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Pelagic habitat mapping: A tool for area-based fisheries management in the Baltic Sea

Baltic Sea Region INTERREG III B

BALANCE

Title Pelagic habitat mapping: A tool for area-based fisheries management in the Baltic Sea		BALANCE Report No. 20			
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0 PREFACE

Observed horizontal and vertical distribution of pelagic habitats for different life stages of Baltic cod and sprat are mapped in the years 1995 and 2003-2005 (cod larvae from 2000). Environmental threshold levels in salinity, temperature and oxygen influencing distribution of cod and sprat life stages, in this case primarily cod spawning, are derived from a literature review on observed vertical distribution patterns and previous experimental studies carried out by DIFRES. Observed hydrographic data is derived from ICES database, supplemented modelled hydrodynamic data from IFM-GEOMAR. Biological data originates from Danish, Swedish and German International Baltic trawl surveys (BITS). Furthermore SFI, Poland has provided acoustic data for inspiration of this report.

Integrating the threshold levels with hydrographic conditions enabled 2D and 3D modelling of pelagic habitat for eggs and adults in space and time. The two species are mapped separately during different periods of the spawning season, as well as together to identify possible vertical and horizontal overlap and thereby possible areas for interactions both spatially and temporally.

Subsequently, the implications for area-based fisheries management in wider marine spatial planning are discussed with specific consideration of the essential fish habitat concept, real time closures and vertical zoning.

The study represents an important component of the BALANCE project being the first pelagic habitat study of its kind in the region and is a promising step towards development and integration of a new type of ecosystem information in transnational management and spatial planning. Some further development of the methods however, is needed for further practical implementation.

The work is part-financed by the European structural fund BSR INTERREG IIIB Neighbourhood Programme and partly by the involved partners. More information on the BALANCE project is available at www.balance-eu.org and the BSR INTERREG IIIB Neighbourhood Programme at www.bsrinterreg.net.

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1 INTRODUCTION

The pelagic ecosystem of the Central Baltic Sea has been studied for a long time and considerable amounts of data on biology and distribution of important fish species in relation to the hydrographical conditions exist.

The work done in relation to BALANCE has focused on the two ecologically and commercially most important pelagic fish species of the Central Baltic Sea, the eastern Baltic cod stock and sprat stock. These two species interact in many ways, i.e., they mutually prey on each other, compete for food in specific life stages, reproduce in the same locations, and their spawning periods largely overlap. However, their reproductive strategies differ considerably and this in combination with heavy differential fishing pressure and the complex species interactions lead to diametric patterns in population dynamics of both stocks. The sensibility of cod and sprat to temperature and salinity is different, which especially is seen during the reproduction period.

During the most recent decade the Bornholm Basin (ICES Subdivision 25), see Fig. 2, has been in focus as it is presently the only spawning ground where cod, the commercially most important fish species in the Baltic Sea, is able to reproduce successfully due to adverse environmental conditions in the more eastern basins (e.g. Gdansk Deep and Gotland Basin). Furthermore, the Bornholm Basin represents an important spawning ground for sprat gaining commercial importance due to a strong increase in stock size. Environmentally defined thresholds and preferences for occurrence determine the distributional overlap in habitat volume of the two species, which are strongly linked by trophic interactions, i.e. adult cod (*Gadus morhua callarias* L.) prey on sprat (*Sprattus sprattus balticus* S.) and sprat prey on cod eggs (Köster et al., 2001). In the Baltic Sea there is a vertical overlap between sprat and cod populations. Spratt is distributed in the intermediate water, in the halocline and in the bottom water, while Baltic cod and herring occur in the halocline and in the bottom water. Salinity stratification and oxygenation of the bottom water seem to determine the overlapping volumes of cod and clupeids in the Baltic Sea (Neuenfeldt and Beyer, 2003). Since the oxygen concentrations in the bottom layers limit the clupeid vertical distribution, during the daylight-feeding period, and the cod eggs are dependent on their density for their vertical distribution, this then result in clupeids occurring below cod eggs during inflow situations, and in high egg density water layers during stagnation years (Köster et al., 2005a).

During the last two decades, in the upper trophic level of the Central Baltic Sea ecosystem a shift from a cod-dominated to a sprat-dominated system was observed (Fig. 1) (Köster et al., 2003). The corresponding decrease in predation pressure on sprat, combined with low fishing mortality and high reproduction success of this species, resulted in a pronounced increase of the sprat stock (Parmanne et al., 1994).

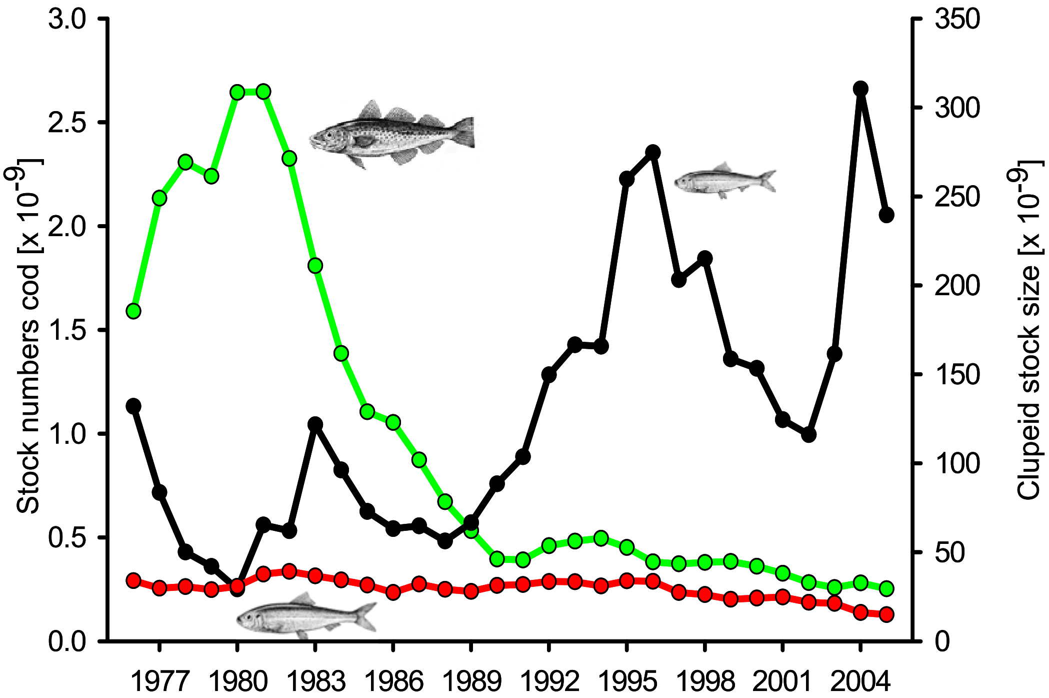

Fig. 1. *Stock sizes of Baltic cod (green), herring (red) and sprat (black). Central Baltic Sea, ICES SD 25-28, cumulative data from area-disaggregated MSVPA from 1976 - 2005 (Figure by G. Kraus based on ICES, 2006).*

Detailed knowledge on the spatial extent of essential habitats for different life stages of these fishes and their food organisms is available for the Bornholm Basin and can be used to evaluate the effects of habitat availability and quality on population sizes and structures. Spatial predictive modelling, using key habitat characteristics, such as hydrography, to identify spatio-temporal regions of particular interest could provide a useful tool in this respect. Using environmental predictors in GIS and Voxler, models may promote a better understanding of these pelagic ecosystems.

