Bakay, 2009). Increase in warm waters in *S. mentella* distribution area was illustrated by an isotherm 4°C located at 200m depth. This migration of aggregations provided for a large-scale international fishery in the Labrador Sea pelagial started in 2001.

As the growth of TSL became stable with a steady location of isotherm 4°C, the tendency of adverse migration of *S. mentella* aggregations became evident. According to the data of surveys 2005 and 2007, despite the fact that during these years a part of fish dense concentrations was in the open part of the Labrador Sea (the NAFO area), another one moved to the north-east to the Greenland area.

This was probably caused by other factors, including biological, which alongside with high water temperature during several years, could influence migration of *S. mentella* aggregations. Although these issues are outside the present study, according to the data of autumn surveys of German exploratory fishing vessel "Walther Herwig III" in the area of the eastern and western Greenland, during the recent years an important climatic aspect of increased flow of Arctic waters through the Denmark Strait was found. This is related to increased stratification in the upper layer resulted from water desalination: high stratification limits the depth of winter convective interfusion and heat transfer from deep layers to surface. This results in growing ice coverage in freezing waters and long-term ice periods. In view of all these effects, variable conditions in Greenland waters indicate a high probability of the fact that in the nearest future marine climate in the northwestern Atlantic and Labrador Sea will evolve towards water cooling and growth of ice coverage (Stein, Borovkov, 2008).

Variation of oceanographic conditions and the structure of *S. mentella* aggregations

Studying the structure of *S. mentella* aggregations in the area of supposed distribution of two separate biological stocks at different depths, compliance of interannual dynamics of fish size composition and variable oceanographic conditions in the studied area were analyzed.

The beginning of TSL growth period since mid 1990-s corresponded to variation in size composition of *S. mentella* in the northern part of the area of pelagic aggregations. In 1995 the mean length of fish in 0-500m layer comprised 36.6cm, over 500m – 40.1cm. In the following years differentiated size composition of fish by depths was clearly observed. By 2001 in both layers their mean lengths were 32,7 and 41,6cm, respectively (Fig.7). In 1995 each size group of *S. mentella* occurred at all depths. Additionally, in the upper 500m layer undersized and medium fish were predominant, in the low 500 m layer – medium and large. Later, despite increased portion of undersized fish in the upper layer, the absolute abundance, resulted from acoustic estimates, sharply decreased – from 452,9 mil fish to 82,7 mil fish in 2001 (Shibanov et al., 1995; Anon., 2001). The portion of medium fish in both layers decreased in 2,5 -4 times in this period. The portion of large fish at large depths increased from 47 to 73 % and fell from 5,3 to 1,6% for fish inhabiting low depths (Fig.8). By 2001 most concentrations of *S. mentella* were observed in low 500m layer and comprised, mostly, fish over 40cm in length. Such variations in the size composition of *S. mentella* were probably caused by migrating fish smaller than 40cm in length from the north of Irminger Sea respectless the depth of their habitat to other areas in summer period.

In the southern part of the Irminger Sea and the NAFO area the growth of TSL and increased density of *S. mentella* aggregations in 1995-2001 were followed by decreased number of medium fish in the upper 500m layer from 36,6 to 34,2 cm and in the low 500m layer – from 40,7 to 36,3 cm. On the whole, the size composition in both layers tended to be equal(see Fig.7). At all depths fish aggregations were recruited with undersized fish, their portion increased in 2-3 times. The largest variations were observed in the number of large fish – they almost disappeared from the upper layer and sharply decreased at large depth (from 54 to 19%) (Fig.9).

As TSL growth in the southern part of feeding area became slow, fish of medium size in the upper 500m layer were gradually increasing, and in low 500m layer – decreasing , comprising in 2007 35,1 and 35,4 cm in length, respectively. Figure 7 shows that by that year the size composition of *S. mentella* had become equal in both layers. These variations were mainly caused by decreased portion of undersized fish in the upper layer from 65 to 51% and one of large fish in the low layer form 19 to 7%. Decreased portion of undersized fish was followed by reduction of their absolute abundance, being equal to 661,1 mil fish in 2001 and 311,3 mil fish in 2007, according to the data of acoustic estimates. Similar variations in the total abundance of medium fish were observed. It decreased from 452,3 mil individuals in 2001 to 242,2 mil individuals in 2007.

In the north of the Irminger Sea in this period variations in the size composition were reverse, in comparison with mid 1990-s. The mean lengths of fish in both layers, after their highest variations in 2001, gradually approximated, being in 2007 37,5 and 40,3cm, respectively. The portion of large fish in the upper 500m layer increased in this period from 2 to 25% and, simultaneously, reduced from 73 to 52% at large depth. The portion of medium fish in each layer increased in 2-2,5 times. Unlike the southern part of the area, where, according to the data of surveys, undersized and medium fish flowed out, in the northern part of the area abundance of fish smaller than 40cm in length slightly increased: from 154,3 mil fish in 2001 to 170,2 mil fish in 2007. As a result, variations in the size composition of fish, observed in the north of the Irminger Sea appeared to be dependent, to a certain extent, on recruitment of aggregations with undersized and medium fish, and, mostly, by means of migration of various size groups by depths.

Thus, results from the studies of interannual dynamics of size composition of *S. mentella* at different areas and depths in the pelagial of the Irminger Sea and adjacent waters indicate relationship between variability of oceanographic conditions in the area and variations in spatial bathymetric structure of aggregations in summer period 1995-2007. In 1995, with the end of cold and beginning of moderate by TSL years, in the northeast of the Irminger Sea undersized and medium fish distributed at wide range of depths, while most large fish inhabited large depths. As TSL was growing, *S. mentella* smaller than 40 cm in length migrated to the upper layers to the southern part of the Irminger Sea and NAFO area. By 2001in this area fish of these size groups dominated at all depths. A slow growth, observed in the following years, and a tendency to TSL decrease corresponded to reverse migration of aggregations from the southwestern area to the north. These processes were followed by structural variations in *S. mentella* aggregations. In the southern part of the area undersized and medium fish flowed out. According to the data of international surveys, most of migrated to NAFO area fish migrated to the area of the eastern Greenland for feeding. Additionally, there is a tendency of further fish movements northwards. However, at present, the main variations in the size composition of fish in the northern part of the feeding area in the period of stabilization and decreased TSL occurred by means of fish migration by depth. By 2007 the vertical distribution of size groups of *S. mentella* was close to one in 1995. Interannual variations in correlation of *S. mentella* size groups at different areas and depths were proved by acoustic estimates of their abundance. Variations in the size composition of *S. mentella* in all feeding area correspond well to interannual variability of fish location and estimates of fish abundance, according to the data of international surveys.

It is known that biological cycles of fish are mostly influenced by climatic processes and factors. Revealed variations in the boundaries of distribution and spatial bathymetric structure of pelagic aggregations of *S. mentella* in the Irminger Sea and adjacent waters have a close relation to one of the most long-term period of fish annual cycle – feeding. In the course of studies previously conducted by the Russian specialists, it was found that dense aggregations of *S. mentella* inhabited areas with concentrations of food organisms (Pavlov, 1992a; Pedchenko et al., 1996; Melnikov et al., 2001). Distribution of food objects, in turn, was mostly effected by oceanographic conditions. Most concentrations of zooplankton were formed in the areas of high biological productivity with intensive rise of intermediate waters, intensively supplemented with biogenic elements. These areas always referred to the northern subpolar front, forming, as a result of interacting warm waters of the Irminger current and cold waters of the east Greenland current (Loktionov, 1986; Pavlov, 1992b). In April-May the northern subpolar front was located in the area of western slopes of the Reykjanes Ridge, where mass *S. mentella* prolarvae were extruded. As water temperature was rising, the northern subpolar front moved westwards to the Greenland area, followed by zooplankton fields and, by July-August, - feeding *S. mentella* (Pavlov, 1992a; Pedchenko et al., 1996; Pedchenko, 2001). Unfortunately, lack of oceanographic data prevented scientists to specify exact location of the frontal zone in the following years and use it for allocation of feeding areas of *S. mentella*. Additionally, well-consistent location of frontal zone, zooplankton aggregations, dense concentrations of redfish and isotherm 4°C in 200m layer in 1980- early 1990-s permitted for applying the last one as the indicator of variable location of main feeding areas in the following years. Figures 4, 5, 6 show that increased advection of Atlantic waters by the Irminger current since mid 1990-s resulted in a considerable spreading of area with temperature over 4°C in the central and northern parts of the Subpolar cyclonic circulation. This caused the spreading of distribution area for food zooplankton to the southwest.

