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Satellite monitoring of SST for forecasting of the North-east arctic cod year class strength

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Abstract

Continuous long-term database on the sea surface temperature (SST) comprising results of regional differentiated satellite monitoring is used to resolve several applied problems. Authors have analyzed indirect influence of SST (the NOAA satellites data) on strength of the North-east Arctic cod year class strength (abundance at age 3+). Four areas have been selected in the area of the cod distribution to analyze SST in particular months: spawning grounds off the Lofoten islands to analyze SST (March –April) and three zones of the larval drift and the pelagic young fish distribution: the West-Spitsbergen waters and the Bear- Spitsbergen (Nordcap) area (May-October), and Murman-Novaya Zemlya area to analyze SST in June-October. Mean monthly SST and anomalous values are computed for the selected areas on the basis of the weekly SST maps for the period of 1998-2008. These maps were plotted with the satellite SST data, as well as information of vessel, buoy, and coastal stations. All data on each the area were classified by seasons and years.

The results indicate that poor generations of cod (2001, 2006, 2007) occurred in years with negative or extremely high positive anomalies of SST in the spawning grounds in March –April. The SST anomalies which were close to normal provide conditions for appearance of generations with average abundance (1999, 2003, 2004, 2005) or even high abundance (1998, 2000, 2002). Similar influence of SST on the cod year-class strength is also seen in areas of the pelagic young fish feeding till the fish migrate to the bottom layer (November-December). Examination of the SST influence on the cod year-class strength during the early life history (March-October), i.e. spawining till migration to the bottom layer allows us to identify a relatively narrow range of the SST anomalies which are optimal for appearance of strong generations of cod (+0.1 - +0.7^{o} C) and a broader range of the SST anomalies (-0.1 - +1.4^{O}C) which are favorable for appearance of generations with average abundance. Poor generations are very likely to occur outside these ranges, i.e. when the SST anomalies exceed +1.4^{O}C or are below -0.1^{O}C. Similar pattern was found in computations based on data for two successive years (the year of spawning and the following year when hydrological conditions indirectly influence the quality of the spawning stock and, consequently, the success of the coming spawning. Results of analysis of the SST data for the first year of the cod life history allow us to assess the recruit abundance, i.e. these data could be used to forecast recruitment two years in advance.

Key-words: *satellite monitoring of SST, North-east Arctic cod, spawning grounds and areas of the early life history, forecast of the cod year class strength at age 3+*

Introduction

Numerous publications on biology of the Northeast Arctic cod *(Gadus morhua)* suggest that formation of the cod new generations is especially dependent on environmental conditions of the cod early life cycle. From the spawning beginning in late February till the underyearling sinking to the bottom waters in October, the cod eggs, larvae, and pelagic fry which drift from the Lofoten waters to the Spitsbergen area or the Murman waters making more than 1,000 km depend on the weather conditions completely. Survival of each new year-class is determined by a set of factors, including the egg incubation time (Trofimov et. al., 2004), availability of food stocks along the drift route of the cod larvae (Nesterova, 1990; Skreslet et. al., 2004), the larvae distribution influenced by the current intensity (Vikebo et. al., 2005), and certainly, temperature which affects the cod development during the early life cycle (Ishevskii, 1961; Krovnin et. al., 2003; Bondarenko et. al., 2003; Borisov et. al., 2006) either directly, or indirectly, through other relevant factors (Godø, 2003; Boitsov et. al., 2003; Sundby, Nakken, 2008).

Introduction of the NOAA advanced meteorological satellites has considerably increased our ability to use the SST data in forecasting of fisheries, particularly the year class strength.

We do not imply that the continuously increasing long-term data base of the regional satellite monitoring of the SST could provide an alternative for traditional hydrologic surveys. On the other hand, it would be unreasonable to ignore advantages which the SST satellite monitoring give us in collecting the hydrological data.

In the past decades, VNIRO has been developing techniques of the complex analysis of the satellite data and the ship observations of the temperature conditions in various fishing grounds of the World ocean with the aim to plot the SST maps with various time discreteness (Vanyushin et. al., 2005). The SST satellite monitoring in the fishing grounds of the North Atlantic and the Barents Sea provides the ongoing operative information about the synoptic, monthly, seasonal, and interannual variability in the SST; such information can be used in forecasting fisheries.

Our main task is to analyze the SST satellite data on those areas of the Northeast Arctic cod distribution which could be used as reference zones in assessment of the generation success. Seasonal temperature conditions in such reference zones, including spawning grounds, drifting routes of the cod larvae and pelagic fry, determine the cod survival in the early life cycle, i.e. the recruitment number and, hence the cod stock biomass and catches.

Materials and methods

The SST values averaged over the spring and summer-autumn seasons and the temperature anomalies were calculated separately for each zone identified as a reference one: the spawning grounds in waters off the Lofoten islands where the SST data were collected in March and April (1); three zones of high density of the drifting larvae and pelagic fry off the West Spitsbergen (2), the Bear Island-Spitsbergen zone or the Nord Cape zone (3) with the SST data analysis for the May-October period, and the Murman-Novaya Zemlya waters (4) with the SST data analysis for June-October (Fig. 1).

Calculations of the SST mean and anomalous values in the reference zones were based on weekly maps of SST in the Northeast Atlantic (NEA) during the 11-year period (1998-2008), which were the results of the combined analysis of data from satellites, ships, buoyed and onshore stations. (Figures 2 and 3 present samples of the NEA SST weekly maps in various seasons). Further, we digitized each map and used them to plot the mean monthly SST maps in the analogous form (Fig. 4) and the matrix one (Fig. 5). These data allowed us to calculate the mean SST values for each the identified zone and the relevant period. Later the results were compared with materials obtained from other sources.

Figure 5 illustrates the SST numerical matrix map of the main spawning ground (1) of the NEA cod in March and April, 2007. Figure 6 is the mean monthly SST analogous map, August, 2007, which completely covers the drifting route of the cod larvae and pelagic fry (2, 3, 4).

The seasonal SST numerical matrices for zones 2 and 3 (June-October) are presented in Figure 7. Figure 8 depicts zone 4 during the same period. The SST anomalous values ranged by seasons and years were determined on the basis of the annual mean seasonal temperature values for each reference zone.

The cod year class strength data at age 3+ and the fishing stock data were taken from reports of the Arctic Fisheries Working Group (AFWG ICES). (Anon, 2008). Ranging of the cod generations at age 3+ by the year class strength was made in accordance with the traditional classification (,000,000 ind.): "poor" (P) – up to 300, "middle" (M) – 301-500, "strong" (S) – 501-900, and "very strong" – exceeding 900 (Boitsov et. al., 2003).

Results and discussion

Comparison of the SST anomalies in the main spawning ground with abundance of the cod year classes at age 3+ (Fig. 9) shows that survival of the cod generations was inhibited by both negative, and positive SST anomalies (above +1.0˚C) in zone 1 during March and April. This conclusion was also supported by results of other studies (Boitsov et. al., 2003; Bondarenko et. al., 2003; Borisov et. al., 2006). When the SST anomalies were close to normal values or did not exceed +1.0˚C the generation success was considered to be middle, while in 1998, 2000, and 2002 the cod year-classes were strong. It is likely that in cold years the incubation time is longer which increases chances of the egg loss. Besides, cold years are generally characterized by a greater number of stormy days, particularly in seasons when cod passes the most vulnerable larval cycle of its life. Negative anomalies are also unfavorable for development of the zooplankton biomass in spring (Nesterova, 1990; Sundby, 2000) and, hence, for availability of food stocks for larvae and, as a result, for the larva survival.

