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Long Term Changes in Abundance and Spatial Distribution of Pelagic *Agonidae, Ammodytidae, Liparidae, Cottidae, Myctophidae* and *Stichaeidae* in the Barents Sea

Elena Eriksen[1,*], Tatyana Prokhorova[2] and Edda Johannesen[1]
[1]*Institute of Marine Research, Bergen,*
[2]*Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk,*
[1]*Norway*
[2]*Russia*

1. Introduction

The Barents Sea is a high-latitude, arctoboreal shelf sea, situated between 70° and 80°N. Its topographical features include Spitsbergen to the North, Novaya Zemlya to the East, the mainland coast of Russia and Norway to the South, and the continental shelf break to the West (Figure 1). In the Barents Sea, warm and saline Atlantic water flows in from the Southwest and meets the cold Arctic water with low salinity, or the mixed waters in the North and East, along the polar front. The interannual variation in sea temperature in the Barents Sea is, to a large extent, determined by the inflow of Atlantic water: in years with strong inflow of Atlantic water the sea temperature is higher (Loeng 1991). This variability in ocean climate strongly influences the abundance of commercially exploited fishes in the Barents Sea ecosystem (e.g. Hamre 1994).

The Barents Sea fish fauna is dominated by 8-10 very abundant, commercially exploited species, and among them some of the world's largest fish stocks: the Northeast Arctic cod *Gadus morhua*, Barents Sea capelin *Mallotus villosus*, Northeast Arctic haddock *Melanogrammus aeglefinus*, and the juvenile Norwegian spring-spawning herring *Clupea harengus*.

The Institute of Marine Research (IMR), Norway, and the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia, have carried out routine surveys to assess stock size of exploited species as basis for advice in the Barents Sea for several decades. Since 1965 an international 0-group fish survey in the Barents Sea has provided pelagic trawl data to give an early indication of year class strength of targeted fish species: capelin, herring, cod, haddock, saithe (*Pollachius virens*), redfish (*Sebastes spp.*), Greenland halibut

* Corresponding Author

(*Reinhardtius hippoglossoides*), long rough dab (*Hippoglossoides platessoides*), and polar cod (*Boreogadus saida*) (Haug and Nakken, 1973, 1977; Dingsør 2005; Eriksen *et al.* 2009). Since 1980 standard trawling procedures have been used (Anon. 1980). Since 2005 standard procedures (stratified sample mean method) have been used to estimate abundance and biomass indices of 0-group fish (Dingsør 2005; Eriksen *et al.* 2009, 2011). On the same survey by-catch of non-targeted species (invertebrates and fishes) has been recorded but these data have never been analysed and published. Non-targeted fishes are much less studied than the exploited species in the Barents Sea. However, these fishes are potentially important components of the food web and thus the functioning of the Barents Sea ecosystem. Also they are of interest because they contribute to the biodiversity of the Barents Sea.

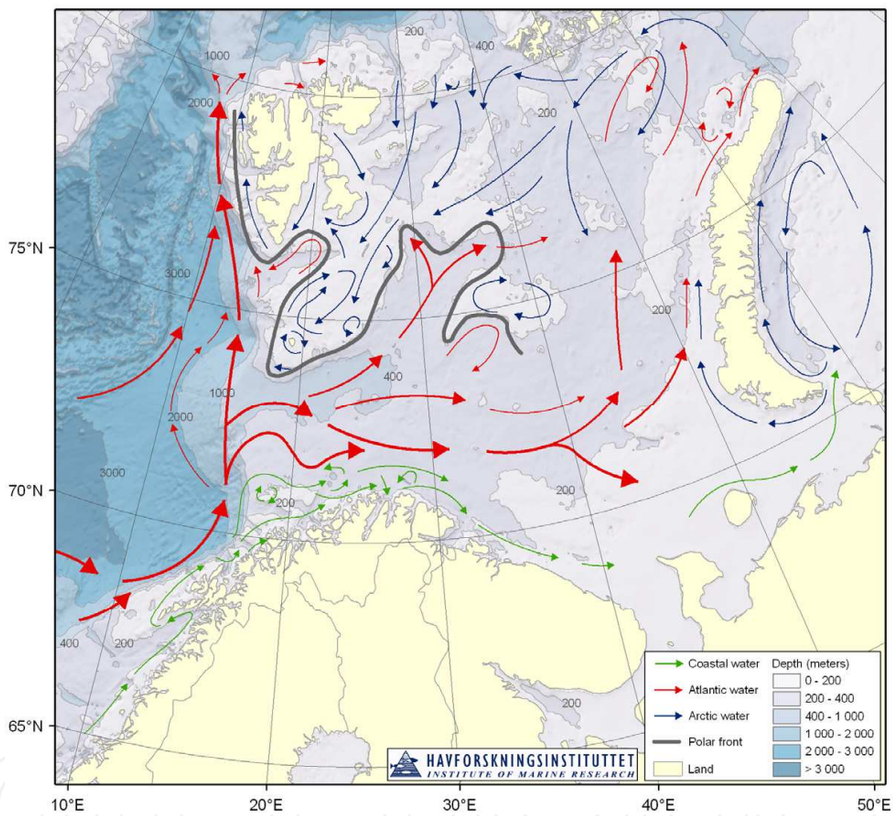


Fig. 1. Overview of the Barents Sea geography and current system.

Several authors, e.g. Andriashev and Chernova (1995) have grouped the Barents Sea fishes into zoogeographical groups that are associated with different water temperatures and water masses (Arctic or Atlantic, above, see material and methods for details on the biology of the studied fishes). Species from different zoogeographical groups are likely to respond differently to climatic change and fluctuations, and thus can serve as indicators of the effect of climate change.

In this paper, we study six families of non-targeted fishes (called "small fishes" here) caught in the 0-group survey from 1980-2009: *Agonidae, Ammodytidae, Cottidae, Liparidae*, *Myctophidae* and *Stichaeidae*.

We calculate indices of biomasses of these fish families and compare the estimates to the biomass estimates of targeted pelagic fish species (0-group and adult, Eriksen *et al.* 2011). We then discuss the potential ecological role of small fishes based on their biomass and distribution.