In such case, a question is expected to be made: why variable location of distribution area for food organisms did not result in the shift of all *S. mentella* feeding area to the southwest, but caused a considerable increase in its area by means of the southern part of the Irminger Sea and the NAFO area with invariable location of the north-eastern boundary. Studied feeding peculiarities of different size groups of *S. mentella* clarify a close relationship between their spacial bathymetric migration in the period of feeding and TSL variability.

According to the analysis, considerable differences in feeding of *S. mentella* size groups in the north of the Irminger Sea were found. Undersized fish fed mainly on plankton Crustacea of orders Copepoda (mostly, *Calanus Finmarchicus*, less – *Calanus Hyperboreus*), Amphipoda (*Parathemisto libellula, Parathemisto abyssorum*), Euphausiacea (*Meganyctiphanes norvegica*). In the feeding of medium fish, the portion of the following fish families increased, such as Myctophidae, Paralepididae, Gonostomatidae, Chauliodontidae, Sternoptychidae, Bathylagidae, Nimichthyidae. (mainly Myctophidae, Paralepididae), Cephalopoda (mostly juvenile squid *Gonatus fabrici*) and Pandilidae (mostly *Acanthephyra pelagica, Pasiphaea multidentat,* as well as *Pasiphaea sivado, Ephyrina figueirai, Gennadas valens, Parapasiphaea sulcatifrons, Sergia robusta*). In the feeding of large fish mezopelagic fish Pandilidae and Cephalopoda were dominant (tables 1, 2) (Bakay, Melnikov, 2008).

Studying the distribution area of food organisms by depths in the north of sea, it was found that dense concentrations of plankton Crustacea mostly located in the upper 400m layer, while those mezopelagic, bathypelagic fishes and macroplankton – over 450m depth, which indicates a wide *S. mentella* vertical distribution (Pavlov, 1992b). Besides, undersized fish distributed mainly in the upper layer, large fish – at large depths, medium – in all areas. Such vertical distribution of *S. mentella* groups favours low food competition within population, complete and efficient use of food supply and indicate ecologically trophic flexibility of species.

Increased since mid 1990-s volume of warm waters in the north of the Irminger Sea provided for movements of plankton Crustacea distributing in the surface layer in the south-western direction. Majority of undersized *S. mentella* migrated following their food objects. The species composition in the deep scattering layer, analyzed according to the materials of surveys, showed that TSL growth did not cause spacial migration of fish objects and macroplankton inhabiting large depths. As a result, large *S. mentella* stayed in the north of the Irminger Sea. Medium fish, being the most flexible in feeding, partially migrated after undersized fish and partially to the large depths, starting feeding on macroplankton and fish objects. Migration of undersized and medium fish following their food objects moved due to variable temperature conditions caused spreading of *S. mentella* feeding area. As a result, when prolarvae excrusion in the open part of the Irminger Sea was completed, *S. mentella* undertook feeding migration in the following directions: undersized and partly medium fish move to the southern part of the Irminger Sea and the NAFO area, large fish – to the north of the Irminger Sea (Melnikov, 2005, 2006; Melnikov, 2007; Melnikov et al., 2007; Melnikov, Bakay, 2007; Melnikov, Popov, 2009).

Moreover, since 2001 despite preserved volume of warm waters in the north of the Irminger Sea (indicated by location of isotherm 4°C) and continued period of warm years, variation in the structure of *S. mentella* aggregations was clearly observed as well as their reverse movement from the southern part of the area northwards. One of the possible oceanographic factors influencing “exclusion” of *S. mentella* aggregations from the Labrador Sea to the Irminger Sea may be a stated tendency of marine climate in the northwestern Atlantic towards further water cooling. It is known that in the annual cycle of *S. mentella* the feeding stage is followed by coupling. Our studies showed that in 2000-2005 coupling of *S. mentella* occurred in August-October in the open part of the Labrador Sea at 200-400m depths (Melnikov, Popov, 2009). We assume that in the period of coupling feeding concentrations of *S. mentella,* influenced by the general water cooling, had to move northwards to the area with favourable weather conditions. Surveys in 2005 and 2007 indicate fish movements towards warm waters to the Greenland area.

Our assumption on coupling moved northwards due to water cooling in the northwestern Atlantic was proved by biological data. If in 2000-2005 the portion of "moving" males in the open part of the Labrador Sea (NAFO area) comprised 15-20%, in the following years it was 1-3%. Additionally, according to the data of Russian observers onboard fishing vessels, in autumn mass "moving" males were observed in the areas of western and eastern Greenland. However, it was not found in the following years (Melnikov, 2008).

Variations in oceanographic conditions and fishery pattern of *S. mentella*.

Statistical data of Russian fishery in the pelagial of the Irminger Sea and adjacent waters 1982-2009 were analyzed to find a possible relationship between variations in oceanographic conditions and catches of *S. mentella*. Unlike data of other countries, only Russian data cover all period, seasons, areas, depths of fishery and, on the whole, correspond to the international fishing statistics (Sigurdsson et al., 2006). During the first decade of fishery, the Russian portion of *S. mentella* was 59-100%, and in the following years – 22-52% from the total catch.

A number of main periods of *S. mentella* fishery were identified. Each period had its own fishery pattern (Fig.10).

In the period of anomalous cold and cold years in 1982-1988 the fishery was mostly conducted in the north of the Irminger Sea. The season started in late March, when *S. mentella* females formed dense spawning concentrations above slopes of the Reykjanes Ridge at 300-500m depths. In late June-first part of July feeding concentrations were fished at 70-150m depths. Fishing season lasted 4-5 months.

In 1989-1992 when temperature was on the level of anomalous cold and cold years, decrease in fishing efficiency effected spreading of fishing area in the central and southern parts of the Irminger Sea. Duration of the fishing season comprised 4-5 months, like in the previous period.

As cold years were changed by normal in 1993-1998, the fishery in the north of the sea moved to the depths over 600m and covered the eastern Greenland area. Fishing season comprised 7 months, until October.

As the water temperature was growing and normal years were changed by warm, by 1999 the fishing area had considerably spread in the southwestern direction, covering Divisions 1F, 2GHJ of the NAFO area. In the following years the fishery started in early April in the north of the Irminger Sea at depths larger than 600-1100m. In May-June aggregations were fished in the same areas being slightly expanded. In July-August the fleet moved to the southern part of the Irminger Sea and further to the NAFO area, where redfish aggregations distributed at 200-500m depths. The portion of *S. mentella* in the north of the Irminger Sea comprised 43-72%, in the southern part and the NAFO area – 28-57%. The fishing season lasted 7 months and ended in early November.

Since 2006, when TSL became stable with decrease in temperature, the fishing area and the catch of *S. mentella* have been gradually decreasing in the southern part of the Irminger Sea and the NAFO area, alongside with a considerable increase in the caught fish in the north of the Irminger Sea. Fishing season became 5 months shorter by means of reduced fishing period in the southwestern area, where *S. mentella* catch had decreased by 2008 to 10,4%. In the north of the Irminger Sea *S. mentella* catch in 400-600m layer grew from 3,6% in 2006 to 25% in 2008. The year of 2009 was the most representative, when the Russian fishery was conducted merely in the north and the central part of the Irminger Sea.

Thus, analyzed during 28 years commercial data indicate a close relationship between areas and depths of *S. mentella* fishery, on one side, and variations in oceanographic conditions in the area of the Irminger Sea and adjacent waters, on the other. During anomalous cold and cold years, the fishery was mainly conducted in the north and central part of the Irminger Sea in the upper 500m layer. As the warming period started, the fishing area was gradually expanding, covering the southern part of the Irminger Sea and the NAFO area with 0-500m depths. In this period in the north of the sea aggregations were mainly fished at depths over 500m. Stabilization and a certain decrease in TSL caused a gradual reduction in the fishing area and the catch in the southwest. The northern part of the Irminger Sea has become again the main fishing area. There *S. mentella* catch was growing in the intermediate 400-600m layer.