The most significant human activity occurring in the sea area east of Bornholm (including the Bornholm Basin) is commercial fishing for especially Baltic cod (*Gadus morhua*), as well as herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and salmon (*Salmo salar L.*). Due to high fishing pressure and unfavourable environmental conditions, the size of the cod population, however, is at an historical low level and has in recent years been considered outside "*biologically safe limits*" by the International Council for the Exploration of the Sea (ICES 2007), a threshold where the sustainability of the stock can no longer be ensured. A complete collapse of the Baltic cod stock would impact both the ecological balance of the Baltic Sea as well as the livelihoods of those dependent on cod fishing. In order to safeguard the spawning cod stock against overfishing, a series of closures for fisheries has been implemented in an area of the central Bornholm Basin, representing one of the most significant area-based management measures.

The case study area of the Bornholm Basin is addressing, at a conceptual level, the application of fishing closures within a broader marine spatial planning context, incl. location and timing of different area-based management measures in and around the Bornholm Basin to protect essential cod habitats, i.e. specific habitats that are essential for growth and development of the cod stock at different stages of its life cycle such as spawning grounds and nursery areas (U.S. Magnuson-Stevens Act). The work covers mapping and analysis of key hydrographical and biological features influencing the spatial and temporal distribution of the different cod life-stages, and the application of this knowledge in design of area-based management measures such as zoning of fishing closures and marine protected areas (MPAs) in a wider marine spatial planning context.

1.1 Aims

Within the Bornholm Basin, data from many years has been analysed, but in this report the main focus are on two distinct years - 1995 and 2003. The reason 1995 was chosen is because it is a couple of years after a major inflow, thereby recognised as a stagnation period - and 2003 because a major inflow occurred at the beginning of this year. These two contrasting years made it possible to compare the effect of the hydrography on two main species in the Bornholm Basin, cod and sprat. The mapping and analysis of a set of hydrographical and biological features governing the spatial and temporal distribution of different cod and sprat life-stages in e.g. adult habitat and egg habitat potential has been carried out, and the application of these findings in area-based management measures, such as zoning of MPAs, is explored. Maps visualising the 3-dimensional distribution of the studied species, as well as their ambient environmental conditions visualised by 2-dimensional hydrographical maps, will allow characterizing essential and preferred habitats for predictive modelling.

2 THE STUDY AREA

Our case study area, the Bornholm Basin, is situated in the Baltic Sea, which is among the largest brackish water areas of the world (Fig. 2). The Central Baltic consists of several deep basins, all of which show a pronounced vertical stratification of the water column. (Neuenfeld & Beyer, 2006).

The combination of freshwater input from the northern most bays of the Baltic Sea (e.g. Bothnian Bay) and the oscillating inflow of highly saline and oxygen rich water along the seabed from the North Sea (trough Kattegat and the Belt Sea), results in saline water entering the Baltic Sea, which generates the annual means of salinity and oxygen in the deep waters (Møller & Hansen, 1994). These inflows are called major inflows and seldom occur. The inflow events result in a low salinity surface layer of about 7 psu, which is typical 50-60 m in thickness in the Bornholm Basin. Below the surface layer, there is an almost 10 m thick layer, called the upper deep-water pycnocline, which overlies the deep saline waters (psu of 11-17). During the main spawning season of cod (March to September; Wieland et al., 2000) and sprat (March to August; Parmanne et al., 1994), the Bornholm Basin is characterised by at thermocline occurring at approximately 20 to 30 m depth and the permanent halocline at between 50 to 75 m (Kullenberg & Jacobsen, 1981; Møller & Hansen, 1994).The permanent halocline forms an effective barrier for water exchange and the hydrographical conditions of the deep layer depend mainly on the frequency and intensity of inflows from the North Sea (Tomkiewicz et al., 1998; Köster et al.,2005b).

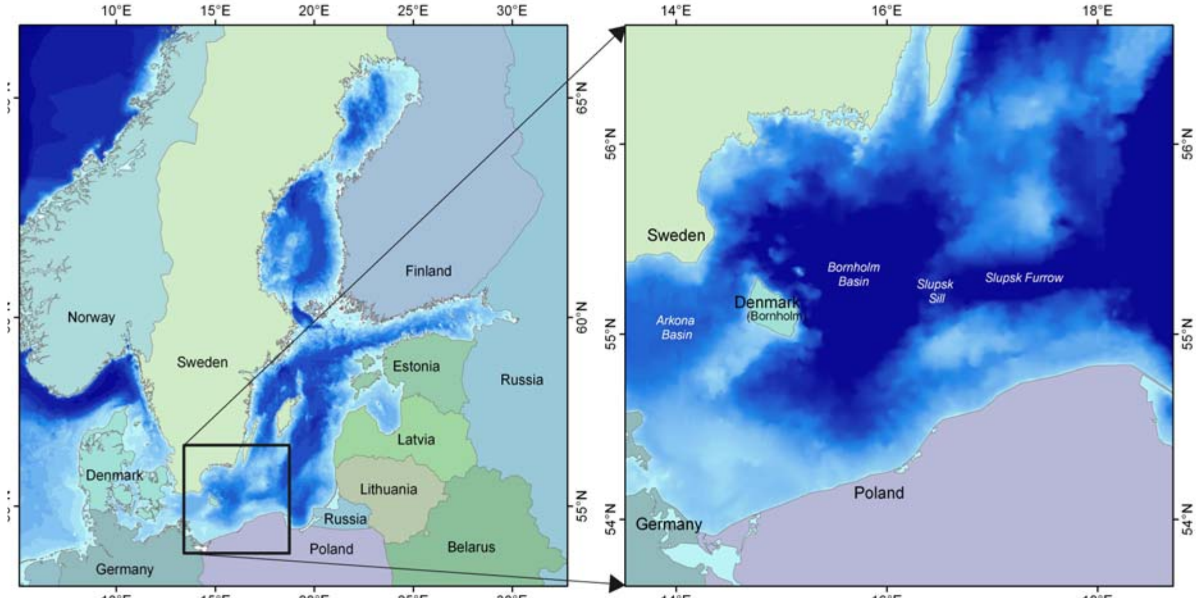

Fig. 2 *Overview map of Northern Europe and a location map of the Arkona Basin, Bornholm Basin and the Slupsk Furrow.*

A seasonal thermocline develops in the spring at 15-20 m depth, due to surface heating and is maintained as a result of solar inputs until the autumn. During the summer the temperature difference is up to 10ºC and causes a horizontal stratification. The implication of this is on the water density, which is sufficient to reduce the vertical mixing within the layer above the upper halocline (Møller & Hansen, 1994). Between the summer thermocline and the halocline exists a cold intermediate layer termed the "winter water". In the autumn the thermocline coalesces with the remnants of the previous winters cold intermediate water resulting in a relatively homogeneous surface mixed layer down to the halocline (for more detailed descriptions see Kullenberg & Jacobsen, 1981; Stigebrandt & Wulff, 1987).

The unique oceanographic conditions of the Baltic Sea, the resultant residence times of the various layers coupled with the sedimentation of organic materials from terrestrial sources and the surface euphotic layer results in a build up in organic materials in the deep layer (e.g. Wulff et al., 1990), which are degraded by bacteria thereby utilising oxygen and resulting in an anoxic bottom layer. Oxygen conditions within and below the halocline are to a lesser degree also affected by winter sea surface temperature (Hinrichsen et al. 2002), wind mixing effects (e.g. Stigebrandt & Wulff, 1987; St. John et al., 1996), the resultant up- and downwelling, and the breaking of internal waves (Krauss, 1981) in regions where the halocline approaches the bottom (e.g. Shaffer, 1979). Neuenfeldt and Beyer (2003) found that the oxygen saturation in July within and below the halocline decreased rapidly, almost linearly from about 80 to 20% saturation between 50-70 m depth. Furthermore, in this period, an increase in temperature is observed from 4ºC at 50 m to 7ºC at 70 m in the same water layers. The principle mechanism influencing the replenishment of oxygen in the deep Basins of the Baltic Sea is the ephemeral inflow of saline oxygen rich waters from the North Sea, which is driven by high air pressure associated with easterly winds over the Baltic Region. This results in below-normal sea level due to reduced precipitation, river runoff and advection of surface water masses to the west followed by longer time periods (several weeks) of zonal winds (from the west) over the North Atlantic and Europe with only small fluctuations in direction (e.g. Matthäus & Franck, 1992; Schinke & Matthäus, 1998). During the past three decades, the frequency of major inflows has decreased drastically. Since 1976 these inflows have only occurred in 1993 and 2003 (ICES 2004). Years without inflows are referred to as stagnation periods.