In "extremely" warm years, there is a much higher chance of the spatial and temporal relative lag of the cod larvae from their principal food *Calanus* nauplii. In such years, the Calanus spawning and the consequent eastward drifting of its larvae advances the cod larvae transition to active feeding. The spatial and temporal asynchronism between the cod development during the early life cycle and the feeding zooplankton leads to elevated mortality of larvae and ultimately to decrease in the generation success.

All the above-said suggest that the SST anomalies in March and April, i.e. during the cod active spawning, could be an indicator of the new generation survival, and hence, a predictor for assessment of the cod recruitment. The SST anomaly in the spawning ground estimated for spring, 2008, was +0.68˚C and suggested possibility of formation of a middle, or even strong year-class of 2008 (Fig. 9) and, a correspondent high abundance of fish at age 3+ in 2011. This abundance will be comparable to that of generations which appeared in 2003-2005.

As to the cod recruitment forecasting, special attention should be paid to analysis of the interannual distribution of the SST anomalies (1998-2008) in zones 2, 3, and 4, where the cod fry migrate in May-October (Fig. 1). Analyzing dynamics of the SST anomalies in these zones (Fig. 10), one could notice that the SST anomaly trends in the West Spitsbergen zone (2) and the Bear Island-Spitsbergen waters (3) were synchronic on the annual scale, while in the Barents Sea (the Murman-Novaya Zemlya waters, i.e. zone 4), the SST anomalies were out of phase with those in zones 2 and 3 up to 2001. After 2001, the curves of all three zones on the anomaly diagram become quasisynchronic. These peculiarities are clarified by analysis of the mean annual temperature anomalies for the water column of 0-200 m at the Cola meridian section (Fig. 11) and their comparison with the SST anomaly trends in zone 4: their variations are almost identical. This phenomenon indicates that the temperature conditions in the Barents Sea are essentially dependent on intensity of the "warm" Murman current. In late 1900s, the temperature anomalies at the Cola meridian section were negative or close to zero and, consequently, in 1998 and 1999, the SST anomalies in zone 4 were also negative. In 2000, when the water temperature anomaly sign at the Cola meridian section became positive, the SST anomalies in zone 4 also became positive; it has become especially obvious since 2004. The anomaly trends in all three zones of early life cycle and the cod fry foraging became synchronic after 2000. (Fig.10).

Increase in the SST anomaly values in zones of early life cycle and fry foraging also affects the cod fish stock biomass (Fig. 12). It is likely to be associated with both recruitment of more abundant generations, and increase in annual growth of individuals in all age groups due to replenishment of food stocks in «warm» years.

Figure 13 illustrates complex impact of the SST anomalies in the spawning grounds (zone 1) and in zones of consecutive distribution of the pelagic fry (zones 2-4) on the generation survival assessed as the year class abundance at age 3+. This nomogram allows us to identify most probable ranges of the temperature anomalies which determine difference in the year class strength (i.e. strong, middle, or poor).

Conclusion

The presented materials and analysis of dynamics of the SST anomalies in the spawning grounds and along the route of the cod larvae and pelagic fry drifting illustrate possibilities of practical use of the SST maps plotted on data of the satellite monitoring in the fishery forecasting. The SST anomalies characterize increase or decrease in input of warm Atlantic waters which form numerous eddies along the flows of the main warm currents thus creating favorable conditions for development of the cod larvae and fry and provide them with food stocks. It was shown that "cold" or extremely "warm" years generally have a negative impact on possibilities of appearance of the strong cod generations. This conclusion was supported by observations collected during other studies.

Use of the SST satellite monitoring data in forecasting of the year-class strength for commercial fish species was fairly successful. The applied technique has a number of advantages compared to traditional ship observations and deserves further development.

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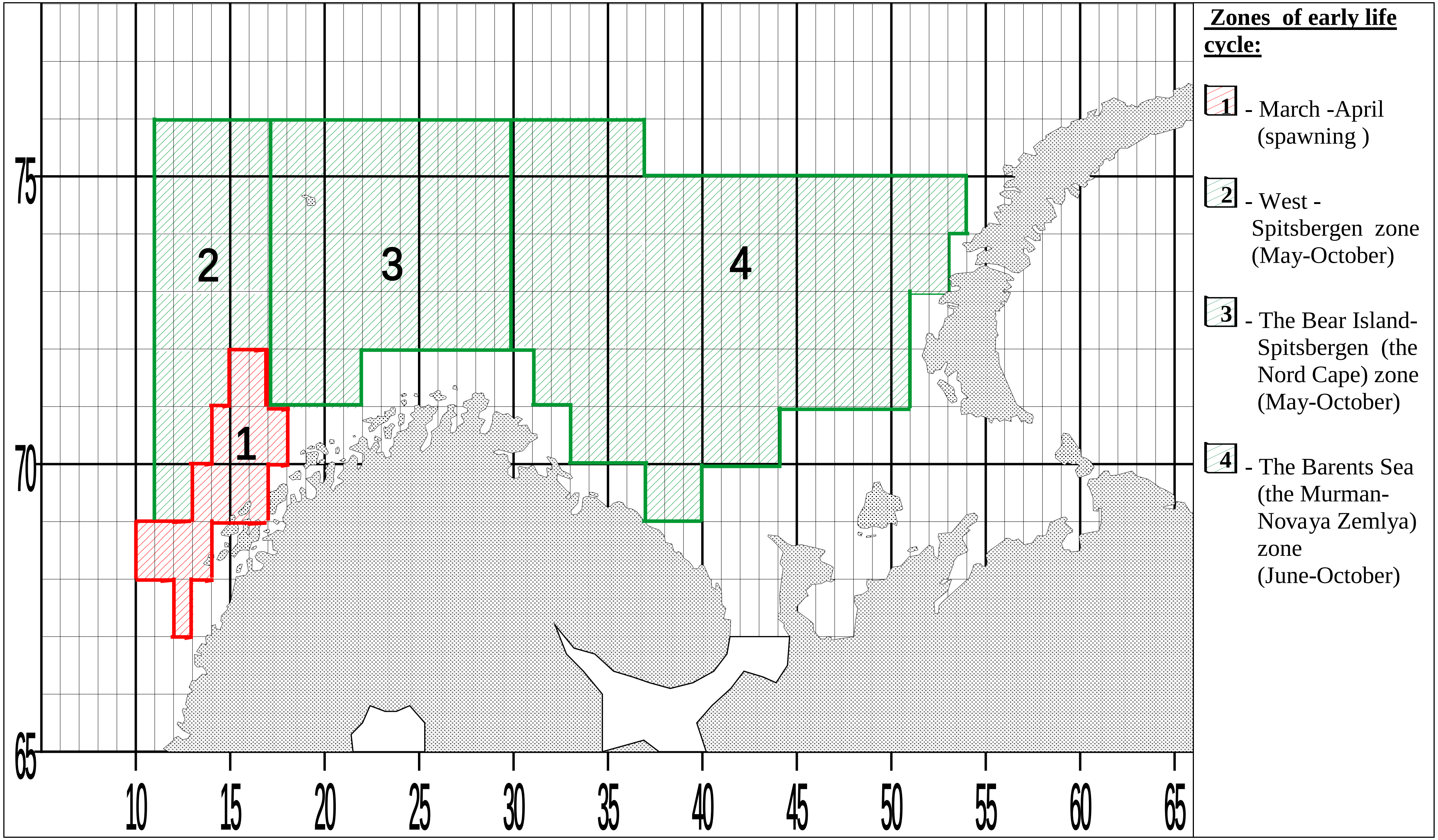