In the course of the analysis, compliance of variable oceanographic conditions and CPUE in the *S. mentella* fishery was found. As the warming period started in the north of the Irminger Sea at the depth over 500m, a steady decline of CPUE from 1,66 t/h in 1996 to 0,83 t/h was observed in 2005. Further stabilization of TSL and its gradual decrease caused the beginning of CPUE growth, which in 2008 reached 1,37 t/h (Fig.11a). In the southwestern area at 0-500m depth, variation of CPUE in relation to TSL was asynchronous to variation in CPUE in the north of the Irminger Sea. During the warming period in 2000-2003 CPUE increased from 1,26 to 1,76 t/h. In the following years statistically significant trend to decreased CPUE was found. It fell to 0,69 t/h in 2008 with a correlation rate $R^2 = 0,848$ (Fig.11b).

A strong and statistically significant positive relationship between fishing efficiency in the southwest in July and TSL in May with a correlation rate R=0,818 (Fig.12) was revealed. In our opinion, such relationship indicates direct relation between conditions for primary production development and fishery in this area. Biological spring in the area between 55-58°N begins in late April-May, followed by mass spreading of phytoplankton and reproducing zooplankton. In May abundance of *Calanus finmarchicus* appeared to increase in 4 times, *Oithona similis* – in 31 time, *Sagitta* – in 200, and eggs and nauplii Copepoda – in 406 times higher than in late May (Pavlov, 1992a). Oceanographic conditions identify rates and strting date of biological spring, thus, having a large impact on phytoplankton development – the first stage in the trophic chain of *S. mentella* feeding. High TSL in May probably provides the most favourable conditions for mass development of phytoplankton. This results in abundant food supply for nauplii and adult Copepoda, and, generally, influence the growth of the total biomass of zooplankton – main food object of *S. mentella* in the southern part of the Irminger Sea and the NAFO area. Abundant food supply in this area effects density of *S. mentella* feeding concentrations and, CPUE growth in July, respectively.

In the north of the Irminger Sea a statistically significant reverse relationship was found between fishing efficiency in April and TSL in February, on one hand, and correlation rate R=-0,620, on the other (Fig.13). It is known that the fishery on *S. mentella* in spring is based on aggregations of females, excruding larvae. It has been already mentioned that water temperature is the main oceanographic factor, indicating density of spawning concentrations of *S. mentella* and, as a consequence, its fishing efficiency. Oceanographic conditions forming in February appeared to have impact on TSL in April. This was proved by relationship between water temperature and fishing efficiency. As a result, the growth of temperature in February led to fall of CPUE in April, and vice versa.

CONCLUSION

Resulted from restored TSL, significant interannual variations in TSL for the period 1901-2008 were found. Quantitative estimation of TSL permits to identify the following categories of years:

anomalous cold, cold, normal, warm, anomalous warm. In view of this classification, two periods of cooling were specified: 1917-1929 and 1967-1995. They were estimated as cold and anomalous cold years by TSL. Since 1966 next warming period was observed with the highest TSL in 2005-2007 and a tendency to their decrease in the following years. According to the forecast, based on the extrapolation of found quasi-frequencies, in 2009-2010 a tendency to decreased TSL will preserve in the area.

In the course of studies, a complex casual relationship between oceanographic conditions in the area of the Irminger Sea and adjacent waters, on one side, and biological cycles of pelagic *S. mentella*, inhabiting that area, on the other, was found. Long-term variations in TSL, impact of TSL on location of zooplankton, vertical distribution of food objects, as well as selective feeding of *S. mentella* size groups are main factors of interannual variability in geographical boundaries, structure and fishery pattern of its feeding concentrations.

In the period of anomalous cold and cold years 1982-1984, *S. mentella* aggregations distributed in the north of the Irminger Sea. In the second part of 1980-s in TSL the feeding area was spreading with decrease in negative anomalies in TSL. Increased volume of warm waters since mid 1990-s in the north of the area caused movements of plankton Crustacea in TSL to the southwest. Majority of *S. mentella* smaller than 40cm in length, following their food objects, moved to the southern part of the Irminger and Labrador Sea of the NAFO area. The growth of TSL did not cause spacial migration of fish objects and macroplankton inhabiting large depths. As a result, large *S. mentella* stayed in the north of the sea. Medium fish, being the most flexible in the feeding, partly migrated with those undersized, and partly moved to the depths over 500m in the north and started feeding on macroplankton and fish objects. Such spatial bathymetric migration of *S. mentella* resulted in a considerable spreading of feeding area with a stable location of its northeastern boundaries. As a consequence, when prolarvae excrusion ended above the Reykjanes Ridge, *S. mentella* feeding migration had two main directions: undersized and partly medium fish moved to the southern part of the Irminger Sea and the NAFO area, another part of medium and large fish migrated northwards of the Irminger Sea.

Evolution of marine climate in the northwestern Atlantic towards water cooling was of the reason of *S. mentella* reverse migration, observed since 2005 from the Labrador Sea to the northeast, while high positive anomalies preserved in the Irminger Sea. Influenced by the general water cooling, feeding aggregations of *S. mentella* before starting coupling, had to move northwards to the area with the most favourable temperature conditions. In the southern part of the area undersized and medium fish moved mostly to the Greenland area. By 2007 in the northern part of the area correlation of *S. mentella* size groups in z-direction had become similar to one in the period of moderate temperature in mid 1990-s.

Variations in water temperature, having impact of distribution and structure of *S. mentella*, influenced pelagic fishery and fishery pattern as well. If in the period of cold years, fishery was conducted in the northern and central parts of the Irminger Sea in the upper 500m layer, in the period of water warming fish migration was followed by increase in the depth of fishing and spreading of fishing area. In anomalous warm and warm years the second fishing area was forming in the southern part of the Irminger Sea and the NAFO area. There feeding and coupling *S. mentella* of small and medium size were fished. Stabilization and a certain decrease in TSL in the north of the Irminger Sea followed by water cooling in the northwestern Atlantic influenced a gradual reduction of fishing area and portion of *S. mentella* in the southwest. As a result, fishery pattern was newly transformed, similar to the period of moderate and cold years.

Thus, steadily variable environmental conditions result in simultaneous variations in distribution, structure of aggregations and fishery pattern of *S. mentella*. This should be certainly considered while developing the strategy of sustainable exploitation of the present species in the pelagial of the Irminger Sea and adjacent waters. Recurrent variations in TSL result in the fact that in different periods pelagic fishery on *S. mentella* may occur in one local area, in one wide area, in two distant local areas and again in one area at constantly variable depths of fishing. Such transformation of fishery pattern makes it problematic to specify any management units for S. mentella, which boundaries "... are based on spatial patterns of the fishery" (Anon, 2009b). Thus, suggested WKREDS (Anon., 2009a) boundaries for *S. mentella* management units in the northeast of the Irminger Sea are groundless, from scientific viewpoint, and inefficient, from practical one. These revealed relations and the forecast of oceanographic conditions suggest that in the northern and central parts of the Irminger Sea in the nearest future (like in 1980-s and early 1990-s) harvested will be the part of *S. mentella* aggregations, which fishery was conducted in 2000-s in the NAFO area and southern part of the Irminger Sea.

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Table 1**.** Frequency of occurrence (% of full stomachs) of main food objects for redfish different size groups in the northern area in June-August

Food objects	Layer, m	Size groups, cm				
		21-30	31-35	36-40	41-45	46-50
Copepoda	0-500	14.0	10.9	10.4	-	-
	501-1000	15.6	3.1	1.4	0.9	5.1
Euphausiacea	0-500	24.6	31.3	19.2	-	-
	501-1000	4.7	3.4	1.6	1.7	2.6
Hyperiidea	0-500	43.9	43.2	25.6	-	-
	501-1000	12.5	7.2	2.3	1.0	2.6
Pandalidae	0-500	14.0	9.4	7.2	-	-
	501-1000	14.1	19.4	27.5	26.0	16.7
Gonatus fabricii	0-500	0.0	5.2	4.0	9.1	0.0
	501-1000	6.3	8.1	13.0	14.1	19.2
Fish	0-500	15.8	25.0	35.2	72.7	100.0
	501-1000	29.7	40.3	35.8	36.2	41.0
Ctenophora	0-500	1.8	2.1	4.0	-	-
	501-1000	9.4	10.3	16.8	18.9	12.8
Number of full stomachs	0-500	57	192	125	11	1
	501-1000	64	320	1108	1039	78

Table 2. Frequency of occurrence (% of full stomachs) of main food objects for redfish different size groups in the southern area in July-September.