Furthermore, we study how variation in the distributions and biomasses of small fishes are related to variation in climate. We use time series of temperature of 0-50 m from Fugløya-Bear Island (FB) oceanographic section (70°30′ and 20°00′ to 74°15′ and 19°10′) as an indicator of climate variation. The FB section is located in the main entrance of the inflow of the Atlantic water masses into the Barents Sea. We predict that the biomass of fishes from families mostly associated with warmer, Atlantic water (*Ammodytidae, Myctophidae* and *Stichaeidae*) should increase in years with high temperatures associated with high inflow of Atlantic water, due to more favourable environmental conditions according to their requirements. We furthermore predict that the distribution of all fish families should be shifted northwards in warm years and southwards in cold years.

2. Materials and methods

2.1 Survey data

Our data was the by-catch from the standardised international 0-group fish survey in the Barents Sea. The survey has been carried out annually during August-September since 1965. Since 2004 the 0-group survey has been a part of the Joint Norwegian-Russian ecosystem survey in the Barents Sea in August-September (Anon. 2004). In 1980 a standard trawling procedure was recommended and applied (Anon. 1980). The standard trawling procedure consists of pelagic tows at predetermined positions 25-35 nautical miles (nm) apart. A "Harstad trawl" trawl having 7 panels and a cod end was used. The panels have mesh sizes (stretched) varying from 100 mm in the first panel to 30 mm in the last panel, and 7 mm in the cod end. The tows are done at three depths: head-line at 0 m, 20 m and 40 m, each tow is 0.5 nautical miles (nm) with a trawling speed of 3 knots. Additional depths are towed (60 and 80 m), at dense concentration of fish recorded deeper than 40 m depth on the echo-sounder (Anon. 1980, 2004). To study pelagically distributed small fishes we used pelagic catches from the 0-group survey (1980-2003) and the ecosystem survey (2004-2009) from a revised and updated 0-group database (Eriksen *et al.* 2009).

We also mapped the demersal distribution of the fishes studied here, using demersal trawl catches from the ecosystem survey (2004-2009). Note that the area covered by the bottom trawl extended further north than that of the pelagic trawl (see Figure 2 and 3). Bottom catches were taken with a "Campelen 1800" shrimp trawl with 80mm (stretched) mesh size in the front and cod end with 22 mm mesh size. Standard towing time was 15 minutes after the trawl had made contact with the seabed and the towing speed was 3 knots. A subsample of each fish species/group, was length measured from all demersal and pelagic trawl stations all years. The average lengths from demersal and pelagic trawls were calculated separately. Individual weights for small, non-targeted fishes were recorded only occasionally. During the ecosystem survey in 2008, fishes from the families that we studied here were sampled from some pelagic and bottom trawl stations, and their otoliths were mounted in epoxy and cut to precision into units of 0.1 mm for later age determination with binocular, the results of age determination are presented in the results section.

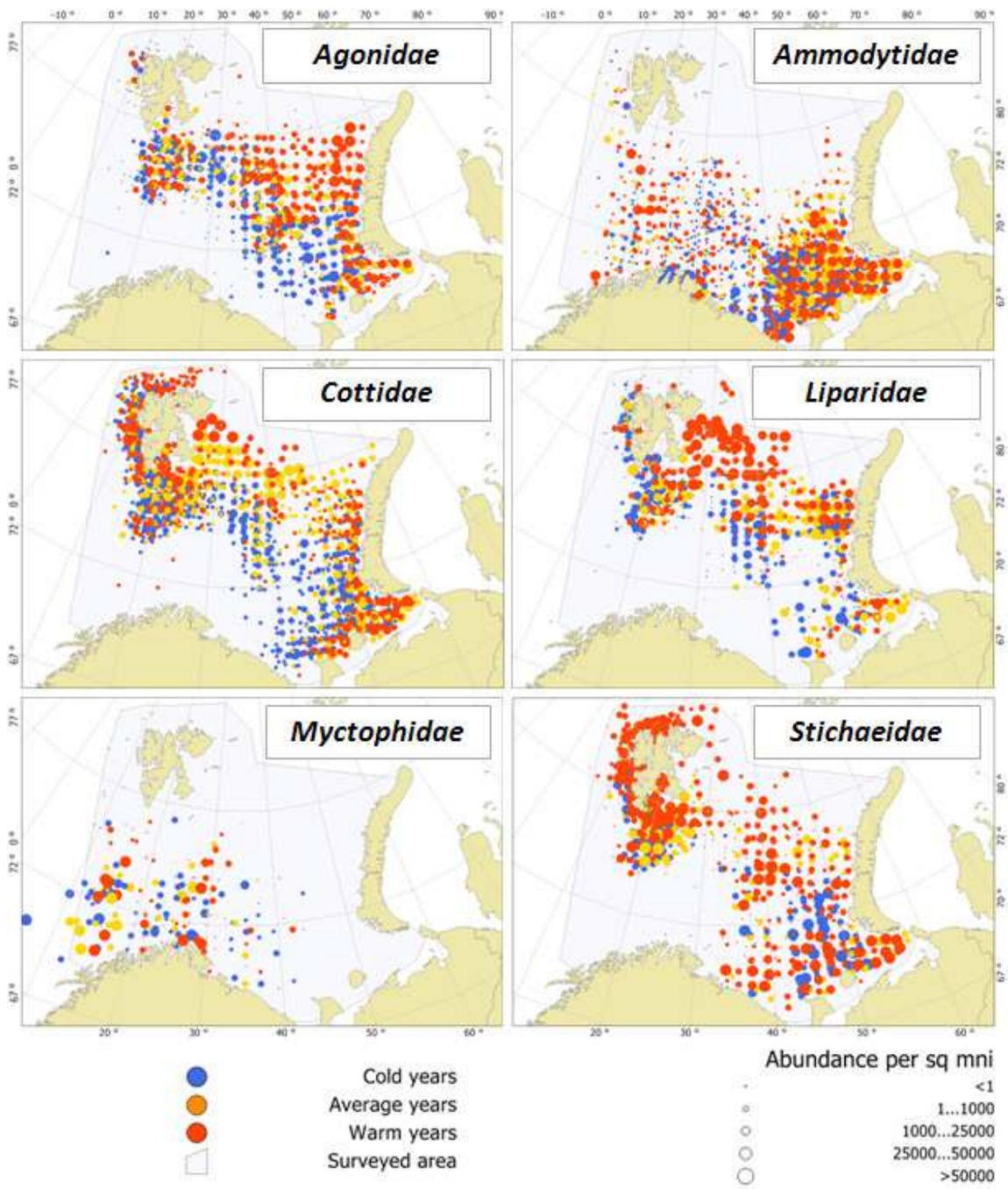


Fig. 2. Spatial distribution of pelagically distributed *Agonidae*, *Ammodytidae*, *Cottidae*, *Liparidae*, *Myctophidae* and *Stichaeidae* in the Barents Sea during 1980-2009. Abundance of small fishes per mn² is shown by circle, where size indicates density of fishes, while colour of circle indicates temperature condition (years which were categorized as cold shown in blue, average in yellow and warm years in red).