Historically, Baltic cod has aggregated in all three deep ocean basins during spawning, i.e. Gdansk Deep, Gotland Deep and the Bornholm Deep. For successful spawning, the Baltic cod is dependent on sufficient oxygen and salinity levels, and to a lesser degree temperature, in the water column at specific time of the year. However, due to eutrophication and other environmental drivers, the oxygen conditions have in recent years become increasingly unfavourable for cod spawning in the Gdansk and Gotland basins, and the Bornholm Deep has therefore become the only active spawning ground for the Baltic cod in the Baltic Sea (Bagge et al. 1994).

3 MATERIAL AND METHODS

This chapter contains a description of the two main species in this report, cod and sprat, and their life stages and habitat preferences, which is important to understand the background of the mapping. Furthermore the collection of the hydrographic data and the hydrodynamic model used for mapping is described as well as the biological sampling methods followed by habitat models with a table showing the threshold used for mapping. At last a section about considerations of data and the model.

3.1 Cod

In the Baltic Sea, two distinct cod stocks exist, the western stock or "Belt Sea cod (*Gadus morhua morhua L.*)" and the eastern stock or "true" Baltic cod (*Gadus morhua callarias L.*). Meristic (Poulsen 1931; Kändler 1944) and genetic studies (Jamieson and Otterlind 1971; Schmidt 2000) as well as tagging experiments (see review by Aro 1989) indicated that the two stocks are located west and east of a borderline at 14°30' longitude near Bornholm Island with some overlap in the Arkona Basin (Fig. 3). Historically, the Eastern Baltic cod stock is one of the largest in the North Atlantic region (Dickson and Brander 1993) with a long-term average of SSB of 400.000 to 500.000 tonnes, whereas the stock level of Belt Sea cod was approximately one order of magnitude lower. However, due to a combination of increasing fishing pressure and low reproduction caused by unfavourable environmental conditions, SSB and recruitment of Eastern Baltic cod showed distinct time trends with the SSB declining from over 700.000t in the early 1980´s to ~70.000t in 2005 (ICES 2006b). At present, the Bornholm Basin is the only cod spawning ground in the central Baltic Sea that allows for successful egg development. Cod spawn from March to September, where the peak in spawning has changed from spring to summer during early 1990's (Wieland et al., 2000b). During recent years, successful spawning of the eastern stock has largely been limited to the Bornholm Basin due to anoxic conditions in the other historic spawning sites (e.g. Bagge et al., 1994; MacKenzie et al. 2000). Consequently, reproductive success of Baltic cod is mainly dependent upon the environmental conditions existing in the Bornholm Basin.

3.1.1 Cod egg habitat

Marine fish species in the Baltic are at the physiological limits of their distribution with respect to salinity conditions. Salinity affects both fertilisation success and egg buoyancy. Experiments have shown that Baltic cod eggs are neutral buoyant at a salinity of 14.5 ± 1.2 which indicate that the eggs are distributed in a narrow layer within the halocline (Nissling and Vallin, 1996). For Baltic cod, a minimum salinity of >11 psu is required for activation of spermatozoa (Westin and Nissling, 1991) and salinity-dependent differences in fertilisation success imply that viable egg production may vary between spawning areas as well as between inflow – and stagnation periods. Neutral buoyancy for cod eggs is generally achieved at a salinity which typically occurs from the lower region of the halocline to the bottom water of the Bornholm Basin (Nissling et al., 1994; Wieland et al., 1994).

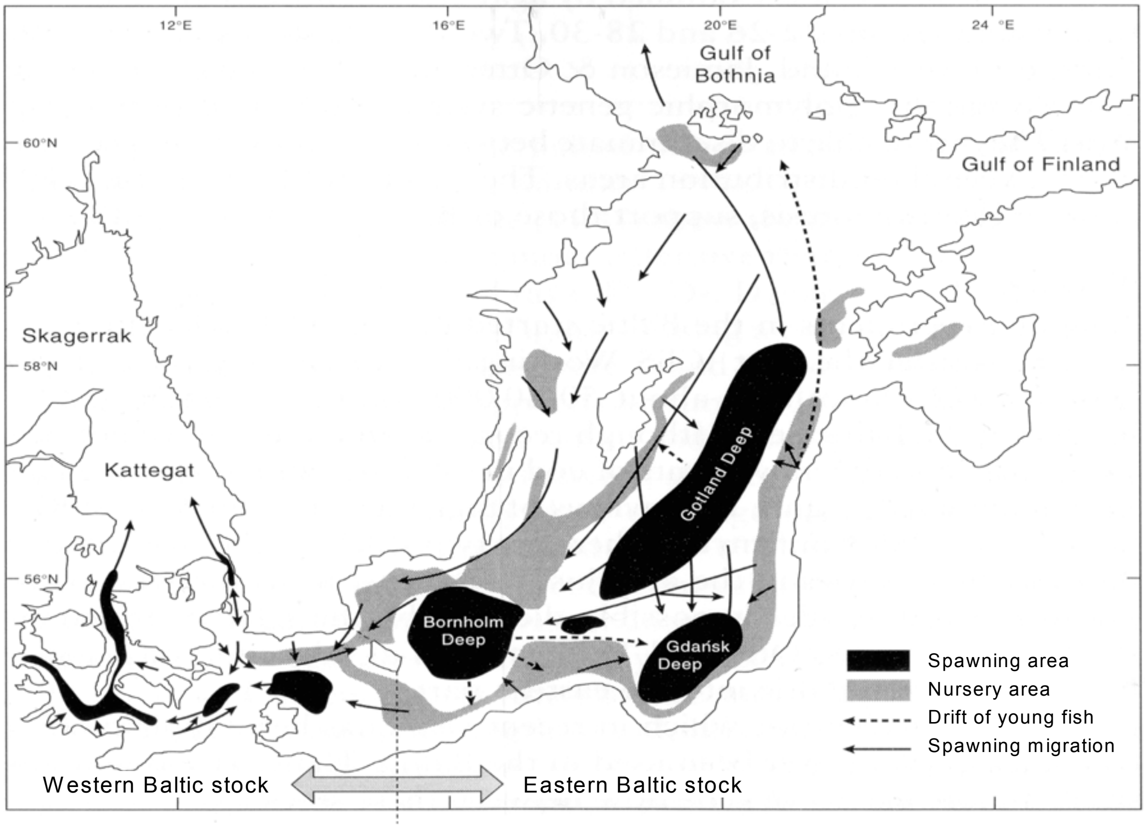

Fig. 3 *Distribution of spawning and nursery areas of cod in the Baltic Sea (redrawn after Bagge et al. 1994).*

Hence, peak abundance of cod eggs occurs in the region of the halocline with some quantities of viable eggs in the more saline deep layer depending on oxygen levels (Kändler, 1944; Müller & Pommeranz, 1984; Wieland & Jarre-Teichmann, 1997). For eggs to hatch successfully a minimum oxygen requirement of 2 ml/l is needed and temperature must exceed 1.5 °Celsius (MacKenzie et al. 2000).

Reproductive volume

The reproductive volume (RV) is an index for potential egg survival, i.e. the volume of water fulfilling minimum requirements for successful egg development. The volumes are estimated by horizontally integrating the spawning layer thickness at a single central hydrographic station across the spawning area. Statistical evidence shows that recruitment is positively connected to a total reproductive volume (Plikshs et al. 1993; MacKenzie et al. 2000). The reproductive volume of the Bornholm Basin is not only dependent on the frequency and magnitude of inflows, but it is also strongly dependent on the temperature of the inflowing water, influencing oxygen solubility and oxygen consumption rates by biological processes (Köster et al. 2005b).