Food objects	Layer, m	Size groups, cm				
		16-30	31-35	36-40	41-45	46-50
Copepoda	0-500	38.3	34.8	28.2	9.3	-
	501-1000	9.9	35.8	27.4	2.2	-
Euphausiacea	0-500	14.5	13.0	14.2	12.1	-
	501-1000	9.3	18.9	16.8	6.5	-
Hyperiidea	0-500	55.3	53.0	54.9	49.5	-
	501-1000	16.3	88.4	70.5	6.5	12.5
Pandalidae	0-500	1.5	2.4	3.4	4.9	100.0
	501-1000	2.9	11.6	11.6	47.8	62.5
Gonatus fabricii	0-500	1.8	3.7	5.8	7.1	-
	501-1000	2.3	6.3	5.3	19.6	12.5
Fish	0-500	4.1	6.7	10.4	19.8	100.0
	501-1000	1.2	10.5	16.8	26.1	12.5
Ctenophora	0-500	0.1	0.6	0.6	0.5	-
	501-1000	0.6	1.1	0.0	6.5	-
Number of full stomachs	0-500	4105	11396	10136	188	2
	501-1000	73	164	141	53	8

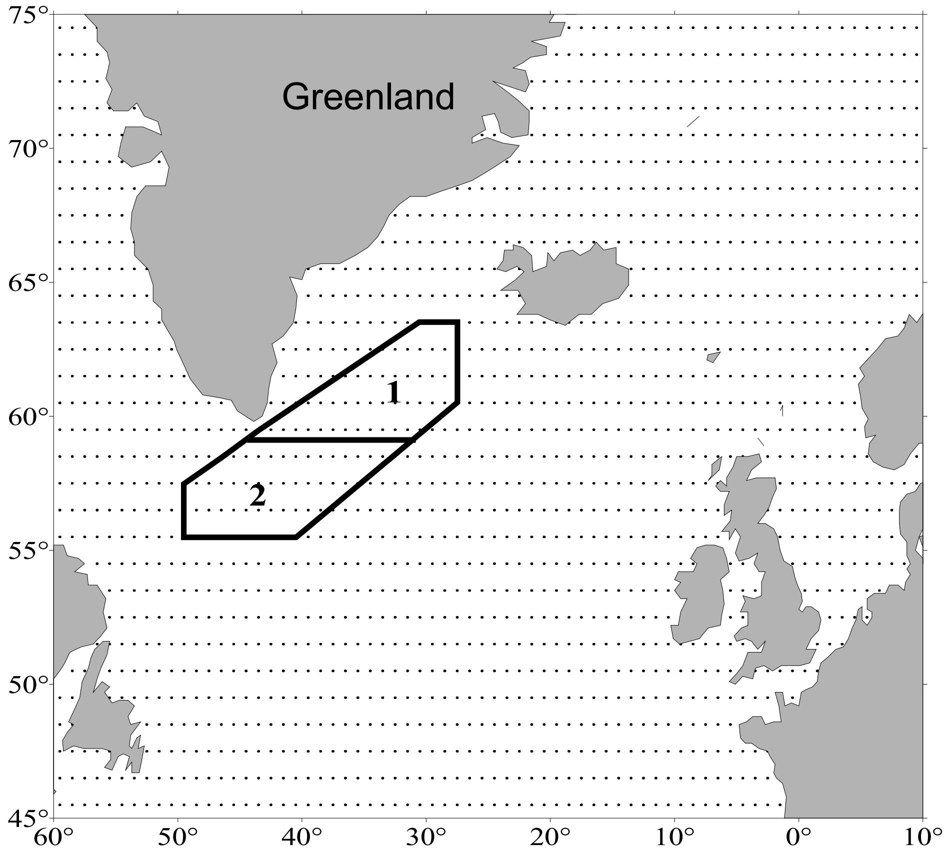

Fig 1. Location of the TSL IGOSS regular grid nodes and boundaries of the studied area: 1– northern area, 2 – southern area.

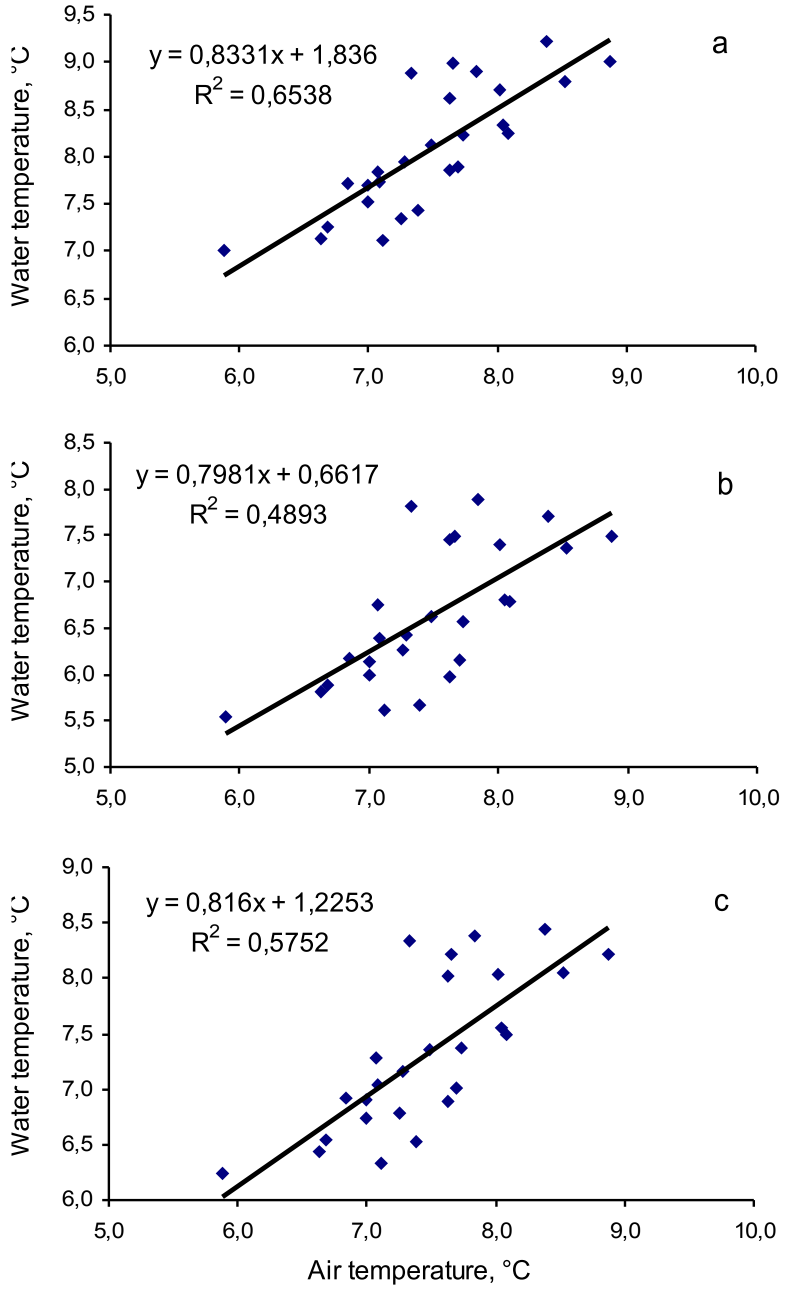

Fig. 2. Charts indicating relation between variations in air temperature at the station Reykjavik and TSL in the Irminger Sea and adjacent waters in 1982-2008: a – northern area; b – southern area; c – all studied area.