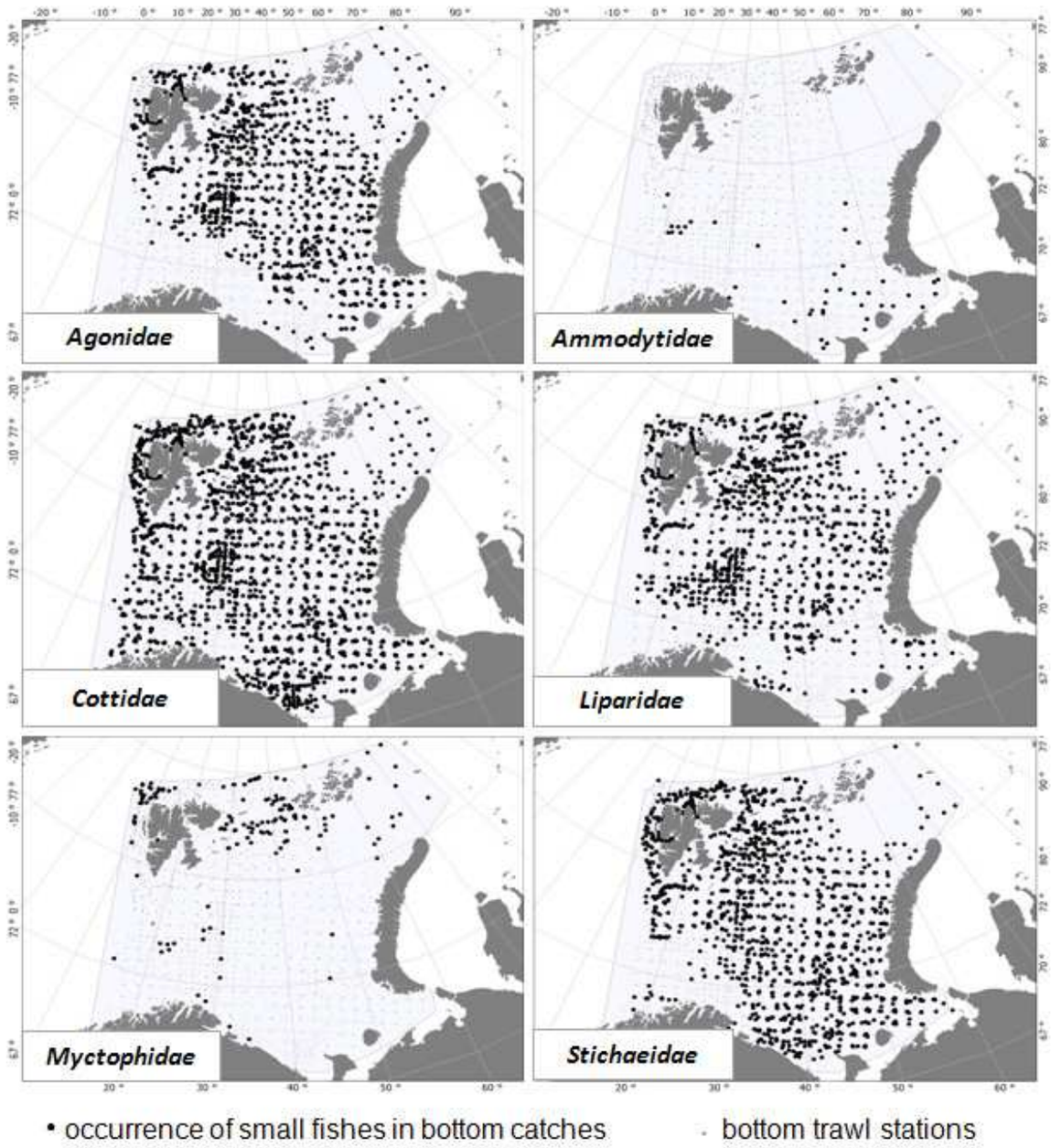


Fig. 3. Spatial distribution of demersal *Agonidae*, *Ammodytidae*, *Cottidae*, *Liparidae*, *Myctophidae* and *Stichaeidae* in the Barents Sea during 2004-2009. Occurrence of small fishes in bottom catches is shown by black circles, while grey and small circles showed bottom trawl stations.

With the exception of redfish (genus level), the targeted fish species (see introduction) were identified to species level during the 0-group survey. The non-targeted small fishes, on the other hand, were at times only identified to family level; in some years up to 50% of the small fishes were identified to the family level only. This was due time constraints on board and difficulties in species identification. We therefore decided to combine the small fishes

into larger groups (families). We excluded the family *Paralipidae*, tusk (*Bromse brosme*), Norway pout (*Trisopterus esmarkii*) and *Phycis sp.*, because they were only present in very low numbers and only in some years. We then analysed the data on the remaining six non-targeted fish families recorded in the survey. Their biology is described below.

2.2 Fish families examined and their biology

Agonidae are small bottom-dwelling cold-water marine fish that are widely distributed in the northern part of the Atlantic and Pacific Oceans. There are three species in the Barents Sea (Karamushko 2008). *Leptagonus decagonus* (Bloch and Schneider 1801) is the most abundant and is widely distributed in both the northern and central areas, however it is rare in the south-eastern part of the Barents Sea and along the Finnmark coast (Byrkjedal and Høines 2007). It is generally found in depths of 120-350 m and at a temperature of between -1.7°C and 4.4°C, while the juvenile fish are found in the upper 100-meter layer (Andriashev 1986; Ponomarenko 1995). The larvae of *L. decagonus* drift from the North and North-east with the colder arctic waters that enter the Barents Sea, and are not observed in the Atlantic waters (Rass 1949). *Agonus cataphractus* (Linnaeus 1758) is mostly distributed along the Norwegian coast and in the White Sea (Andriashev 1986). *Ulcina olriki* (Lütken 1876) is a small arctic fish, distributed in the northern parts of the Atlantic and Pacific Oceans, and found on sand and mud bottoms, mostly at temperatures that are below 0°C, and rarely up to 2-3°C (Andriashev 1954, 1986). *Agonidae* generally feed on small crustaceans and worms that are found on the sea-bed (Andriashev 1954, 1986; Pethon 2005).