Fig. 1 The spawning grounds and zones of the consecutive drift of the NEA cod larvae and pelagic fry

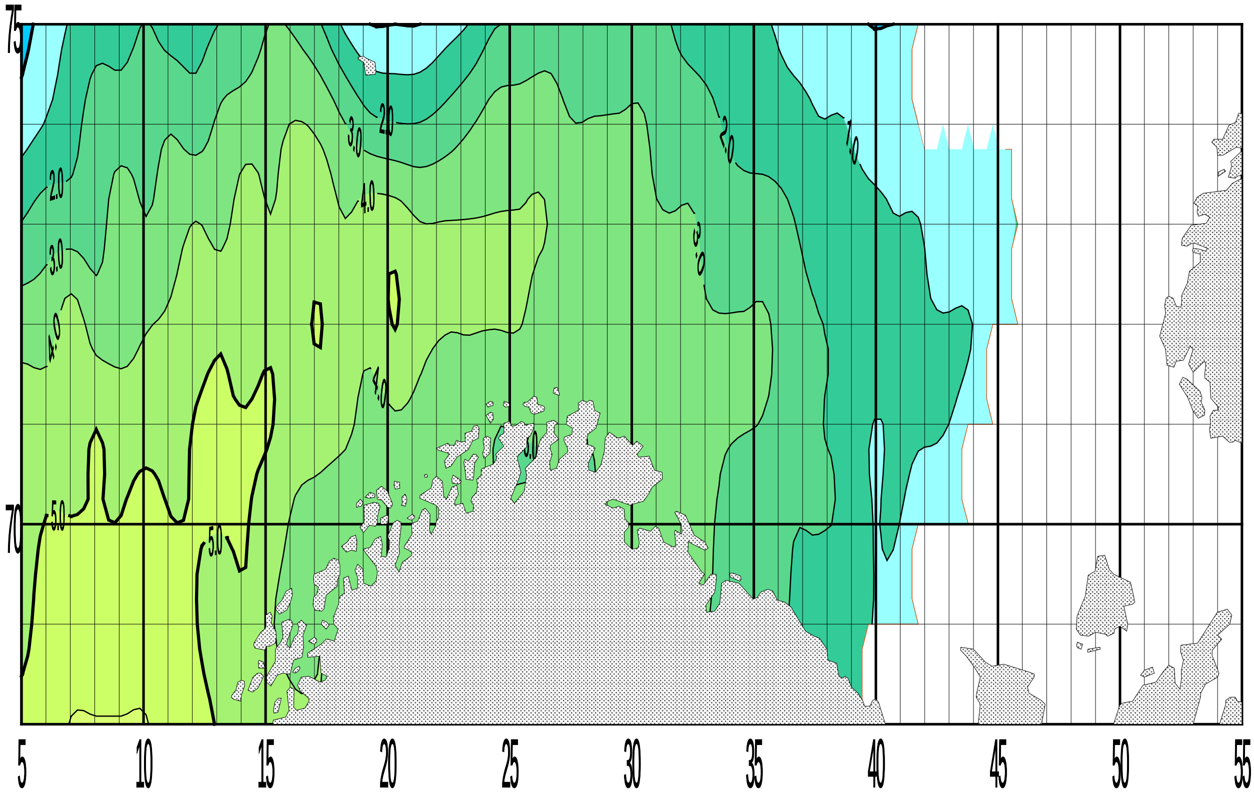


Fig. 2 Sample map of the NEA weekly SST, 15-21.04.2008.

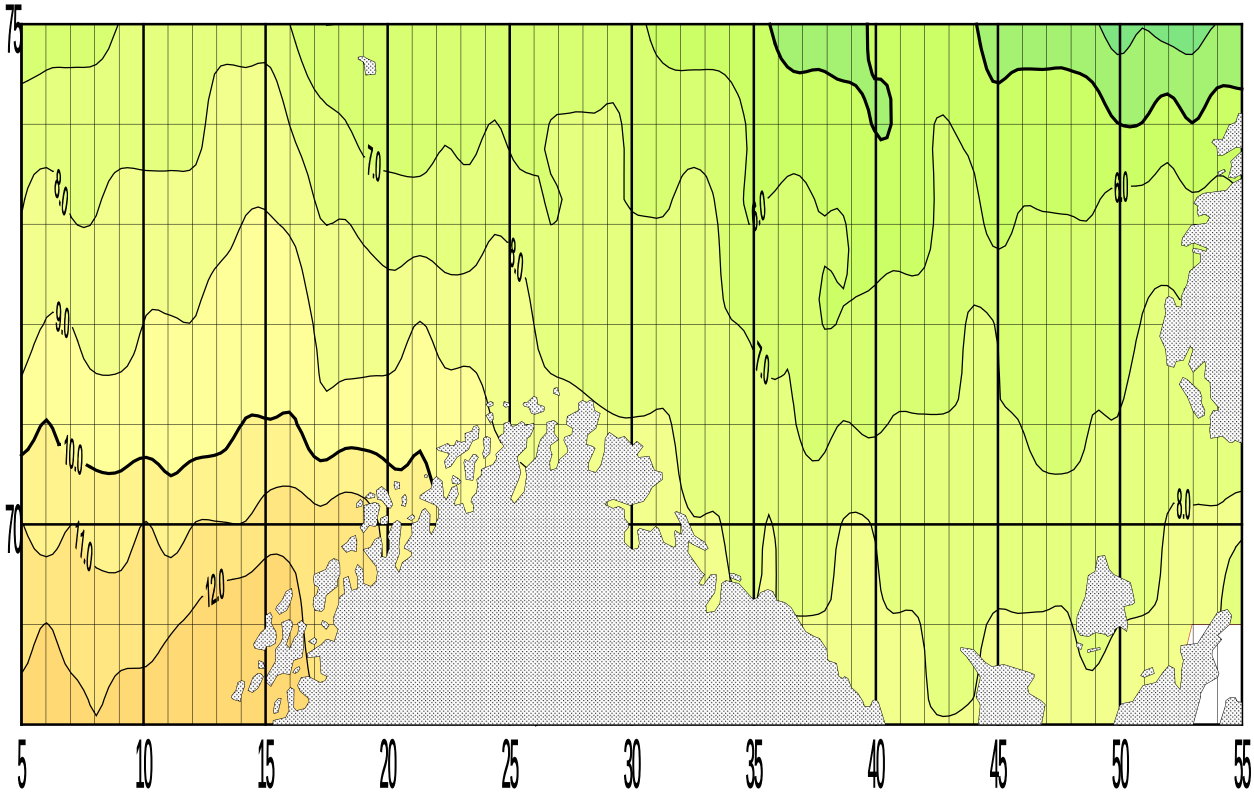


Fig. 3 Sample map of the NEA weekly SST, 12-18.08.2008.