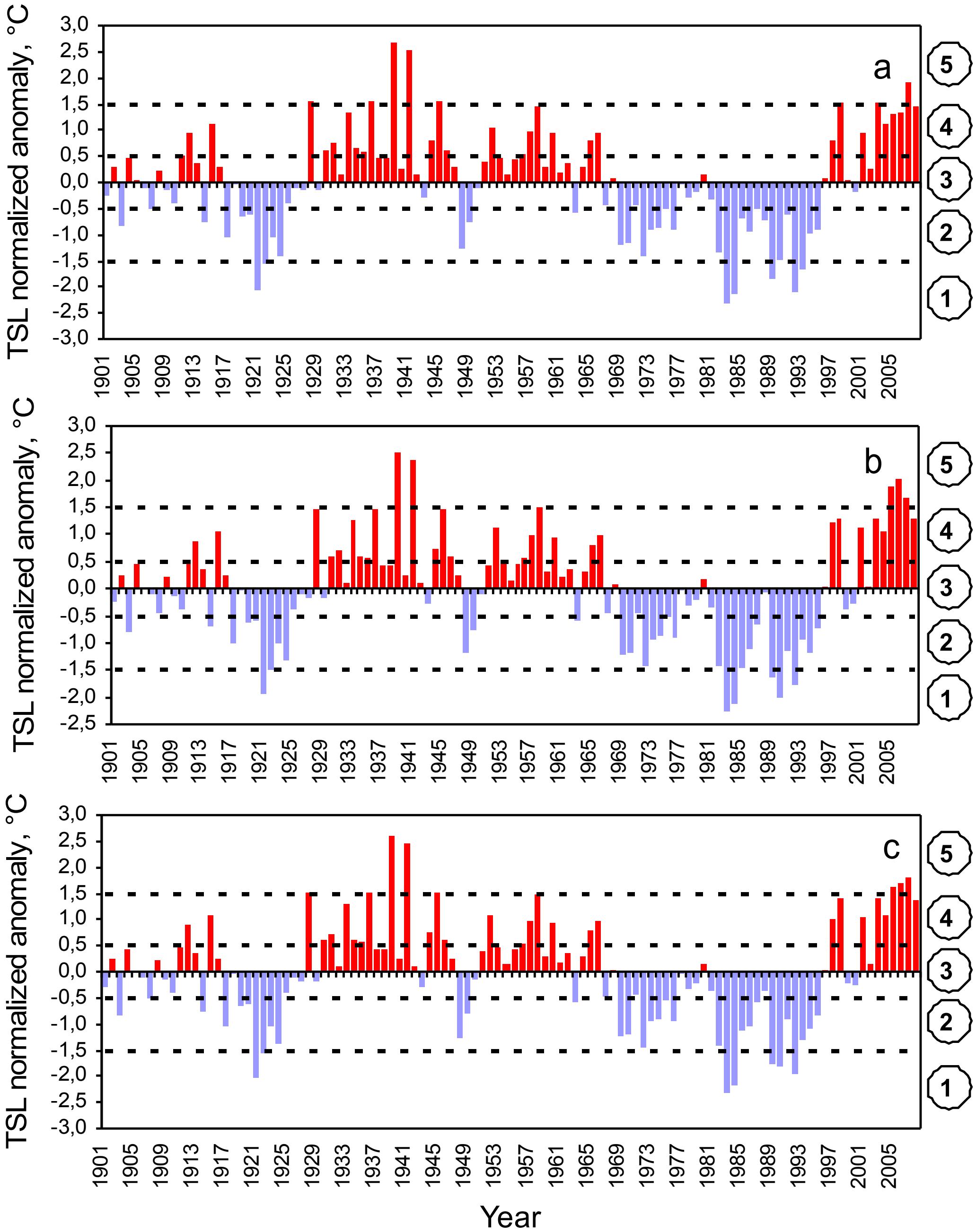

Fig. 3. TSL normalized anomalies in the northern (a), southern (b) area and in all area (c) of the Irminger Sea and adjacent waters in 1901-2008 and categories of years by V.V. Tereschenko classification: 1– anomalous cold, 2 – cold, 3 – normal, 4 – warm, 5 – anomalous warm.

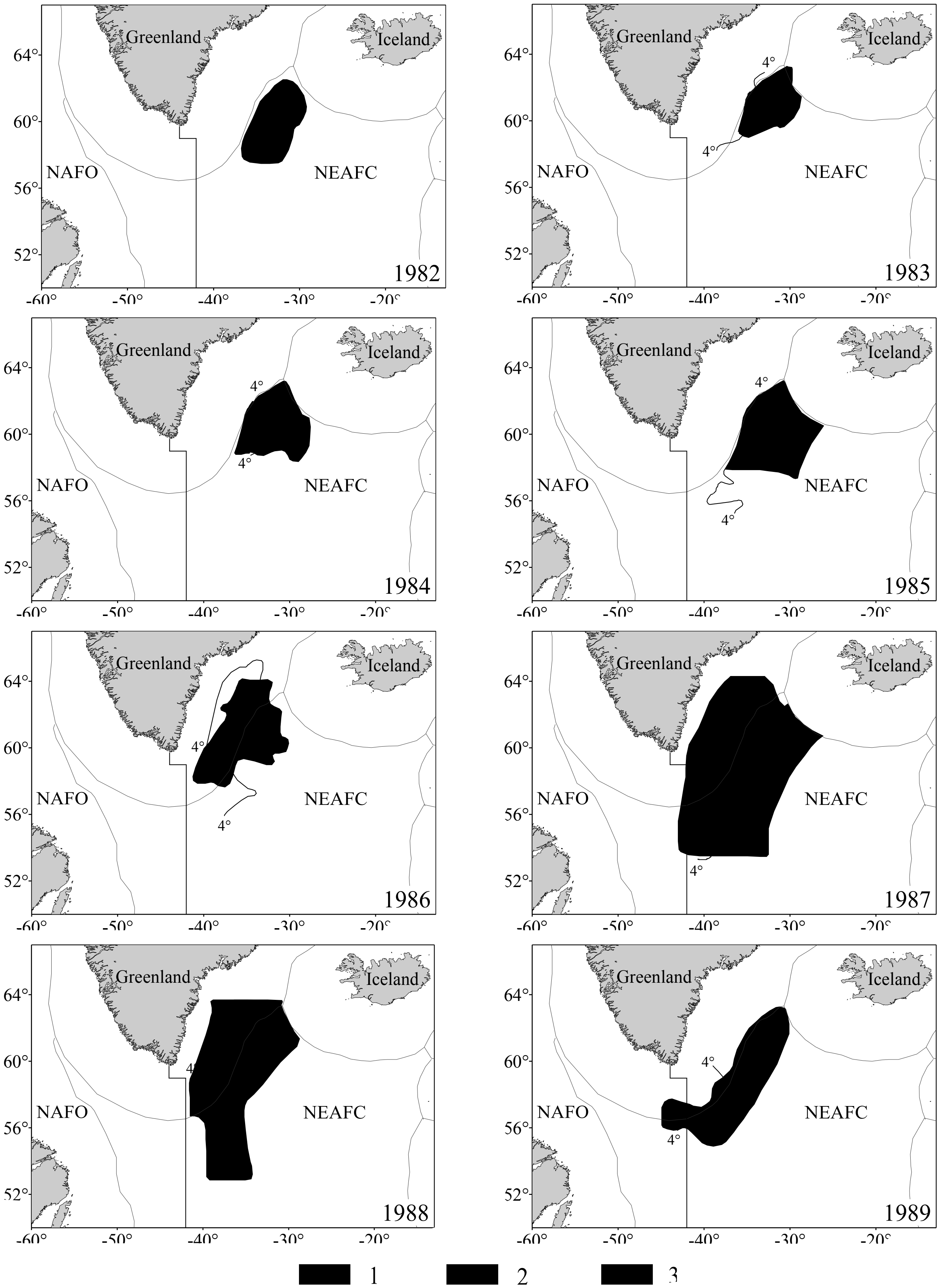

Fig.4. Distribution of redfish aggregations in the pelagial of the Irminger Sea and adjacent waters in 0-500m layer and location of isotherm 4^0 C in 200m layer, resulted from summer trawl acoustic surveys in 1982-1989. Density of concentrations (SA $m^2/mile^2$): 1 – 0-10; 2 – 11-20; 3 – >20.