Ammodytidae are small schooling benthopelagic fish, which are usually found at depths of 10-150 meters, and in the brackish and marine waters of the Atlantic, Pacific and Indian Oceans, mainly in the northern hemisphere. In the Barents Sea, *Ammodytidae* are represented mostly by *Ammodytes marinus* (Raitt 1934) which is distributed along the Norwegian coast, in the Southeast and between Novaya Zemlya and Bear Island (Andriashev 1954). *Ammodytes tobianus* (Linnaeus 1758) and *Hyperoplus lanceolatus* (Le Sauvage 1824) were reported by Andriashev and Chernova (1995) along Murman and the Norwegian coasts, but have not been observed more recently. *A. marinus* spawns during November-February (Rass 1949) at depths of 25-100 m, and feeds on plankton. During low light intensity (night and winter) they bury themselves in the bottom sediment (Muus and Nielsen 1999). In periods with strong tidal currents they leave their bottom hides and form large shoals. Several fish species (cod, flatfish and others), sea birds and seals have been observed to be feeding on *Ammodytidae* in the Barents Sea (Adriashev 1954; Viller 1983; Krasnov & Barret 1995; Borisov *et al.* 1996; Yezhov 2008, 2009; Sakshaug *et al.* 2009).

Cottidae is a large family consisting of about 800 species (Pethon 2005). They are small bottom-dwelling fish that are found in marine, brackish and fresh waters, and most species occur in Arctic or temperate waters. In the Barents Sea 11-13 species were found (Pethon 2005; Byrkjedal and Høines 2007; Karamushko 2008). *Artediellus atlanticus* (Jordan & Evermann 1898), *Myoxocephalus scorpius* (Linnaeus 1758), *Taurulus bubalis* (Euphrasen, 1786), and *Triglops murrayi* (Günther 1888) are mostly boreal species and linked to Atlantic water masses. Others such as *Artediellus scaber* (Knipowitsch 1907), *Gymnocanthus tricuspis* (Reinhardt, 1830), *Icelus bicornis* (Reinhardt 1840), *Triglops nybelini* (Jensen, 1944) and *Myoxocephalus quadricornis* (Linnaeus 1758) are Arctic, while *Icelus spatula* (Gilbert & Burke

1912) and *Triglops pingelii* (Reinhardt 1937) are Arctoboreal species. Earlier studies have reported occurrences of pre-spawned *Cottidae* females, egg and larvae (Rass 1949; Kazanova and Perzeva-Ostroumova 1960; Ponomarenko 1995; Mukhina 2005), indicating spawning in the Barents Sea. *Cottidae* feed on small fish, bottom crustaceans and worms. Cod have been observed to be feeding on *Cottidae* in the Barents Sea (Borisov *et al.* (1996)).

Liparidae are small bathypelagic or bottom fish, and is one of the most diverse and abundant fish families that dwell in polar and deep-sea habitats (Chernova 1991, 2005a). The biology of many of these species is poorly studied. In the Barents Sea, *Liparidae* are represented by approximately 12 species, however, their taxonomy is under revision (e.g Chernova 2005b). In the Barents Sea, *Liparidae* from the *Liparis* and *Careproctus* (Pethon 2005; Byrkjedal and Høines 2007) are abundant and widely distributed throughout the North and Northeast. Species from the genera *Paraliparis* and *Rodichthys* are very rare. Species identification is complicated due to their wide morphological variation (Fevolden *et al.* 1989; Knudsen *et al.* 2007). Several species of *Liparis* spawn during winter, while some species of *Careproctus* spawn during late summer (Ponomarenko 1995). However, the spawning biology is unknown for several species (Pethon 2005). *Liparidae* feed on small pelagic and bottom crustaceans and worms (Stein and Able 1986). Gadoids, skates, seals and auks prey on *Liparidae* (Berestovskij 1990; Borisov *et al.* (1996); Pethon 2005).

Myctophidae include more than 200 circumglobal, high-oceanic, mesopelagic fish species (Hulley 1990). Almost all *Myctophidae* undergo vertical migration associated with foraging on planktonic crustaceans (euphausiids and copepods). They have been observed at depths between 10-200 m at night, and at 375-800 m during the day (Hulley 1990). Not all individuals undertake diel vertical migration (Pearcy *et al.* 1979). *Benthosema glaciale* (Reinhardt 1837), which is very abundant in the North Atlantic, is the only species found in any quantity in the Barents Sea (Kristoffersen and Salvanes 2009). Both males and females of *B. glaciale* mature at age 2-3, when they are between 45-50 mm in length. *B. glaciale* spawns in fjords and along the Norwegian coast, and is an important food resource for several fish, especially for salmon along the coastal area (Giske *et al.* 1990; Salvanes and Kristoffersen 2001; Salvanes 2004; Kristoffersen and Salvanes 2009).

Stichaeidae are circumpolar elongated small bottom fish that are found in northern oceans: Arctic, North Pacific and Northwest Atlantic (Coad and Reist 2004). The Barents Sea *Stichaeidae* include *Lumpenus lampraetaeformis* (Linnaeus 1758), *Leptoclinus maculatus* (Fries 1838) and *Anisarhus medius* (Reinhardt 1837) (Byrkjedal and Høines 2007). *Lumpenus fabricii* (Reinhardt 1836) are very rare. *L. lampraetaeformis* spawns during the winter, but the spawning biology of the other species is not known. However, their larvae and younger fish have been found pelagically. *Stichaeidae* feed on small crustaceans, worms, clams and fish. Cod have been observed to be feeding on *L. lampraetaeformis* in the Barents Sea (Borisov *et al.* (1996)).

2.3 Data analyses

The capture efficiency of the sampling trawl differs between species and decreases with the fish length (Godø *et al.* 1993; Hylen *et al.* 1995). Species specific catch correction functions dependent on length are established and used in the annual computations of 0-group abundances for cod, haddock, herring and capelin (Anon. 2004; Dingsør 2005;

Eriksen *et al.* 2009). The species specific and length dependent catch efficiencies are unknown for all our study fishes. We assume that the small fish were only captured by the panels with less than 50 mm mesh size which was the last two panels and the cod end. The mouth opening of the 50 mm mesh panel is 4 meters, so this is the effective wingspread of trawl used here.