For Baltic cod the lower limit of the reproductive volume in the water column is defined by a minimum oxygen requirement for egg survival and the upper limit is defined by salinity with an additional temperature threshold. The site with the largest and least variable reproductive volume for cod in the Baltic Sea is the Bornholm Basin. In May and August, when estimates for the central Gotland Basin are available, the Bornholm Basin represents 70 - 74% of the total reproductive volume in the Baltic Sea. Whereas for the other months, which exclude contribution from the Gotland Basin the Bornholm Basin contains 82 - 87 % of the reproductive volume (MacKenzie et al. 2000).

The dynamics of habitat volumes and overlaps are determined by vertical variations in oxygen saturation and by changes in the vertical position of the halocline. These vertical variations are caused by variation in the annual inflow of oxygen-rich and high-saline deep water from the North Sea. Compared to changes in the depth of the oxygen threshold, changes in the vertical position of the halocline have a greater effect on habitat volumes due to the conical geometry of the basin. This is because the halocline always occurs at a shallower depth than the oxygen threshold. It is, however, the magnitude of the relative changes that determines overlap dynamics (Neuenfeldt & Beyer, 2006).

Oxygen related cod egg survival function.
The oxygen-egg survival relationship ($r^2 = 0.94$) showed that oxygen concentrations above the threshold level of 2ml/l, used in the definition of RV, have a pronounced impact on egg survival (Köster et al. 2005a).

Relative viable hatch = $(1 - e^{-(0.71 \cdot \text{oxygen content (ml/l)})})^{11.63}$

Fig. 4 *Cod eggs with developing embryos 4 days after fertilisation (Photo from: S. Riis Sørensen, RESTOCK)*

3.1.2 *Cod larvae*

When approaching the end of the yolk-sac stage, the larvae perform a vertical migration into intermediate water layers, concentrating below the warm surface layer (thermocline). Here they are transported mainly by wind to their nursery areas along the coast of the Baltic region. After approximately three months, the pelagic juveniles settle and take up a demersal life. When growing larger, i.e. during their second and third year of life, the juveniles migrate to more offshore feeding grounds. Cod reach maturity at around age three, after which they migrate to spawning grounds to spawn.

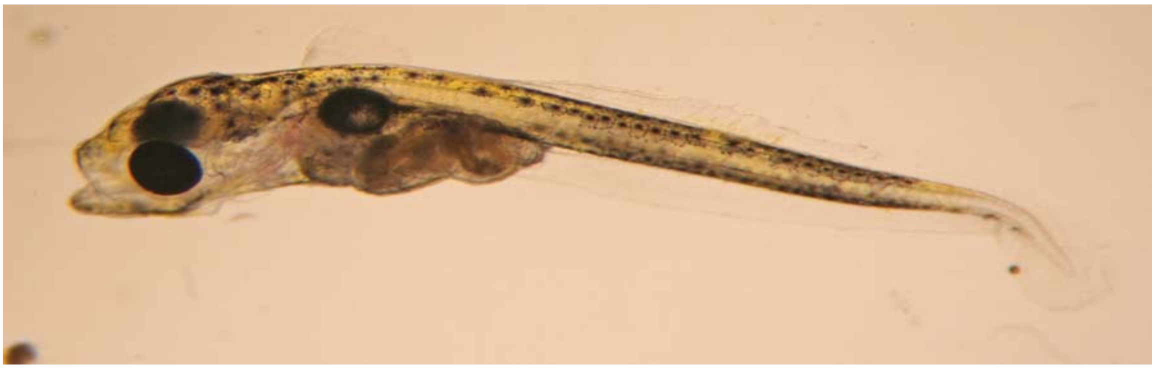

Fig. 5 *Cod larvae, 31 days old (Photo from: S. Riis Sørensen, RESTOCK).*

3.1.3 Habitat preferences of adult cod

Experiments have shown that Atlantic cod avoid oxygen saturations <28 % (Plante et al., 1998). Others have observed that cod in general avoided zones of low oxygen (< 50 % saturation at 5°C), but voluntarily entered regions with concentrations as low as 16 % for short feeding excursions (Claireaux et al., 1995). Atlantic cod did not survive 96 hours at 10% oxygen saturation under laboratory conditions, and only few survived at 16% saturation, whereas no mortality occurred at 34 % and 40 % oxygen saturation (Plante et al., 1998). Although it has been argued that cod can compensate for hypoxia by selecting lower temperatures Schurmann and Steffensen (1992), Plante et al. (1998) could not identify a significant effect of temperature conducting their experiment at 2°C and 6°C. For Atlantic cod under experimental conditions, decreasing oxygen saturation from 100 % to ~50 % was followed by decreased oxygen consumption over the whole range of swimming speeds and decreased resting heart rate. Lowering the oxygen levels decreased the oxygen transported per heart beat (Claireaux et al. 1995).

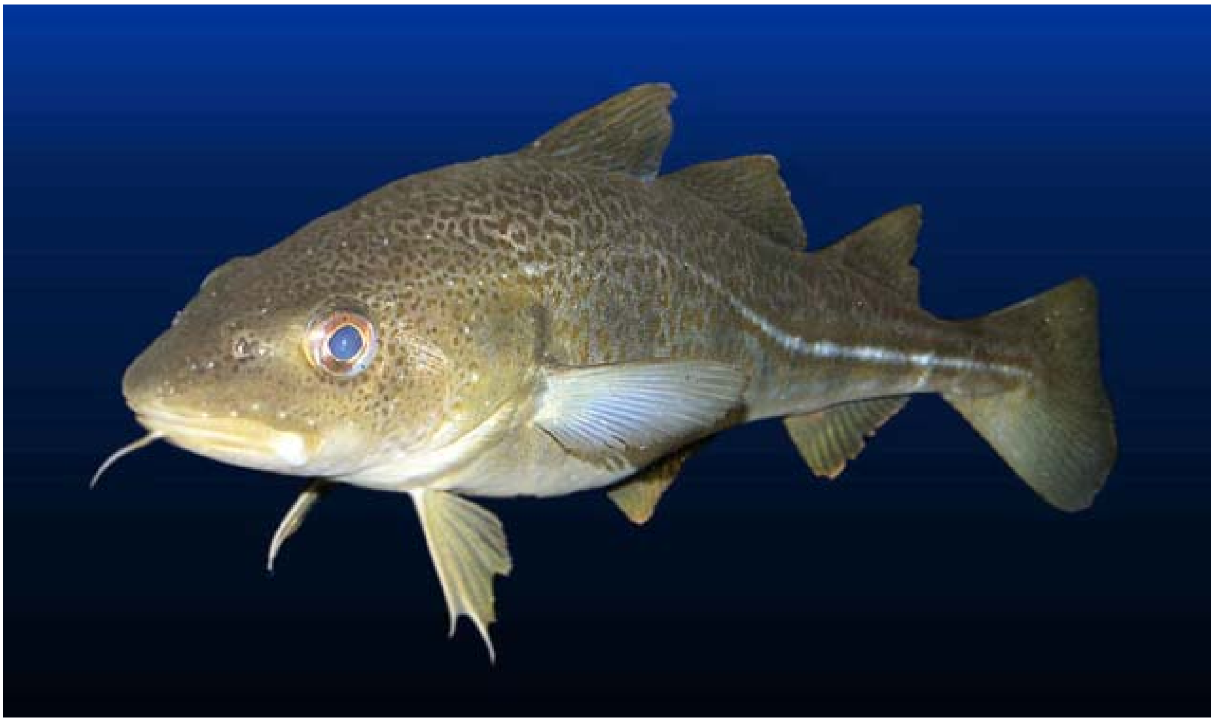

Fig. 6 *Adult cod (Photo from: http://www.fishbase.de/Photos/ThumbnailsSummary.php?ID=69, last accessed 30/7/2007)*