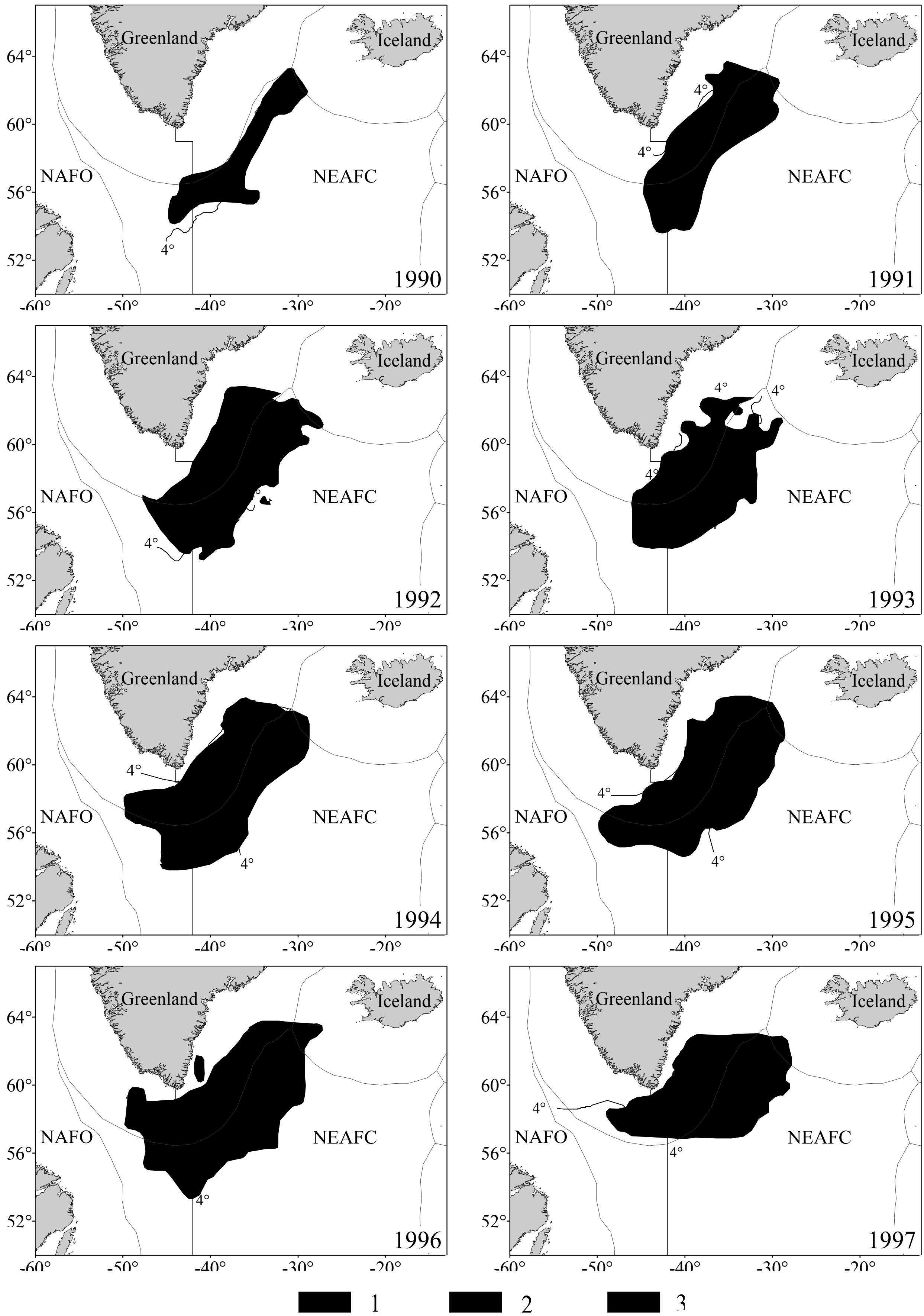

Fig. 5. Distribution of redfish aggregations in the pelagial of the Irminger Sea and adjacent waters in 0-500m layer and location of isotherm 4^0 C in 200m layer, resulted from summer trawl acoustic surveys in 1990-1997. Density of concentrations (SA $m^2/mile^2$): 1 – 0-10; 2 – 11-20; 3 – >20.

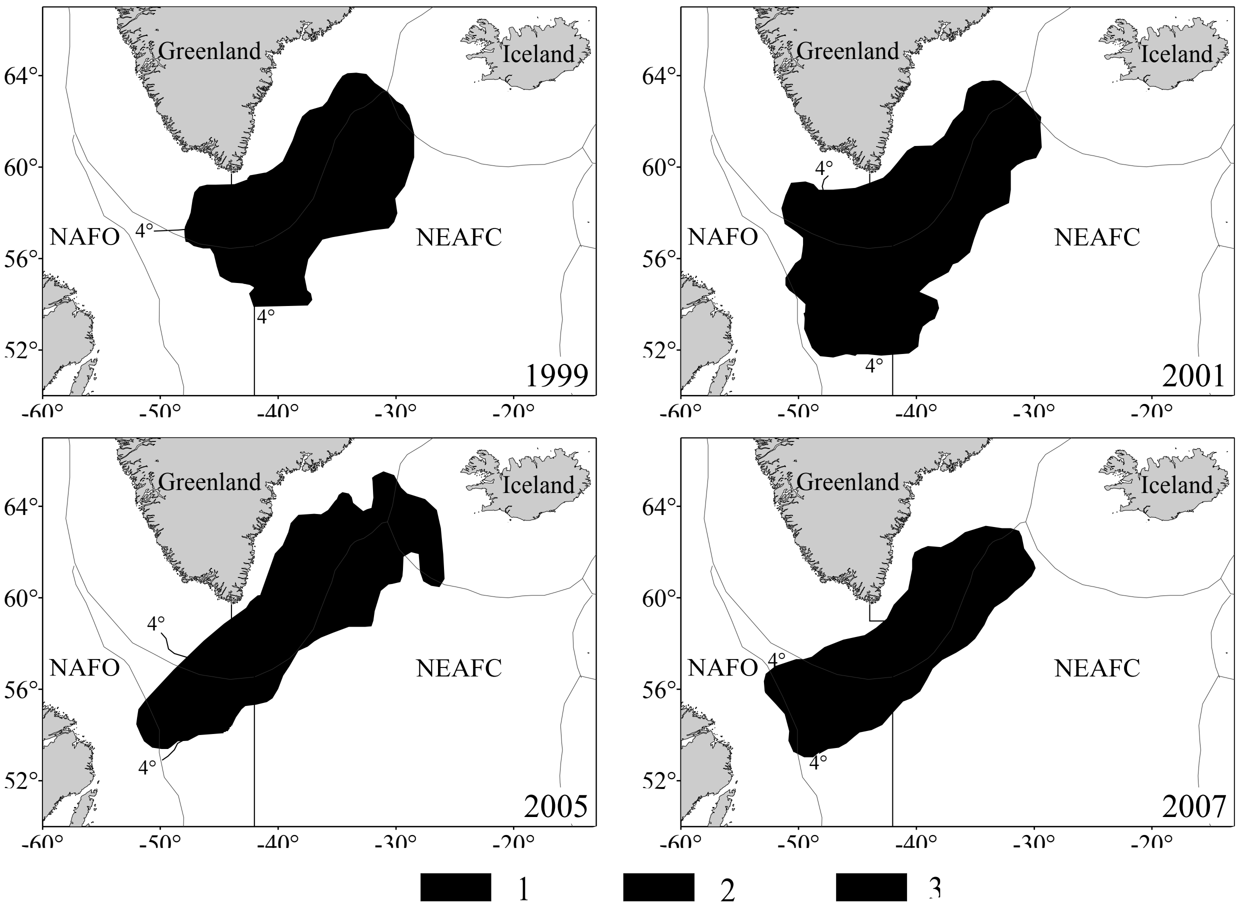

Fig. 6. Distribution of redfish aggregations in the pelagial of the Irminger Sea and adjacent waters in 0-500m layer and location of isotherm 4^0 C in 200m layer, resulted from summer trawl acoustic surveys in 1999-2007. Density of concentrations (SA $m^2/mile^2$): 1 – 0-10; 2 – 11-20; 3 – >20.