Abundance indices (AI) were calculated for the studied fish families by the standard procedures (equations 1, 2 and 3, below) used for commercial fish species. The stratified sample mean method described by Dingsør (2005) and Eriksen *et al.* (2009) was employed, using the Barents Sea 0-group strata system, consisting of 23 strata.

First the fish density (p_s individuals per square nautical mile) at each station, s, was calculated from the following equation

$$p_S = \frac{n_S \cdot 1852}{wsp * (td_s / dl_s)} \tag{1}$$

where n_s is the observed number of fish at station s, wsp is the effective wingspread of the trawl (4 m), td_s (nm) is the total distance trawled at station s, and dl_s is the number of depth layers at station s.

The average density y_i in stratum i was then calculated from

$$\bar{y}_i = \frac{1}{n_i} \sum_{s=1}^{n_i} p_S \tag{2}$$

where n_i is the number of station$s$ in stratum i.

Finally, the abundance estimate (AI) was then calculated from

$$AI = \sum_{i=1}^{N} A_i \bar{y}_i \tag{3}$$

where N is the number of strata and A_i is the covered area in the i-th stratum.

Yearly estimates of the relative biomasses indices of *Agonidae, Ammodytidae, Liparidae, Cottidae, Myctophidae* and *Stichaeidae* were calculated as a product of the yearly relative abundance indices and average fish weight. Data on individual weight were however, scarce (see above). Therefore, we pooled all available weights from pelagic hauls and calculated average individual weights across all years: *Agonidae (*0.30g), *Ammodytidae (*0.50g), *Liparidae (*0.35g), *Cottidae (*0.30g), *Myctophidae (*0.45g) and *Stichaeidae (*0.50g).

To visualise a huge amount (30 years) of spatial distribution of the small fishes in relation to temperature we separated the time series into three categories. We categorised the temperature conditions in the Barents Sea based on the mean annual temperature at the Kola section (average surface to bottom). The temperature data from the Kola section is the

longest time series in existence from the Barents Sea (1900-), and is regarded as a good indicator of the temperature variation in the Barents Sea. The mean annual temperature from 1980 to 2009 was 4.2°C, with minimum of 3.2°C and maximum of 5.1°C. Years with the mean annual temperatures at the Kola section being less than 4°C were classified as cold (1980-82, 1985-88, 1994, 1996-98, a total of 11 years); temperatures between 4 and 4.5°C were categorised as average (1984, 1989, 1991, 1993, 1995, 1999 and 2001-03, a total of 9 years) and temperatures higher than 4.5°C were described as warm (1983, 1990, 1992, 2000, 2004-09, a total of 10 years). Maps of pelagic fish distribution that separated warm, cold and intermediate years were produced using the manifold software (Manifold System 8.0.15.0 Universal Edition).

In addition, catches from the ecosystem survey bottom trawls were mapped in order to compare distributions of the fish families caught in demersal trawls. All years of the ecosystem survey were classified as warm (2004-09).

3. Results and discussion

3.1 Spatial variation

Agonidae and *Liparidae*, mostly arctic fishes, were observed over large area in the north and in the east, with some scattered occurrences in the central part of the Barents Sea. The densest concentrations were found around the Svalbard archipelago and along the western side of Novaya Zemlya (Figures 2 and 3).

Ammodytidae, Myctophidae and *Stichaeidae*, mostly boreal fishes, were recorded in the south-eastern and central parts of the Barents Sea, some of *Stichaeidae* were also found along southern and western side of Svalbard archipelago. The main findings for each family group is summarized in Figures 2 and 3. We also had some data at the species level recorded during the 0-group survey (pelagic trawl) and at the ecosystem survey (pelagic and demersal trawl), described below under their respective families.

3.1.1 *Agonidae*

Pelagically distributed *Agonidae* were mostly found on the banks south and east of the Spitsbergen archipelago to the Novaya Zemlya (Figure 2). Demersally distributed *Agonidae* occupied almost the entire Barents Sea, except the south-western area (Figure 3). At the species level, we found that *L. decagonus* was widely distributed in the central and northern areas of the Barents Sea, while *U. olriki* was distributed along the western part of Novaya Zemlya. A few individuals of *Agonus cataphractus* were found in the colder coastal waters of the eastern part of the Barents Sea on the survey in the pelagic trawl.

The mean fish length of pelagic *Agonidae* in the period of 1980-09 varied from 2.8 to 4.6 cm. The long term average length of pelagically distributed fish was 3.7 cm, while the average length of bottom distributed fish was much higher (12.6 cm, Figure 4). The higher mean length of demersal *Agonidae* supported the assumption that the *Agonidae* at age 0 live pelagically, while the distribution of adults is near the bottom. There were no otoliths sampled from the *Agonidae*.

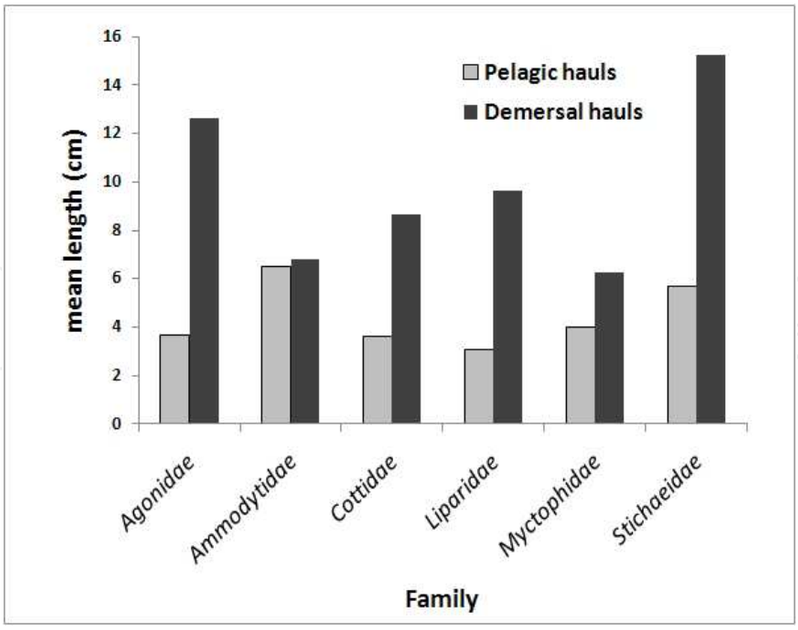


Fig. 4. Mean length of small species from pelagic and bottom trawl catches.