In July 1999 very low values of Baltic cod cpue was observed at oxygen saturations < 20% and between 60 and 90% compared to cpue between 17 and 60% saturation. At salinities <11 psu a low cpue was seen, which corresponded to the oxygen saturation between 60 to 90% and temperatures <5.5ºC. This resulted in a vertical distribution of cod in the region of the halocline because of the low salinity above the halocline limiting the distribution range (Neuenfeldt and Beyer, 2003). Atlantic cod is considered to be an euryhaline fish (Odense et al. 1966, Fletcher 1978 a,b). In spite of the current demographic situation for cod, 7 psu have been chosen as distribution limit, allowing for salinity-unlimited dispersal over the known area of occurrence in the Baltic Sea. Cod eggs, on the other hand, need at least salinity around 11 psu to be fertilized successfully and to survive (Nissling & Westin 1991, Westin & Nissling 1991). Hence, there is a strong indication that adult cod will migrate to below the halocline during the spawning season between March and October which is supported by field data from the Bornholm basin (Tomkiewicz et al.1998, Wieland et al. 2000a).

Cod inhabits a high variety of temperatures from -1.5ºC to 20ºC but in general cod in different ecosystems occupy temperatures between 6ºC and 10ºC during spawning season. There is no clear match between temperature and seasonal trends in the Baltic Sea which could be due to the complex hydrography and changing oxygenation which exerts effect upon habitat selection of cod (CODYSSEY, 2007). Hjelm et al. (2004) found a positive correlation between oxygen as well as salinity and the abundance of cod in the Baltic Sea but oxygen was suggested to be the main factor influencing the cod distribution.

3.2 Sprat

Sprat (*Sprattus sprattus balticus S*) is distributed mainly in the open Baltic and the western and central Gulf of Finland. The year class abundance of sprat and sprat predation by cod (*Gadus morhua callarias L.*) are regarded as the chief variables influencing fluctuations in sprat biomass (Aps 1989; Grauman and Yula, 1989; Köster et al., 2003; Alheit et al., 2005). In periods of warm winters and good oxygen conditions in deep layers, the volume of water habitable by sprat increases. This facilitates reproduction, feeding and normal wintering of sprat and supports its domination in the pelagic layers of the sea. Sprat is known to be a batch spawner with an individual spawning period of about two months. The spawning period for sprat in the Baltic Sea is usually from March to August, concentrating in cod spawning areas in times of high cod egg abundance ((Parmanne et al. 1994; St. John et al., submitted)

3.2.1 Sprat egg habitat

During spawning period sprat eggs experience different buoyancy and in spring sprat eggs are found in deep layers at a salinity of 9-13 psu while during summer the eggs are distributed in surface layer at salinity of 7-8 psu. In the Bornholm Basin eggs are buoyant in and below the halocline at ca. 50-70 m depth early in spawning season and are distributed in and above the halocline from ca. 20-60 m during peak spawning while they towards the end of spawning season are distributed over the halocline (Nissling et al., 2003). Nissling et al. (2003) found an egg specific gravity of ± S.D. 1.00858 ± 0.0116 g cm^{-3} in the months of May and June, which showed a significant higher gravity in the beginning and a significant lower gravity towards the end of the spawning season.

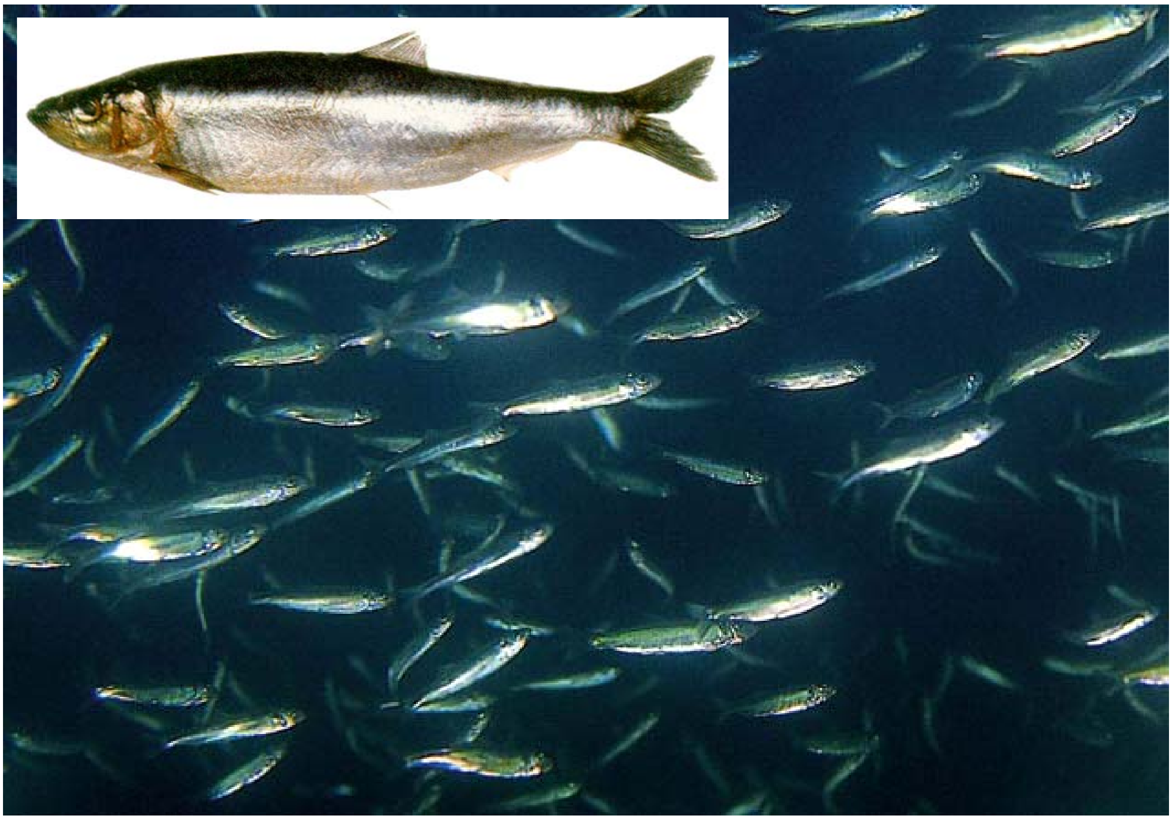

Fig. 7 *Adult sprat (Photo from: http://www.fishbase.de/Photos/ThumbnailsSummary.php?ID=69, last accessed 30/7/2007).*

Salinity is important for sprat egg survival due to the great influence of salinity on buoyancy. At low salinities the density of the eggs may be too high which cause an increase in egg mortality due to the fact that the eggs are incapable of staying buoyant in the water column and instead are found on the bottom where the water is oxygen depleted. In water with salinity below 6 psu the pelagic sprat eggs are less buoyant and die (Parmanne et al. 1994)

As eggs occur in deeper water layers early in spawning season they may develop under unfavourable oxygen conditions and a threshold level for successful egg development at 0.7-1.0 ml/l has been suggested (Grauman and Yula, 1989). Sprat spawning compared to cod spawning is more spatially distributed and less restricted to the deep layers due to the higher buoyancy of sprat eggs and thereby less affected by the oxygen depletion in the deep water. On the other hand sprat eggs are sensitive to low temperatures and the cold water layer between the thermo- and halocline formed in the Central Baltic during winter may influence the eggs (Köster et al., 2003). In Bornholm Basin the temperature seems to be the most important factor influencing sprat egg development (Nissling et al., 2003).