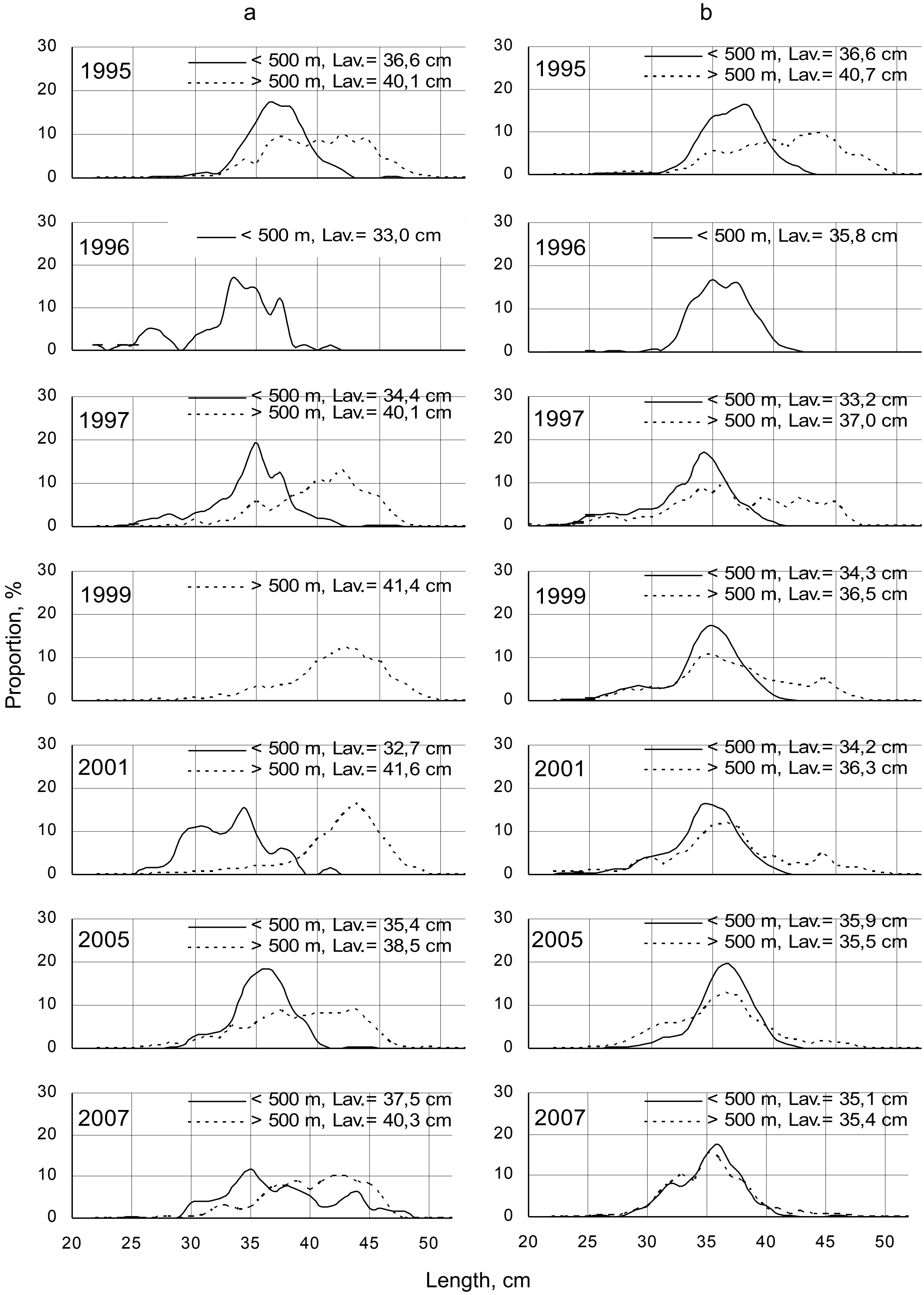

Fig. 7. Size composition of *S. mentella* in the northern (a) and southern (b) areas in the pelagial of the Irminger Sea and adjacent waters at the depth less than 500m and over 500m, resulted from summer trawl acoustic surveys in 1995-2007.

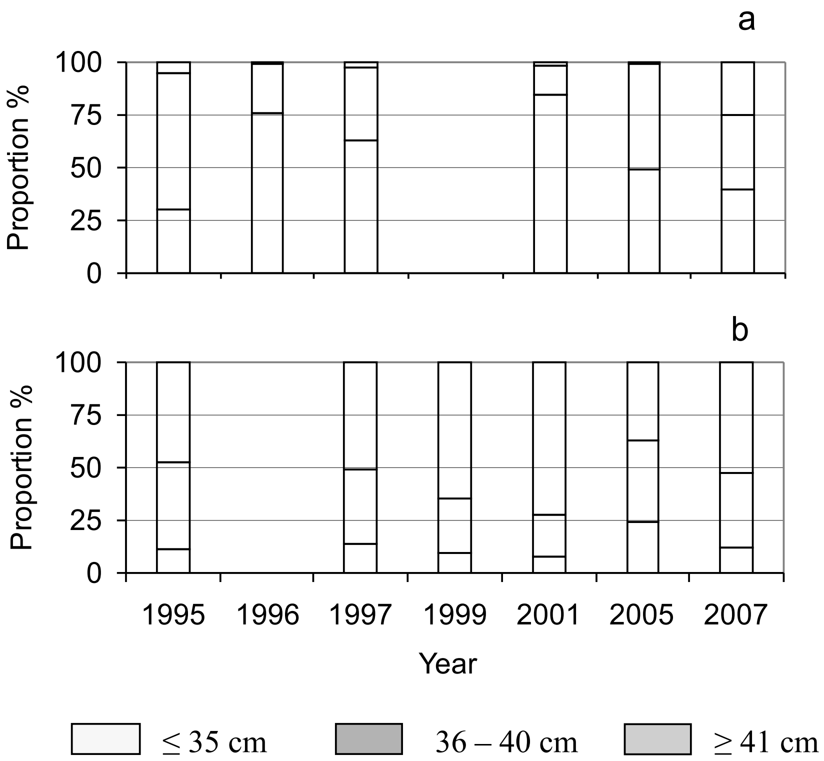

Fig. 8. Correlation of size groups of *S. mentella* in the northern area in the pelagial of the Irminger Sea at the depth less than 500m (a) and over 500m(b), resulted from summer trawl-acoustic surveys in 1995-2007.

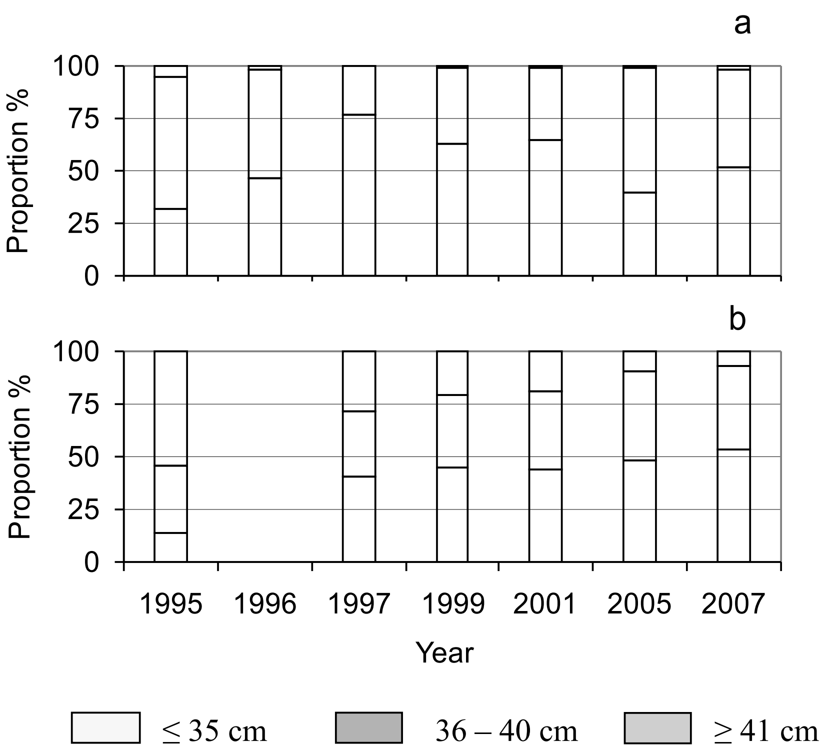

Fig. 9. Correlation of size groups of *S. mentella* in the southern area in the pelagial of the Irminger Sea at the depth less than 500m (a) and over 500m(b), resulted from summer-trawl acoustic surveys in 1995-2007.