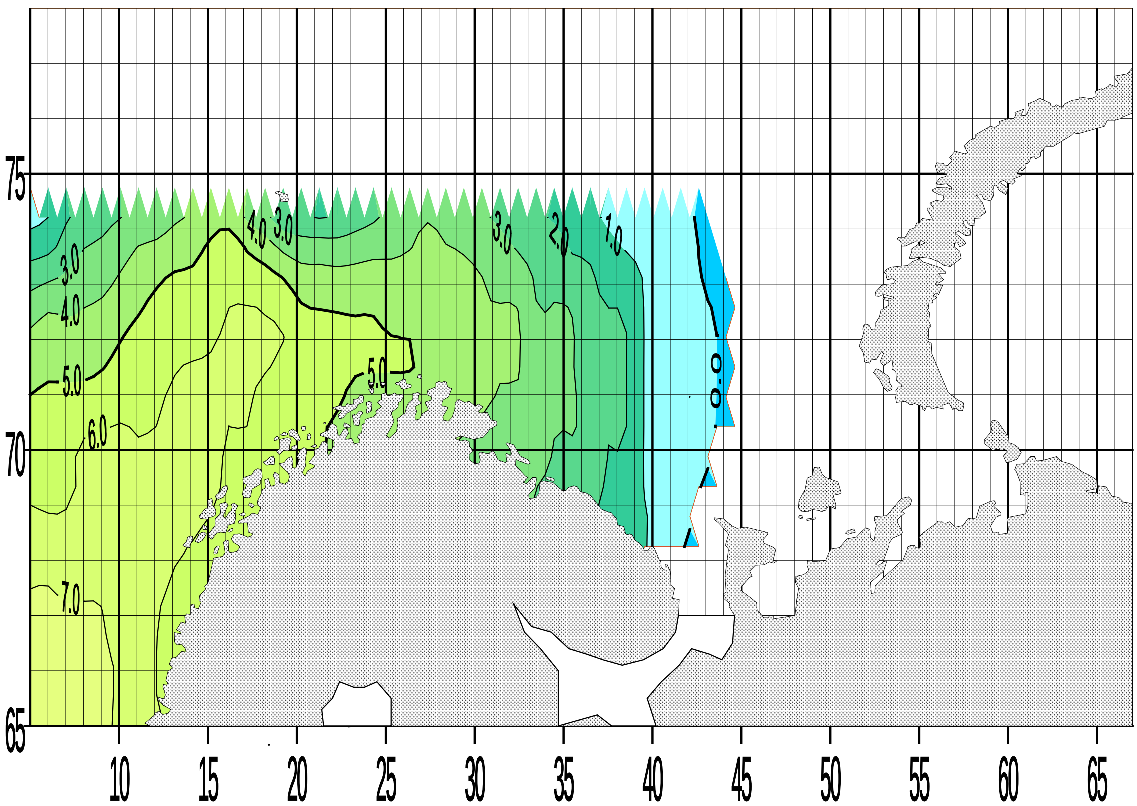


Fig. 4 Sample map of the NEA monthly SST, April 2007

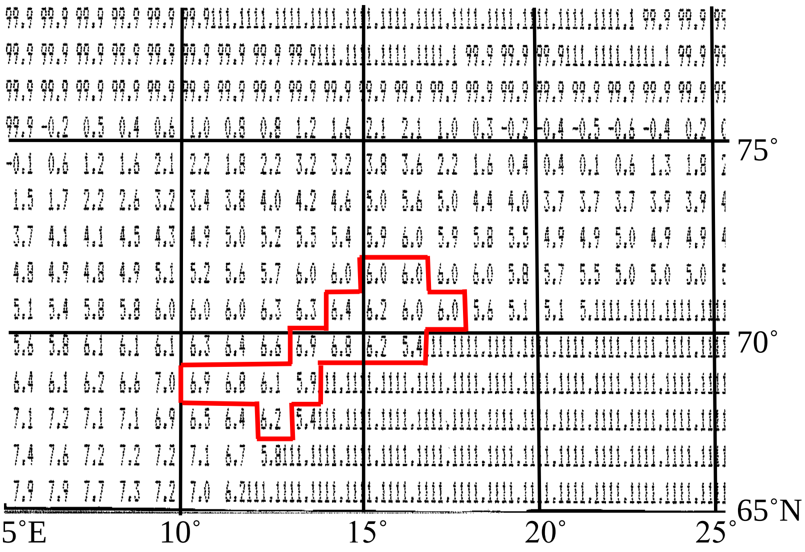


Fig. 5 Sample SST matrix for the cod main spawning ground.