MacKenzie and Köster (2004) showed that warm temperature benefits sprat reproduction and recruitment in Baltic Sea (in the period 1973-1999) and an indication of significant lower sprat recruitment in cold years. The optimal requirements for successful hatching of sprat eggs are temperatures between 5-13◦C (Nissling 2004) but high sprat egg abundance in the Baltic Sea are observed below 5ºC (Nissling et al., 2003; Nissling, 2004). This could indicate that temperature is not the only factor important for successful egg hatching.

3.2.2 *Adult sprat habitat preferences*

Sprat is a widely distributed species in north-eastern Atlantic waters – from the Baltic to the North Sea and even as far north as the Lofoten Isles and west of the British Isles. Its distribution is also found along the Iberian coast as well in the northern Mediterranean and Black Sea. This versatility of distribution shows a high adaptability of sprat to rather different environments in term of salinity and temperatures (Parmanne et al. 1994). Sprat prefer habitats with warmer waters (temperature > 5.1 °C) and have a lower distribution rate of 1.0 ml/l oxygen (Stepputtis, 2006; PhD thesis, Univ. Kiel). During the day sprat tend to reside in the intermediate and bottom layers while at night they aggregate in the surface layers where they have limited contact with cod (Nilsson et al. 2002; Neuenfeldt & Beyer, 2006).

3.3 *Hydrographic data*

Regular hydrographical measurements in the Baltic Sea have been carried out since the beginning of the last century (see Fig. 8). ICES maintain the largest bank of oceanographic data supplied by Member Countries, dating back to the early 1900s covering the entire Northeast Atlantic. Submission to the databank is subject to intense quality control, thus providing some measure of validation. The hydrographical data set received from ICES contained only few data for the area in question in the years of 2000 and 2003. For 1995, ICES CTD data has been used, since there were enough stations to give a satisfactory representation of the hydrographic conditions (at the time). For the reconstruction of realistic hydrographic environmental variables in the Baltic Sea for 2003-2005, a comprehensive database containing the spatial and temporal development of the relevant hydrographic conditions was created from the ICES database and complemented by data from national German and Danish surveys in the Bornholm Basin.

3.3.1 *Hydrodynamic model*

In order to obtain temperature, salinity and oxygen conditions at temporal and spatial scales much finer than possible from field observations a hydrodynamic model, based on the free surface Bryan-Cox-Semtner model (Killworth et al. 1991) which is a special version of the Cox numerical ocean general circulation model (Bryan, 1969 and Cox, 1984) was used. A detailed description of the equations and modifications made, necessary to adapt the model to the Baltic Sea can be found in Lehmann (1995) and Lehmann and Hinrichsen (2000). Physical properties simulated by the hydrodynamic model agree well with known circulation features and observed physical conditions in the Baltic (for further description see Lehmann 1995; Hinrichsen et al. 1997; Lehmann and Hinrichsen 2000). The model domain comprises the entire Baltic Sea including the Gulf of Bothnia, Gulf of Finland, Gulf of Riga as well as the Belt Sea, Kattegat and Skagerrak. The horizontal resolution is 5 km, with 60 vertical levels specified. The thickness of the different levels is chosen to best account for the different sill depths in the Baltic.

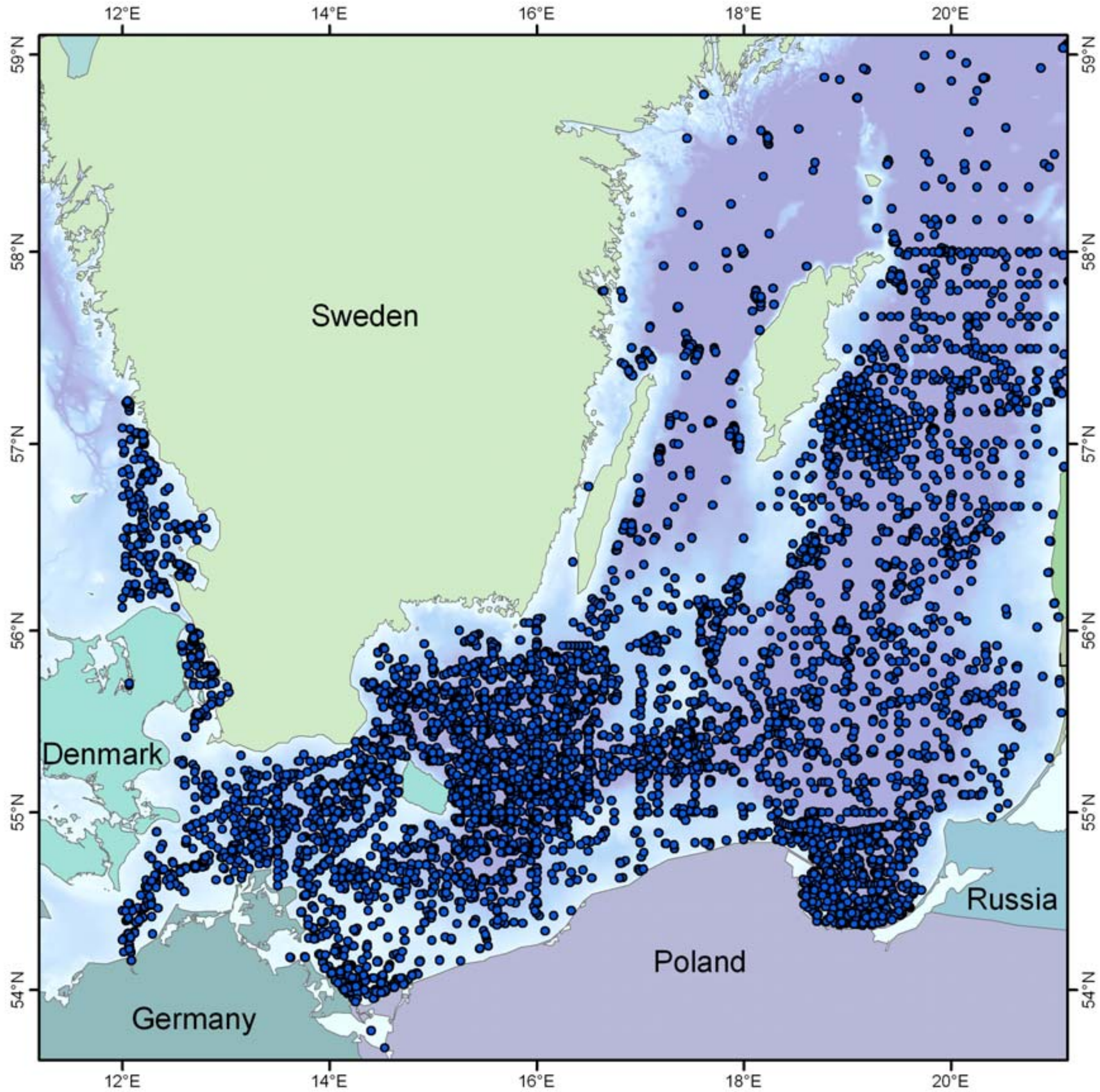

Fig. 8 *ICES CTD sample stations from 1994 - 2005 in SD 21 – 29.*

The Baltic Sea model is driven by atmospheric data provided by the Swedish Meteorological and Hydrological Institute (SMHI: Norrköping, Sweden) and river runoff taken from a mean runoff database (Bergström and Carlsson 1994). The meteorological database covers the whole Baltic Sea drainage basin with a grid of 1° x 1° squares. Meteorological parameters, such as geostrophic wind, 2-m air temperature, 2-m relative humidity, surface pressure, cloudiness and precipitation are stored with a temporal increment of 3 hours.

Prognostic variables of the hydrodynamic model are the baroclinic current field, the three-dimensional temperature, salinity and oxygen distributions, the two-dimensional surface elevations and barotropic transport. These prognostic variables were extracted from the model every 24 hours, and formed the geolocation database for the subsequent analysis.