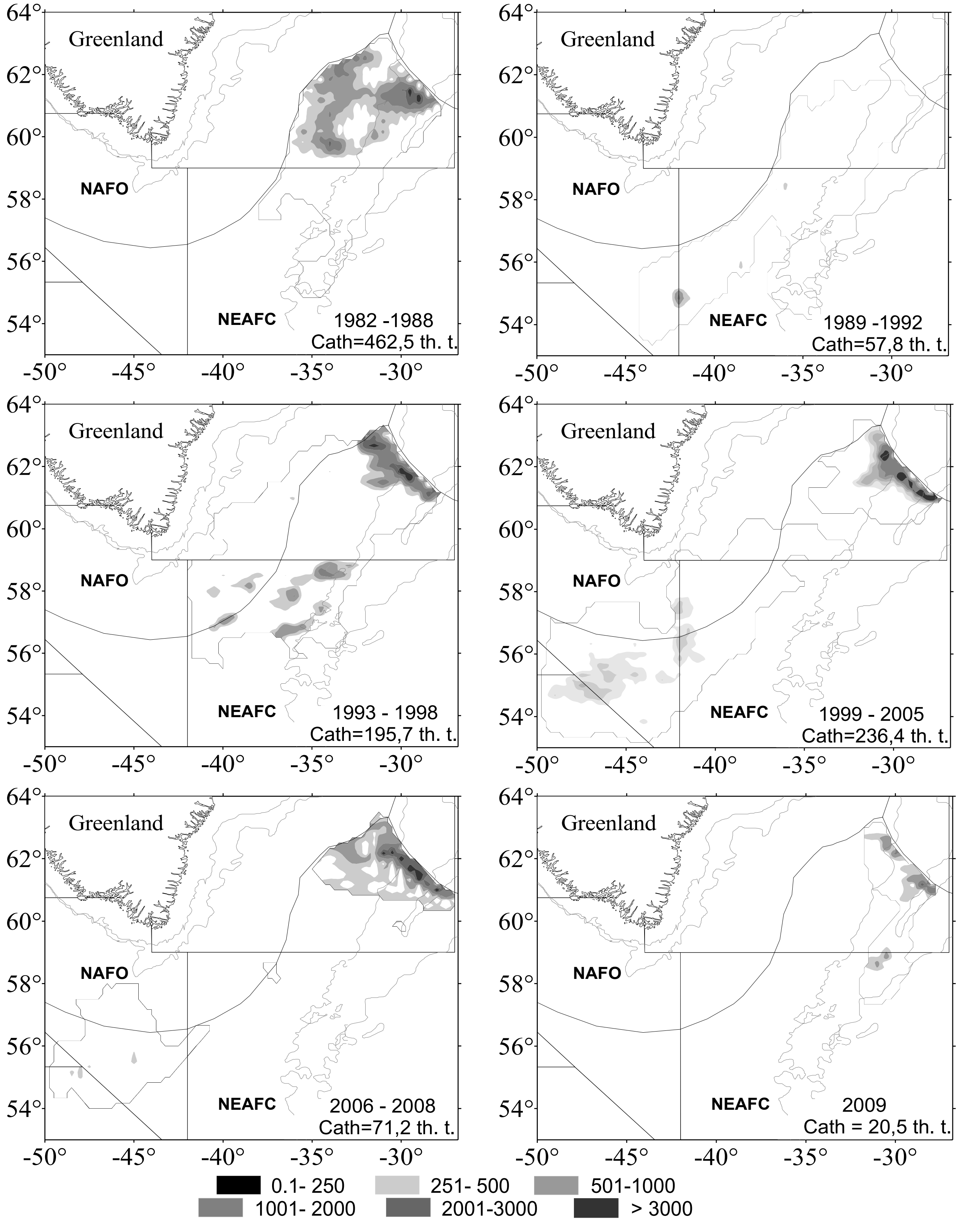

Fig. 10. Fishing areas and the catch (squared t, 10' in latitude and 15' in longitude) of *S. mentella* by Russian vessels in 1982-2009.

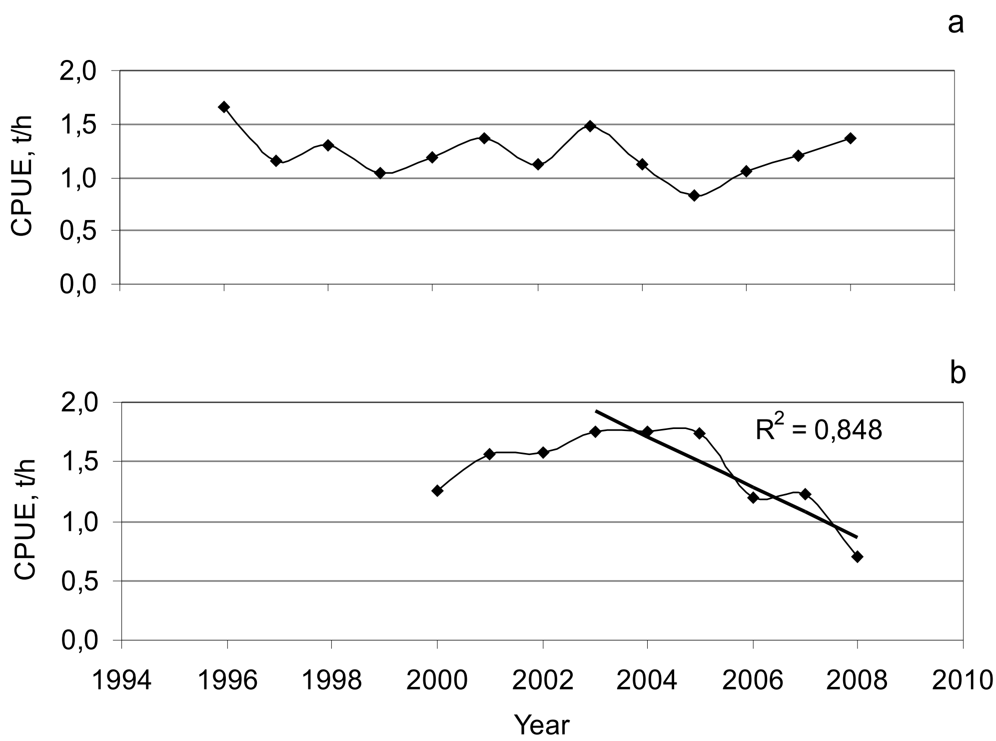

Fig. 11. Fishing efficiency of *S. mentella* in the northern (a) and southern (b) areas of the pelagial of the Irminger Sea and adjacent waters in 1996-2008.

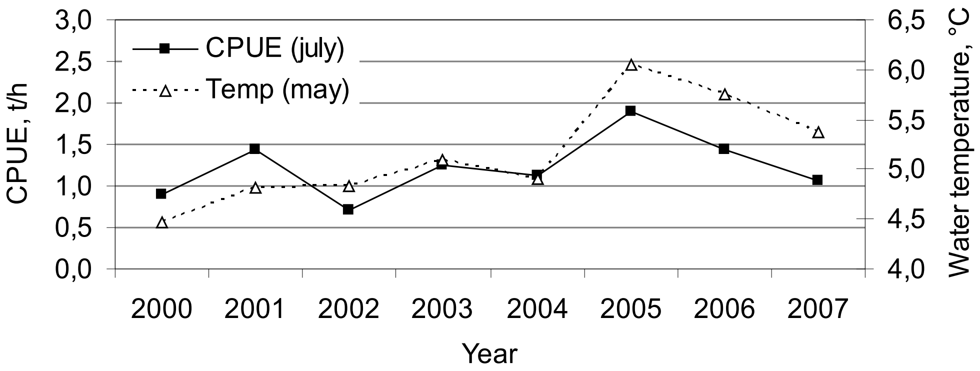

Fig. 12. Fishing efficiency of Russian vessels in the southern area in July and water temperature in May 2000-2007.

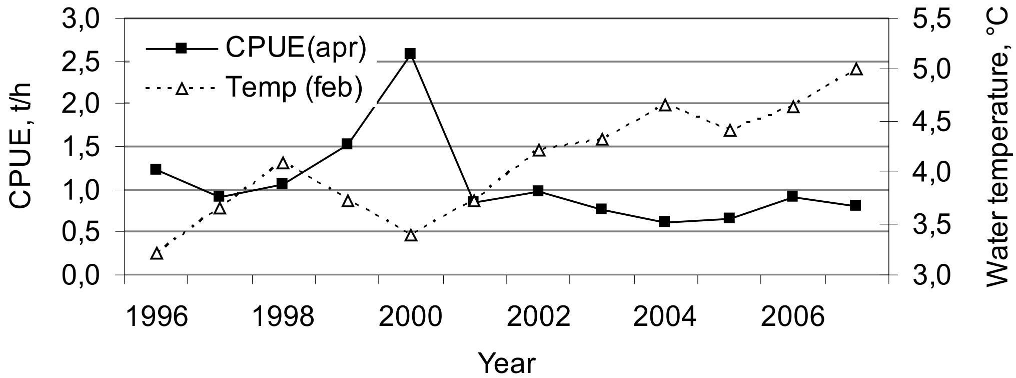

Fig. 13. Fishing efficiency of Russian vessels in the northern area in April and water temperature in February 1996-2007.