3.1.2 *Ammodytidae*

Pelagically distributed *A. marinus* was observed mainly in the south-eastern area of the Barents Sea (Figure 2). Small catches were also registered in the central and western areas. Demersally distributed fish were observed scattered throughout the south-east, while some were found in the western part of the Barents Sea (Figure 3). The average lengths of pelagically and bottom distributed fish were similar, 6.5 and 6.8 cm, respectively. Therefore, we believe that individuals from the pelagic and demersal hauls were part of the same component of the stock, and that the variation in their vertical distribution reflects feeding migrations for planktonic crustaceans. A total of 20 otoliths were studied, and showed that the 0-group fish were between 5.2-6.9 cm in length, while fish at age 1 were between 6.0-7.6 cm and fish at age 2 and older were longer than 8.9 cm. Therefore we believe that our abundance estimates represented both young and adult fish.

3.1.3 *Cottidae*

Cottidae were observed in shallow areas in the whole area (Figure 2). They showed a clear shift in their area of occupation during different temperature conditions. In colder years they were observed in North Kanin, Central Bank and the Svalbard bank, while in warmer years they were also observed further north in the Great Bank and Novaya Zemlya Bank. Demersally distributed *Cottidae* were observed widely during the warm years when the Barents Sea ecosystem survey was conducted (Figure 3).

The mean length of the fish observed pelagically varied between 3.0 and 4.2 cm, with much lower average lengths than of bottom distributed fish (3.6 cm and 8.7 cm, respectively, see Figure 4). Otoliths were taken from both pelagic and demersal trawl catches from the following species: *A. atlanticus* (24 fish), *I. bicornis* (3 fish) and *T. nybelini* (5 fish). The length

of the one-year-old *T. nybelini* varied between 6.1 and 7.3 cm. Two year old *A. atlanticus* (5.4-6.5 cm) were smaller than *T. nybelini* (10.4-11.4cm), 3-5 years old *A. atlanticus* were between 5.9 and 9.7cm, while 3-5 year old *I. bicornis* were 4.8-6.8. As expected, this showed that different species exhibit different growth patterns. We believe that our results on abundance, biomass and distribution from pelagic trawl represented mostly juvenile fish.

3.1.4 *Liparidae*

The following species was recorded during the 30 years of observations: *Liparis liparis, L. cf. fabricii, L. cf. gibbius, Paraliparis bathybius* and *Careproctus reinhardti* (species complex under taxonomic revision). However, the taxonomy in this family is relatively unknown because of the rarity of many species and difficulties in identifying distinct morphological characteristics. Therefore, we believe that our results apply mostly at the genus level, with *Liparis* and *Careproctus* being much more abundant than the others. Pelagically distributed *Liparidae*, like *Cottidae*, were generally found over shallow areas and banks (Figure 2), while demersally distributed *Liparidae* were more widely observed, but not found in coastal areas (Figure 3).

Three otoliths of *Careproctus sp.* were taken from fish larger than 8 cm. Age determinations showed that the fish of 8.3 cm were 3 years old, while two fish of 9.8 and 10 cm were 4 years old. The calculated mean length varied between 2.1 and 4.0 cm for pelagically distributed fish (Figure 4). The average length of pelagically distributed fish was much lower than of bottom distributed fish, (3.1 cm and 9.6 cm, respectively, Figure 4), therefore our results represent juvenile fish.

3.1.5 *Myctophidae*

The Barents Sea *Myctophidae* are largely represented by *B. glaciale.* Pelagic *B. glaciale* were found in the south-western part of the Barents Sea (Figure 2). The demersal distribution is shown in Figure 3, with most fish found in the northern parts of the Barents Sea, where there were only a few pelagic catches. Records of such a northerly distribution of *B. glaciale* are absent in the literature. B. *glaciale* is a good swimmer, and catchability is low due to high avoidance of the pelagic trawl (own experience), resulting in strong underestimation of abundance. In this study the mean length of pelagically distributed fish varied between 3.1 and 5.2 cm, and their average length was somewhat lower than the demersally distributed fish (4.0 cm and 6.0 cm, respectively, Figure 4). *Myctophidae* mature at age 2-3, when the fish are 4.5-5.0 cm in length, therefore we believe that our result mainly represents adult fish that are migrating to the surface to feed on small crustaceans.

3.1.6 *Stichaeidae*

The pelagically distributed *Stichaeidae* was found in shallow waters (Figure 2). *L. maculatus* was most abundant and was widely distributed, while *L. lampraetaeformis* and *A. medius* were mostly found near Spitsbergen archipelago and Novaya Zemlya, although *L. lampraetaeformis* was also frequently found in the northern Barents Sea. Demersally distributed *Stichaeidae* were found widely in the Barents Sea (Figure 3). During the studied period (1980-09) the mean length of fish varied between 3.4 and 8.1 cm. The average length of pelagic fish was much lower than that of the bottom distributed fish (5.7 cm and 15.3 cm,

respectively, Figure 4). In addition otoliths studies (a total of 27 fish) showed that the growth rate of *L. lampraetaeformis* was higher than that of *L. maculatus*, and the fish length of those of age 1 and older was 12.8 cm and 9.1 cm, respectively. Our results from pelagic trawls represented younger fish.

3.2 Biomass and abundance

Relative abundance and biomass indices were calculated for *Agonidae*, *Ammodytidae*, *Liparidae*, *Cottidae*, *Myctophidae* and *Stichaeidae* for the period of 1980-2009. The biomasses varied greatly between fish families, and were dominated by boreal fishes, *Ammodytidae* and *Stichaeidae* (Table 1).

The total biomass of small fishes varied between from 2 to 90 thousand tonnes, with long term average of 23 thousand tonnes for the 1993-2009 (Table 1), The average biomass of the most abundant 0-group fishes (cod, haddock, herring and capelin) 1993-2009 was ca 1 million tonnes, so the small fishes was only 2.3% the biomass of the most abundant 0-group fish.