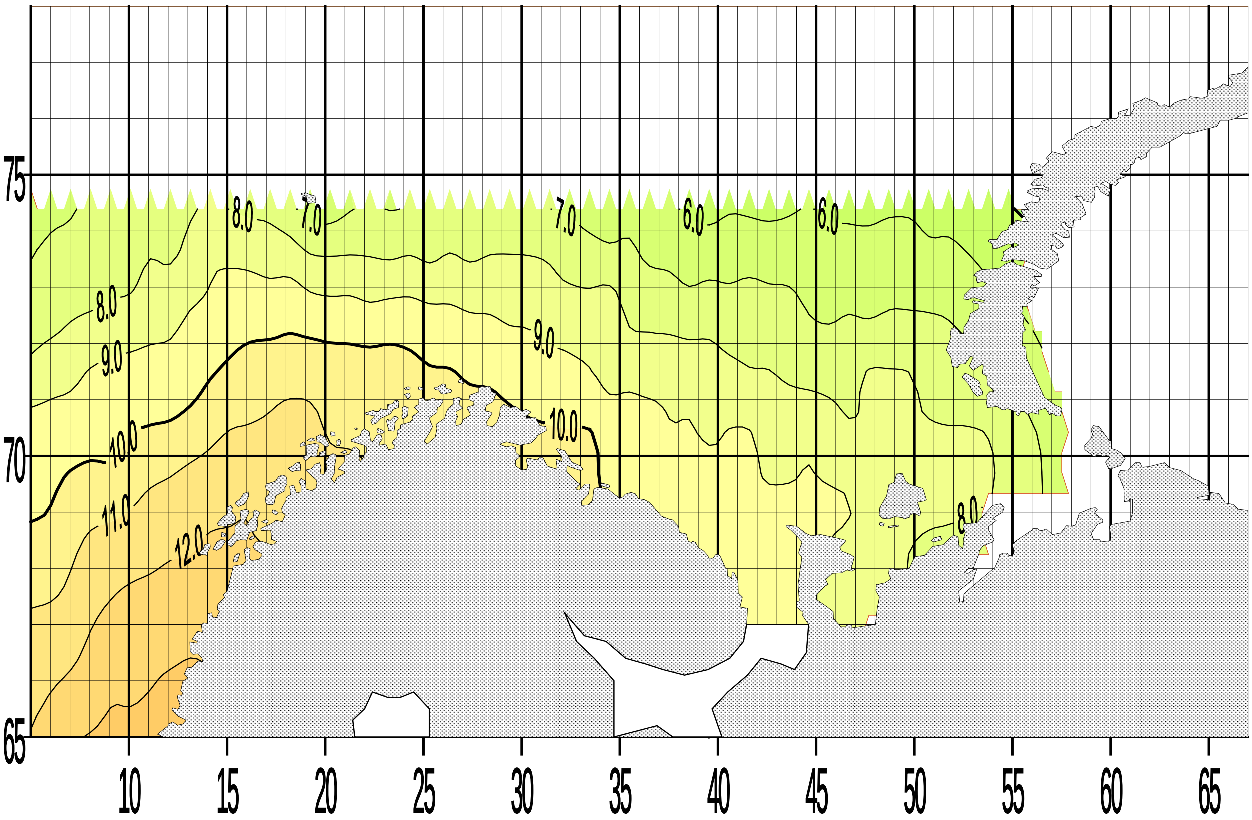
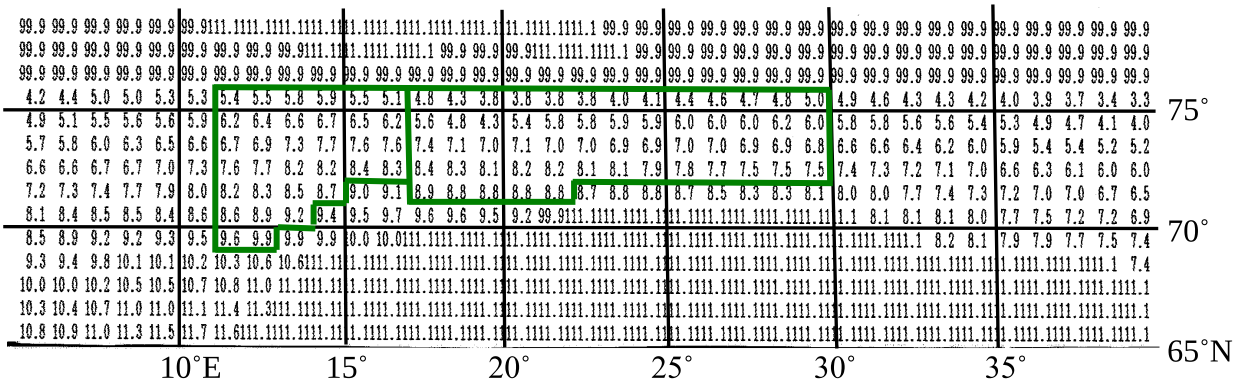
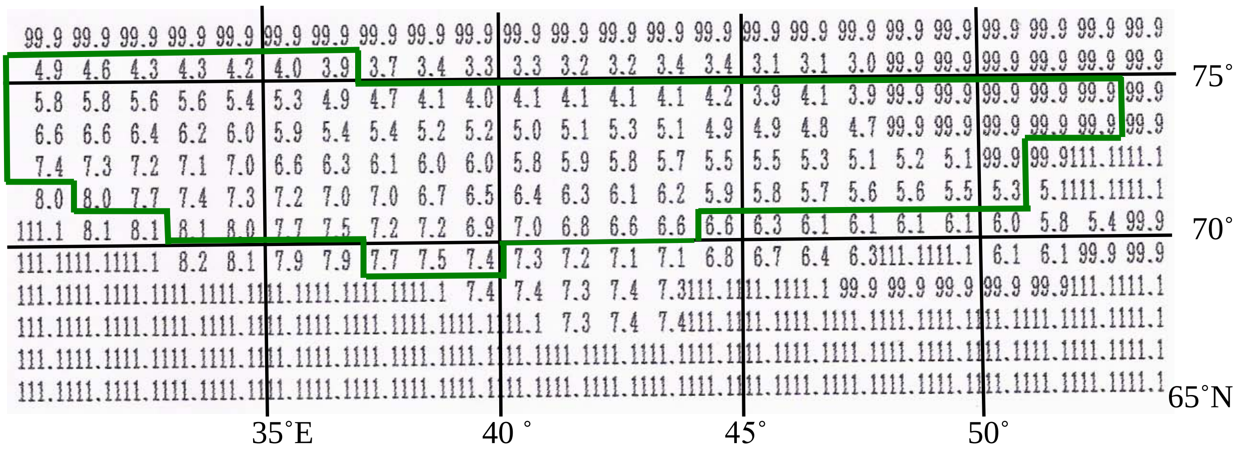


Fig. 6 Sample map of the NEA mean monthly SST, August 2007



99.9	99.9	99.9	99.9	99.9	99.9	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	111.1	111.1	111.1	111.1	99.9	99.9	99.9	111.1	111.1	111.1	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
4.2	4.4	5.0	5.0	5.3	5.3	5.4	5.5	5.8	5.9	5.5	5.1	4.8	4.3	3.8	3.8	3.8	3.8	4.0	4.1	4.4	4.6	4.7	4.8	5.0	4.9	4.6	4.3	4.3	4.2	4.0	3.9	3.7	3.4	3.3
4.9	5.1	5.5	5.6	5.6	5.9	6.2	6.4	6.6	6.7	6.5	6.2	5.6	4.8	4.3	5.4	5.8	5.8	5.9	5.9	6.0	6.0	6.0	6.2	6.0	5.8	5.8	5.6	5.6	5.4	5.3	4.9	4.7	4.1	4.0
5.7	5.8	6.0	6.3	6.5	6.6	6.7	6.9	7.3	7.7	7.6	7.6	7.4	7.1	7.0	7.1	7.0	7.0	6.9	6.9	7.0	7.0	6.9	6.9	6.8	6.6	6.6	6.4	6.2	6.0	5.9	5.4	5.4	5.2	5.2
6.6	6.6	6.7	6.7	7.0	7.3	7.6	7.7	8.2	8.2	8.4	8.3	8.4	8.3	8.1	8.2	8.2	8.1	8.1	7.9	7.8	7.7	7.5	7.5	7.5	7.4	7.3	7.2	7.1	7.0	6.6	6.3	6.1	6.0	6.0
7.2	7.3	7.4	7.7	7.9	8.0	8.2	8.3	8.5	8.7	9.0	9.1	8.9	8.8	8.8	8.8	8.8	8.7	8.8	8.8	8.7	8.5	8.3	8.3	8.1	8.0	8.0	7.7	7.4	7.3	7.2	7.0	7.0	6.7	6.5
8.1	8.4	8.5	8.5	8.4	8.6	8.6	8.9	9.2	9.4	9.5	9.7	9.6	9.6	9.5	9.2	99.9	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	8.1	8.1	8.1	8.0	7.7	7.5	7.2	7.2	6.9
8.5	8.9	9.2	9.2	9.3	9.5	9.6	9.9	9.9	9.9	10.0	10.0	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	8.2	8.1	7.9	7.9	7.7	7.5	7.4
9.3	9.4	9.8	10.1	10.1	10.2	10.3	10.6	10.6	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	7.4
10.0	10.0	10.2	10.5	10.5	10.7	10.8	11.0	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1
10.3	10.4	10.7	11.0	11.0	11.1	11.4	11.3	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1
10.8	10.9	11.0	11.3	11.5	11.7	11.6	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1

Fig. 7 Sample SST matrix for zones 2 and 3.