3.4 Biological sampling Methods

The horizontal distribution and abundances of cod eggs and larvae were obtained with a

Bongo net equipped with 335 and 500 µm mesh size and sampled with double oblique hauls covering the entire water column. The Bongo (60 cm diameter) was equipped with flowmeters in each of the nets. Fish eggs and larvae were sorted from the samples and staged (cod larvae samples was not included before 1997). The counts were standardized to 1 m² by the volume of water filtered and the maximum depth of the tow (~2 m above the ground). Egg staging was performed according to a 5-stage system based on morphological criteria (Westernhagen, 1970; Thompson and Riley, 1981), which was adopted for the Baltic (Wieland, 1988; Wieland and Köster, 1996). The station grid in use comprised 30 stations in 1987-90, 36 stations in 1991-93 and finally 45 standard stations from 1994 on (see Fig. 9). The station grid was always sampled around the clock, i.e. catches were obtained both during day and night.

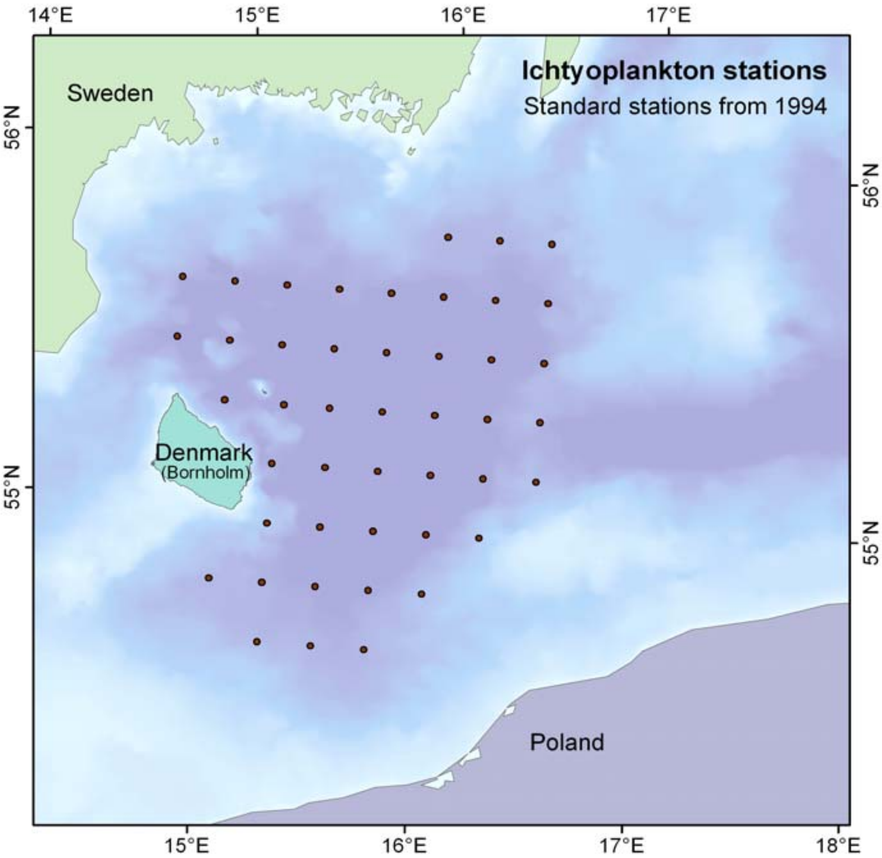

Fig. 9 *Ichtyoplankton standard sampling stations from 1994 and onwards in the Bornholm Basin*

3.5 Habitat models

As described earlier, threshold levels of environmental variables forming the physiological preferences or boundaries for the distribution of adult cod and sprat as well as their eggs are readily available from published literature as well as past and ongoing projects. However, there is a difference in how well the thresholds are described and whether the threshold described is one single value or a span of values ranging from very good to very bad conditions for the species and life stage studied. In the scope of this project, it has therefore been possible to make differentiated maps for adult cod and cod eggs while maps for adult sprat and sprat eggs are more rigid in their expression.

The physiological thresholds have been applied to available hydrographic data considering temperature, salinity and oxygen conditions, depending on the species and life stage studied. As described in the paragraph about the hydrographic data, for the year of 1995, CTD and oxygen data from the ICES database have been used to obtain three dimensional pelagic habitats while for the years 2003-2005, output from a hydrodynamic model has been utilized as input for the habitat estimation. The following physiological threshold values are available at present and have been utilized in the pelagic habitat models (Table 1).

Tabel 1 *Hydrographical thresholds used for cod and sprat in mapping their habitats.*

Species	Stage	Month	Temperature (˚C)	Salinity (PSU)	Oxygen saturation	Oxygen comments	Density (σ_t = p-1000 & mg/ cm^3)	Source
Cod	**Egg**		**>1.5**	**> 11**	**> 2 ml/l**			MacKenzie et al. 2000; Westin and Nissling, 1991
Cod	**Adult**			**> 7**	**> 60 %**	**No impact**		Codyssey 2007
Cod	**Adult**			**> 7**	**> 35-60 %**	**Reduced vertical activity**		Codyssey 2007
Cod	**Adult**			**> 7**	**< 34 %**	**Spend limited time there**		Codyssey 2007
Sprat	**Egg**	**April**					**10.08–11.76**	Nissling et al., 2003
Sprat	**Egg**	**May/ June**					**7.29–10.31**	Nissling et al., 2003
Sprat	Adult		> 1.5		> 1 ml/l			Stepputtis, 2006; PhD thesis. Uni. Kiel

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The data was used as an input to the Golden Software Program Voxler. This program is designed for the visualization of three-dimensional data, but is not a GIS program as such, challenging the user when visualising and projecting geographical data, which usually has quite different dimensions in the x and y directions than in the z direction. The data was restricted to a specific area and the date in question. Three dimensional gridding could then take place with the help of the Inverse Distance Weighted Interpolation method available in Voxler. After that, the threshold values for the species and life stage in question were applied and the data was visualized either by contouring or iso-surfaces, depending on the desired output. For some of the maps, a clip plane was applied, meaning that a transect was cut through the entire investigated area, revealing patterns in the x/z direction. Voxler has in the used version (1.1) only limited possibilities for layout creation, but hopefully this will change in one of the next versions, it was still a fairly new program that was available at the time of preparation of this report.

3.6 General data and model considerations

The CTD and oxygen data set received from ICES contained over 400.000 records spread over the years 1994 to 2005 for the entire Baltic Sea. The data set contained data measured with CTD as well as bottle data. Data was thinned to contain measurements for 10 different depths for each station on average. Unfortunately, the data was not evenly distributed, either throughout the years or geographically. In 1994, there were for example more than 120.000 records available, whilst in 2005, not even 7000 records were held. In May 2003 the received data set contained nearly 1000 records for the entire Baltic Sea, corresponding to about 100 stations, of which only 3 stations were found to be in the Bornholm Basin, an area of over 10.000 km^2. As a consequence of the uneven distribution in space and time, data was insufficient to justify an interpolation at specific times and areas and, as described earlier, data from the hydrographical model was used to fill the gaps.

3.6.1 Hydrography

When working with the creation of the habitat models, values for density of oxygen saturation were needed amongst others. The data from the hydrographical model already contained these parameters, whilst it was necessary to calculate them for the hydrographical data received from ICES. Water density was calculated from values for depth/pressure, temperature and salinity, whilst oxygen saturation was calculated from values for temperature, salinity and oxygen concentration. Using acknowledged references on the Internet to find the right formula, the calculation was checked against the values in the model data file, and a slight discrepancy between the data was found. However, having in mind the purpose and scale of this study and the measurement uncertainty of the raw data, it was concluded that this fact was insignificant.