Year	*Agonidae*		*Ammodytidae*		*Cottidae*		*Liparidae*		*Myctophidae*		*Stichaeidae*		Total	FB 0-50,
	AI	B	AI	B	AI	B	AI	B	AI	B	AI	B	biomass	August
1980	758	227	133169	66584	1640	492	1216	426	521	234	4180	2090	70053	8.34
1981	855	256	202	101	535	160	521	182	30	14	3482	1741	2455	7.78
1982	1048	314	56872	28436	154	46	290	101	8	3	0	0	28902	7.69
1983	276	83	24049	12024	762	229	151	53	430	194	39	20	12602	7.41
1984	199	60	4030	2015	1337	401	61	21	595	268	4	2	2768	7.30
1985	456	137	1733	866	1515	454	697	244	70	32	4576	2288	4022	8.10
1986	652	196	51172	25586	1824	547	380	133	77	35	1	0	26497	8.29
1987	339	102	103686	51843	1142	343	139	49	153	69	0	0	52405	7.18
1988	341	102	39482	19741	3248	974	345	121	1236	556	3877	1939	23433	8.78
1989	145	43	48330	24165	14980	4494	471	165	683	307	1878	939	30114	8.17
1990	226	68	10819	5409	938	281	1	0	14	6	6193	3096	8862	9.62
1991	888	266	8766	4383	17992	5398	2115	740	31	14	10262	5131	15933	7.95
1992	425	128	6833	3417	1155	346	178	62	1367	615	3276	1638	6206	8.93
1993	58	17	17607	8803	415	125	77	27	7679	3456	1	0	12428	8.98
1994	3224	967	165192	82596	18171	5451	55	19	66	30	0	0	89064	7.62
1995	188	57	22560	11280	432	130	8	3	1	1	15	8	11477	7.84
1996	585	176	40791	20395	1606	482	179	63	1372	617	0	0	21733	8.25
1997	178	53	18652	9326	1611	483	1008	353	52	24	11460	5730	15969	8.02
1998	564	169	2283	1141	2336	701	778	272	69	31	8707	4354	6668	9.27
1999	1794	538	8877	4439	12859	3858	4582	1604	2	1	5312	2656	13095	8.31
2000	1671	501	43244	21622	5077	1523	2426	849	1094	492	10036	5018	30007	7.99
2001	410	123	6316	3158	1161	348	598	209	767	345	4740	2370	6554	8.21
2002	98	29	16180	8090	265	79	330	115	85	38	0	0	8352	9.56
2003	150	45	3048	1524	8389	2517	45	16	10	5	278	139	4245	8.90
2004	804	241	21472	10736	1127	338	1023	358	0	0	378	189	11862	9.49
2005	1823	547	75874	37937	2458	738	19304	6756	209	94	2984	1492	47564	8.33
2006	2183	655	110823	55411	465	139	10096	3533	159	72	5995	2997	62808	9.10
2007	1237	371	4158	2079	2073	622	423	148	123	55	1430	715	3991	9.23
2008	548	164	886	443	48	14	122	43	338	152	1823	912	1728	8.33
2009	1787	536	53719	26859	16580	4974	5079	1778	2165	974	23012	11506	46627	8.50
Mean	797	**239**	36694	**18347**	4077	**1223**	1757	**615**	647	291	**3798**	1899	**22614**	**8.38**
CV	0.95		1.16		1.42		2.23		2.22		1.32		0.99	
% of total biomass		1		58		11		4		2		25		
Spearman *r*	0.25		-0.01		-0.00		0.17		0.15		0.20			
and *p* value	0.18		0.96		0.98		0.36		0.42		0.29			

Table 1. Abundance indices (AI) (in millions), biomass (B) (in tonnes) of pelagically distributed *Agonidae*, *Ammotydae*, *Liparidae*, *Cottidae*, *Myctophidae* and *Stichaeidae* and water temperature (0-50 m) at FB-section in August over the period 1980-2009. In addition, the long term mean of fish amount (AI and B), coefficient of variation (CV) and Spearman rank correlation (r and p value) between fish abundance and temperature are given.

However, small fishes can be locally important in some areas. In the North, especially near the banks around Spitsbergen, the abiotic conditions are very variable. The waters are thoroughly mixed throughout the year yielding high primary production (Sakshaug and Slagstad 1991). Only ca 5 % of the most abundant 0-group fish were distributed in the northern areas of the Barents Sea, where smaller fishes are abundant (Figure 5). Therefore, in some years (e.g. 1994, 2001 and 2009) with low 0-group fish abundance, the relative importance of small fishes may increase in the northern areas. Polar cod occupies northern Barents Sea, adult capelin occupies the central and northern areas, and thus both these species are important components of ecosystem in the north. The polar cod stock is a comparatively large (average 1986-2009, 0.8 million tonnes), while the capelin stock is largest pelagic stock in the Barents Sea (average 1973-2009, ca 3 million tonnes (Anon. 2009)). In this study, *Ammodytidae* constituted 58 % of the total biomass of small fishes in the pelagic layer. This corresponds to approximately 18 thousand tonnes annually, and the majority of this biomass is found in the south-eastern area. In this area, juvenile herring is also found, with its biomass varying greatly according to the year class strength. In the Barents Sea *Ammodytidae* biomass is low in comparison to e.g. the North Sea, where the sandeel spawning stock varied between 475 thousand and 1 million tonnes from 1983 to 1998 (Lewy *et al.* 2004). The ecology of Barents Sea *Ammodytidae* is insufficiently known. One problem is that younger *Ammodytidae* have very small otoliths (0.5-1.2 mm length) with large shape variation, therefore otoliths are often impossible to identify due to digestion and this substantially increases uncertainties in diet analyses (Eriksen Svetocheva, 2011). However, several studies from other areas, ranging from the North Sea to the Bering Sea have reported that *Ammodytidae* are important prey for a long list of predators, including fish, seals,