99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
4.9	4.6	4.3	4.3	4.2	4.0	3.9	3.7	3.4	3.3	3.3	3.2	3.2	3.4	3.4	3.1	3.1	3.0	99.9	99.9	99.9	99.9	99.9	99.9
5.8	5.8	5.6	5.6	5.4	5.3	4.9	4.7	4.1	4.0	4.1	4.1	4.1	4.1	4.2	3.9	4.1	3.9	99.9	99.9	99.9	99.9	99.9	99.9
6.6	6.6	6.4	6.2	6.0	5.9	5.4	5.4	5.2	5.2	5.0	5.1	5.3	5.1	4.9	4.9	4.8	4.7	99.9	99.9	99.9	99.9	99.9	99.9
7.4	7.3	7.2	7.1	7.0	6.6	6.3	6.1	6.0	6.0	5.8	5.9	5.8	5.7	5.5	5.5	5.3	5.1	5.2	5.1	99.9	99.9	111.1	111.1
8.0	8.0	7.7	7.4	7.3	7.2	7.0	7.0	6.7	6.5	6.4	6.3	6.1	6.2	5.9	5.8	5.7	5.6	5.6	5.5	5.3	5.1	111.1	111.1
111.1	8.1	8.1	8.1	8.0	7.7	7.5	7.2	7.2	6.9	7.0	6.8	6.6	6.6	6.6	6.3	6.1	6.1	6.1	6.1	6.0	5.8	5.4	99.9
111.1	111.1	111.1	8.2	8.1	7.9	7.9	7.7	7.5	7.4	7.3	7.2	7.1	7.1	6.8	6.7	6.4	6.3	111.1	111.1	6.1	6.1	99.9	99.9
111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	7.4	7.4	7.3	7.4	7.3	111.1	111.1	111.1	99.9	99.9	99.9	99.9	99.9	111.1	111.1
111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	7.3	7.4	7.4	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1
111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1
111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1	111.1

Fig. 8 Sample SST matrix for zone 4.

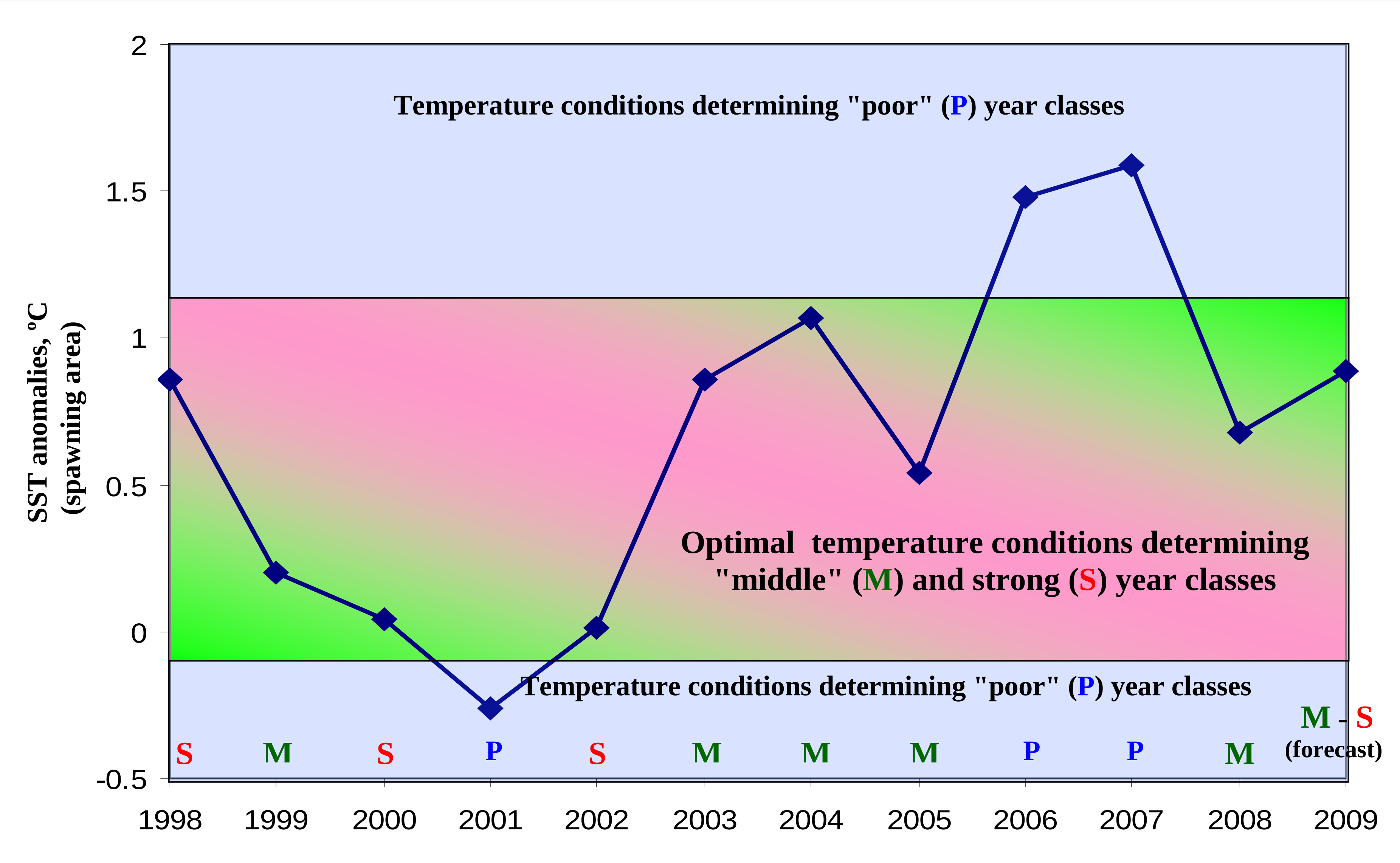


Fig. 9 Comparison of the cod year class strength (at the age of 3+) with the SST anomalies in the main spawning ground (March -April)

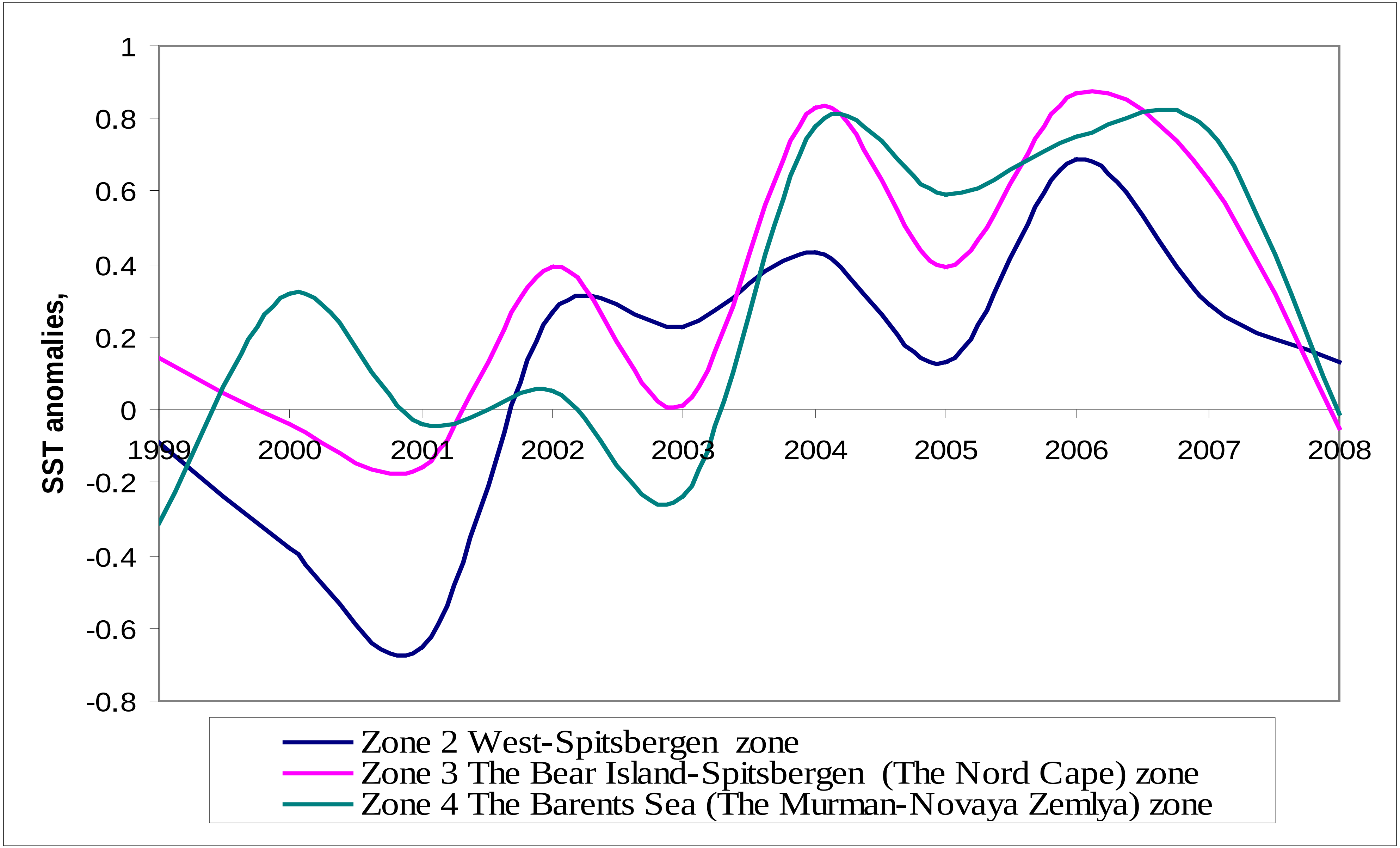


Fig. 10 Trends in the SST anomalies in zones 2, 3, and 4 during the summer-autumn period.

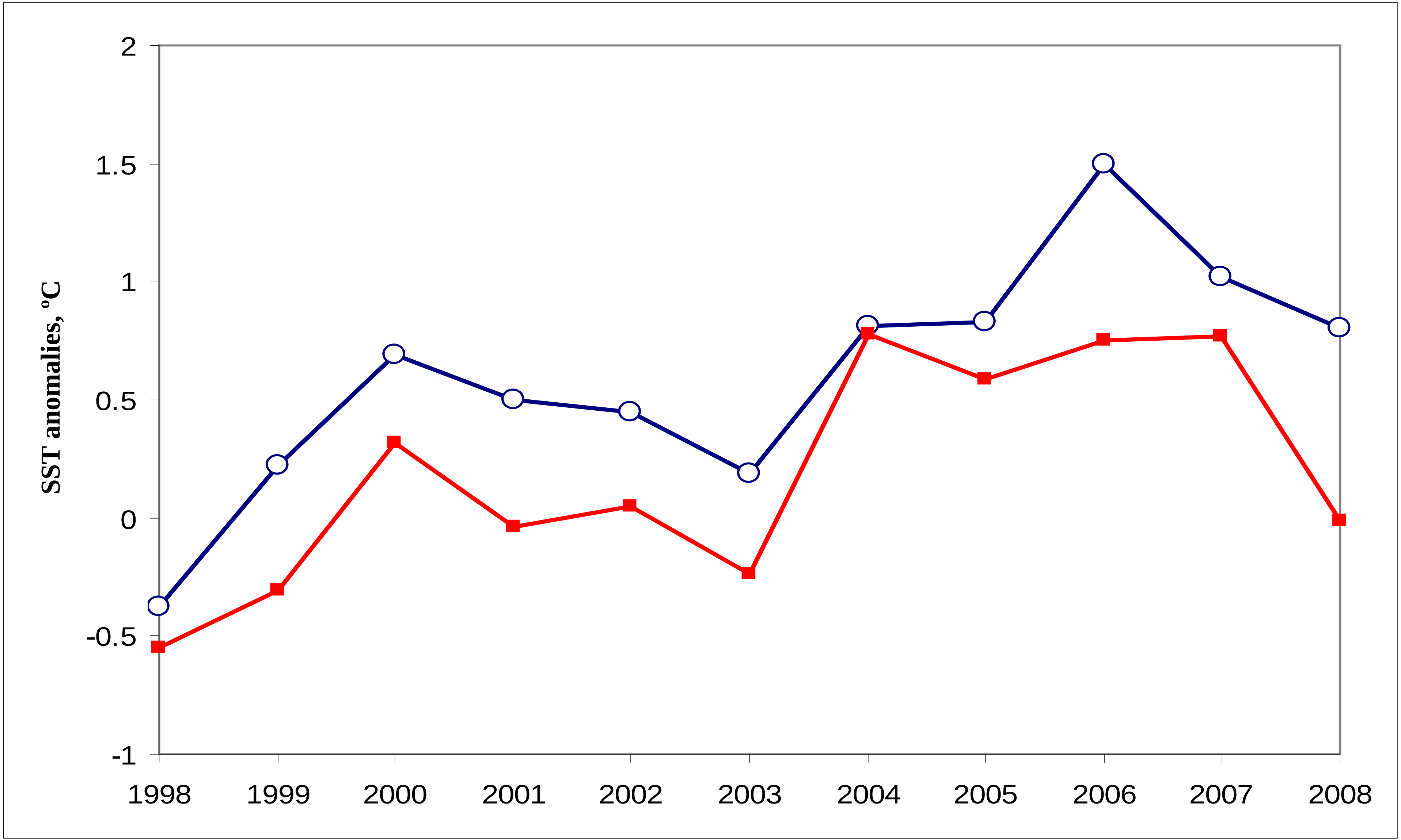


Fig. 11 The temperature anomalies at the Cola meridian section (—○—) and in the Murman-Novaya Zemlya zone in the Barents Sea (—■—) (zone 4).