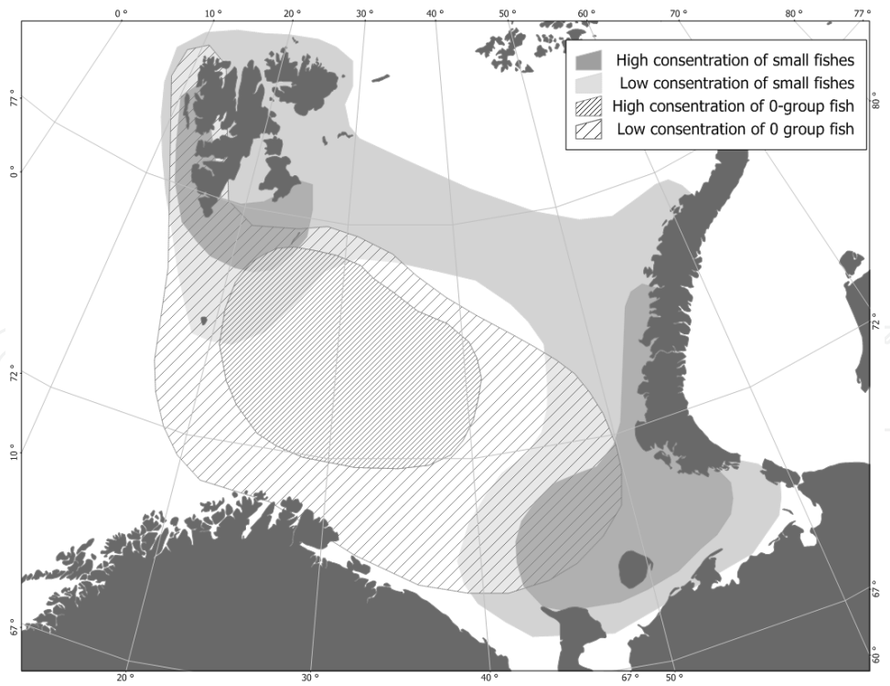


Fig. 5. Distribution of 0-group (cod, haddock, herring and capelin) and small fishes. The distribution of 0-group fish is modified from Eriksen and Prozorkevich 2011 and Eriksen *et al.* (2011).

whales, dolphins, porpoises, and many species of seabirds in different areas (Andriashev 1954; Viller 1983; Wright & Begg 1997; Wanless *et al.* 1998, Yezhov 2008, 2009). The south eastern part of the Barents Sea is known as the migration routes of seals and whales, and being close to large seabird colonies, *Ammodytidae* is likely an important food source there, especially in years with low abundance of juvenile herring.

In some years the rich fauna of small fishes may be a locally important addition to the large pelagic stocks and 0-group of commercially important fish, and make a significant contribution to the energy transport between the different trophic levels in the Barents Sea. This is likely to occur in years with low abundance of the large pelagic stocks, and in areas bordering the main distribution of the pelagic fish and 0-group fish, where their abundance varies greatly.

3.3 Variation in abundance and distribution in relation to temperature

Agonidae and *Liparidae*, mostly arctic fishes, showed a shift in their occupation area towards the North in warm years (Figure 2). *Cottidae*, including boreal, Arcto-boreal and Arctic fishes, showed, as *Agonidae* and *Liparidae*, a shift in the occupation area towards the North in warm years. *Stichaeidae* in the Barents Sea is dominated by mostly boreal species and was more widely distributed during warmer years. *Ammodytidae* and *Myctophidae* are mostly boreal fishes. Their occupation areas were mostly unchanged in cold vs. warm years. When comparing the small fish abundances indices with temperature from the FB oceanographic section (0-50m), no significant Spearman's rank correlations were found (Table 1).

Warmer temperature conditions associated with the increased inflow of Atlantic water are commonly considered an indicator of good feeding conditions in the Barents Sea (Sætersdal and Loeng 1987; Loeng and Gjøsæter 1990; Ottersen and Loeng 2000). Most of the studied fish feed on small crustaceans during their pelagic juvenile stages. The increased inflow may transport Atlantic plankton further north-eastwards, and this redistribution of food resources may have an impact on the survival of fish in specific areas, changing the overall distribution area.

Distribution of the boreal fishes *Ammodytidae* and *Myctophidae* were mostly unchanged as temperature varied. This is probably due to specific habitat requirements. *Ammodytidae* depends on bottom sediment (sand), where they bury themselves in the bottom to avoid predators; whereas *Myctophidae* is mostly restricted to areas deeper than 300 m. These restrictions might limit the potential for distributional changes in response to changes in temperature and prey availability.

We have used many assumptions in our analysis and interpretation, therefore our results are only crude approximations. The length distribution differences found between fish caught by pelagic and demersal trawls might reflect a difference in catchability related to size rather than age specific differences in vertical distribution. Most of small fishes are bottom fish with have pelagic life stages, and they are probably also distributed deeper than the surveyed layer. Hence, we acknowledge that the abundance and biomass indices are most probably underestimated. Despite these shortcomings, this unique long term data set provides new information on poorly known fish species, and their long term fluctuations in pelagic distribution, abundance and biomass.

4. Acknowledgments

We thank G.E. Dingsør for help with SAS programming, Eike Rachor and Anne Gro Vea Salvanes for valuable comments on the manuscript. We thank Sven Lemvig (IMR) for otolith preparation and age determination and Daniel Howell for proofreading. We also thank The Barents Sea Program at the Institute of Marine Research and the Norwegian Research Council project ("BarEcoRe", ref nr 200796) for funding.

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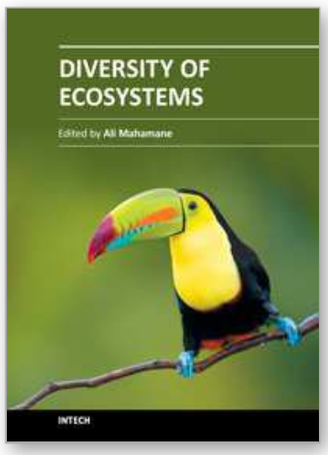
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ISBN 978-953-51-0572-5
Hard cover, 484 pages
Publisher InTech
Published online 27, April, 2012
Published in print edition April, 2012

The ecosystems present a great diversity worldwide and use various functionalities according to ecologic regions. In this new context of variability and climatic changes, these ecosystems undergo notable modifications amplified by domestic uses of which it was subjected to. Indeed the ecosystems render diverse services to humanity from their composition and structure but the tolerable levels are unknown. The preservation of these ecosystemic services needs a clear understanding of their complexity. The role of research is not only to characterise the ecosystems but also to clearly define the tolerable usage levels. Their characterisation proves to be important not only for the local populations that use it but also for the conservation of biodiversity. Hence, the measurement, management and protection of ecosystems need innovative and diverse methods. For all these reasons, the aim of this book is to bring out a general view on the function of ecosystems, modelling, sampling strategies, invading species, the response of organisms to modifications, the carbon dynamics, the mathematical models and theories that can be applied in diverse conditions.

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