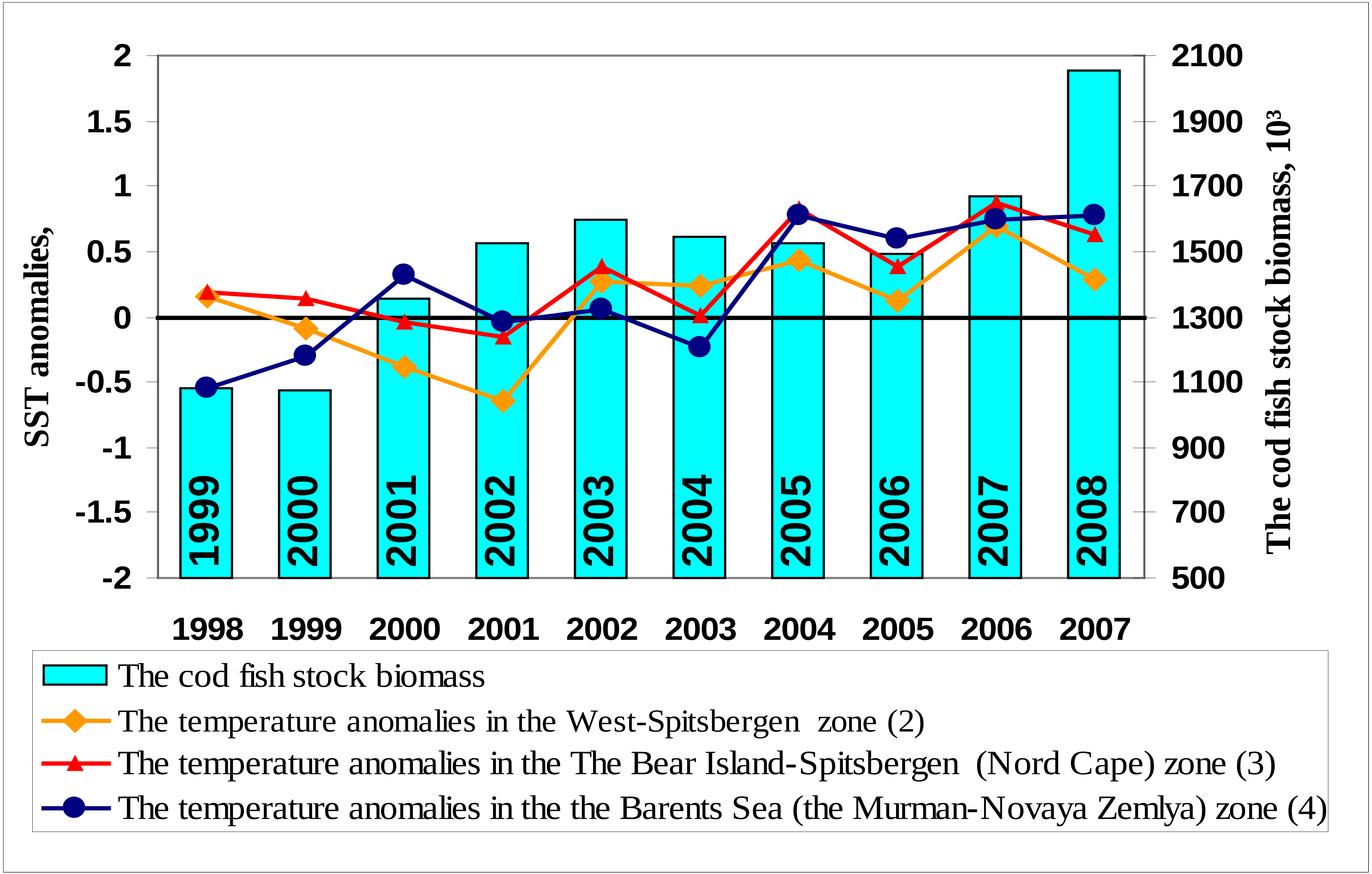


Fig. 12 Dependence of the cod fish stock on the SST anomalies in May-October of the preceding year in zones 2, 3, and 4.

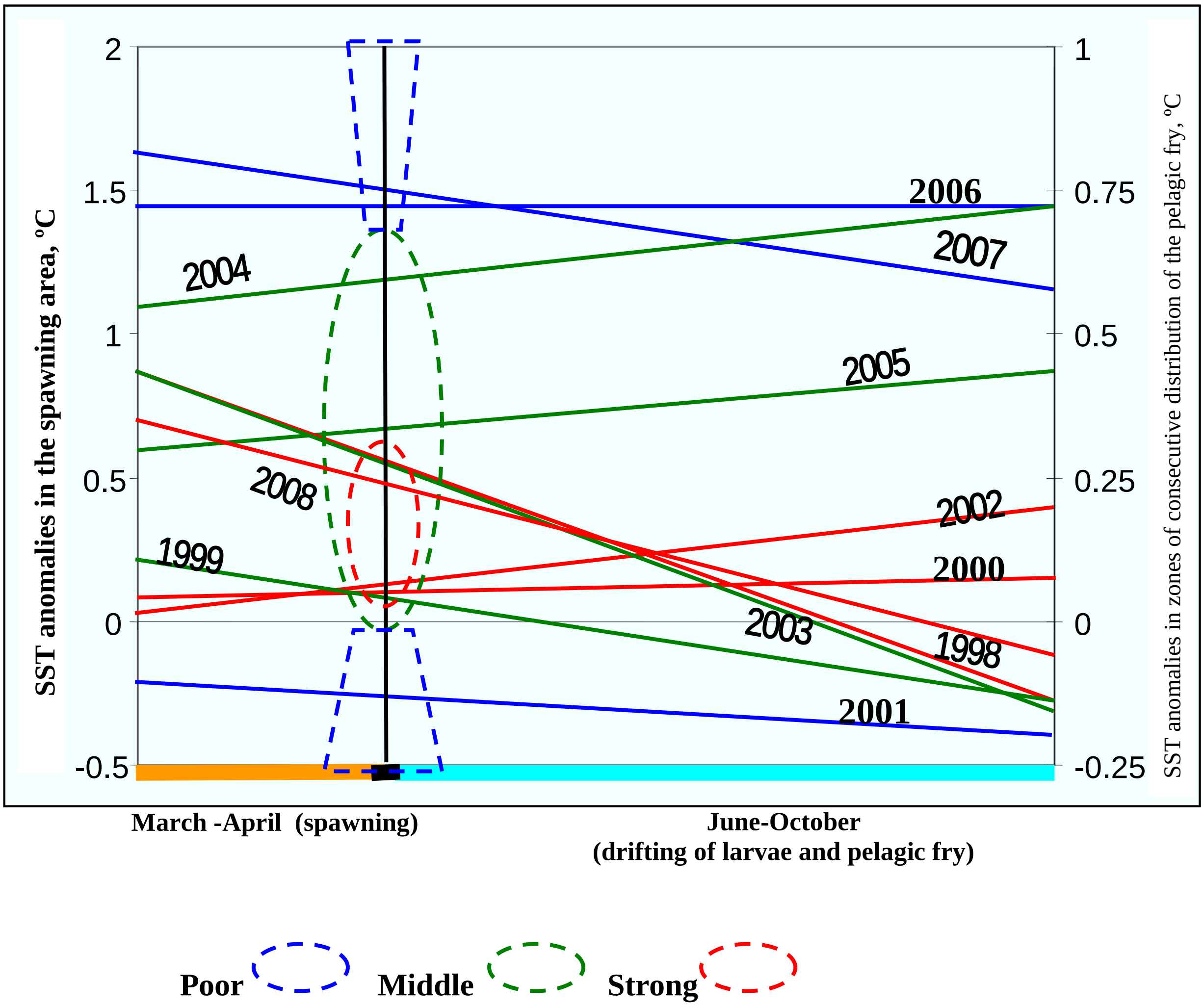


Fig. 13 Comparison of the SST anomalies in the spring and summer-autumn periods in the year of the cod year classes appearance with their abundance at age 3+