3.6.2 2D mapping

For the maps showing 2D overlay of oxygen concentration and salinity with the Ichtyoplankton data, an interpolation of the hydrographical features was carried out between data points. ArcGIS was used as the software platform for the creation of these overlaid maps. Data in the study area for the desired time was selected. To be able to make a cut in the vertical direction, only data for approximately 60 m depth was used. The depth of 60 m was chosen because it is here the biggest concentration of eggs is expected, owing to the fact that the deep-water halocline is present around this depth. For a detailed description see the section about the hydrography in the study area. Interpolation of the data was carried out with the Natural Neighbour method using the ArcGIS Spatial Analyst extension. The interpolation was carried out in the UTM zone 34N projection with the WGS84 datum and a grid cell resolution of 500 meters. A common legend was applied for the different parameters at the various times of investigation to ease comparison of the maps.

4 RESULTS

The employed hydrography data for mapping in 1995 is taken from ICES CTD data and oxygen, whereas in 2003, hydrographical model data are used. All the results in this report are presented on maps and are mainly based on hydrography and biological thresholds.

4.1 Hydrography

All hydrography GIS maps are shown as a horizontal cut at a depth of approximately 60 m, i.e., the average depth of the halocline in the Bornholm Basin and the Slupsk Furrow with isoclines representing salinity and the full colour scale the oxygen concentration in the water. The grey colour in the 2D maps masks areas lower than 60 m.

1995 was two years after an inflow leading into a stagnation period with depletion of oxygen and salinity (Fig. 10, April 1995). In the winter 2002-2003 a major inflow found place into the Baltic Sea and the result of the inflow of saline oxygen-rich water can be seen on Fig. 10 (April 2003).

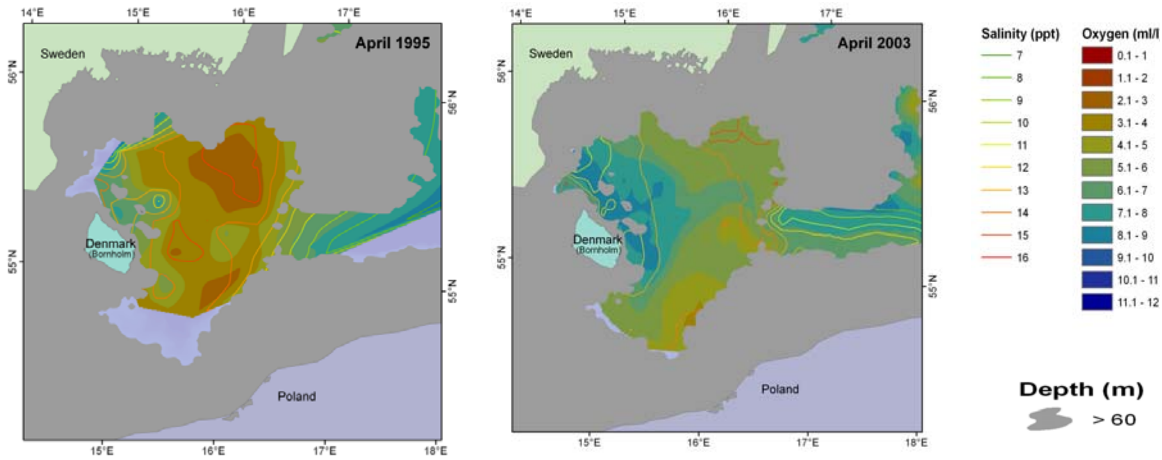


Fig. 10 *Hydrography in Bornholm Basin and the Slupsk Furrow in April 1995 and 2003. ICES CTD and oxygen data is used for mapping in 1995 while hydrographical model data are used in 2003.*

4.2 Cod

The reproductive volume of Cod was determined in the Bornholm Deep in the area east of the Island of Bornholn.

4.2.1 Cod egg

The cod egg abundance in Bornholm Basin 1995 is increasing from April to July but when September is reached a decrease in abundance is observable which corresponds to the end of the spawning season (Fig. 11).

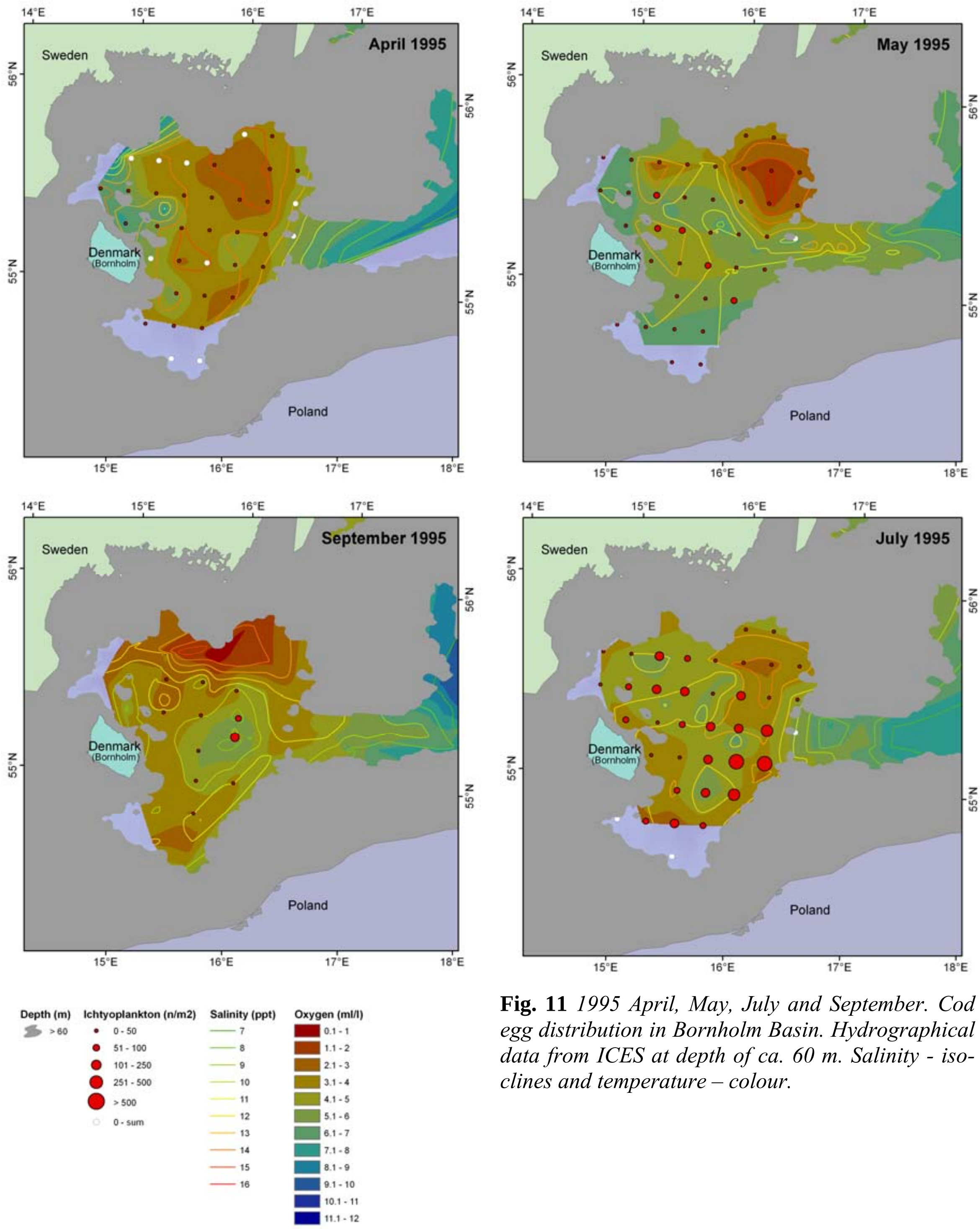
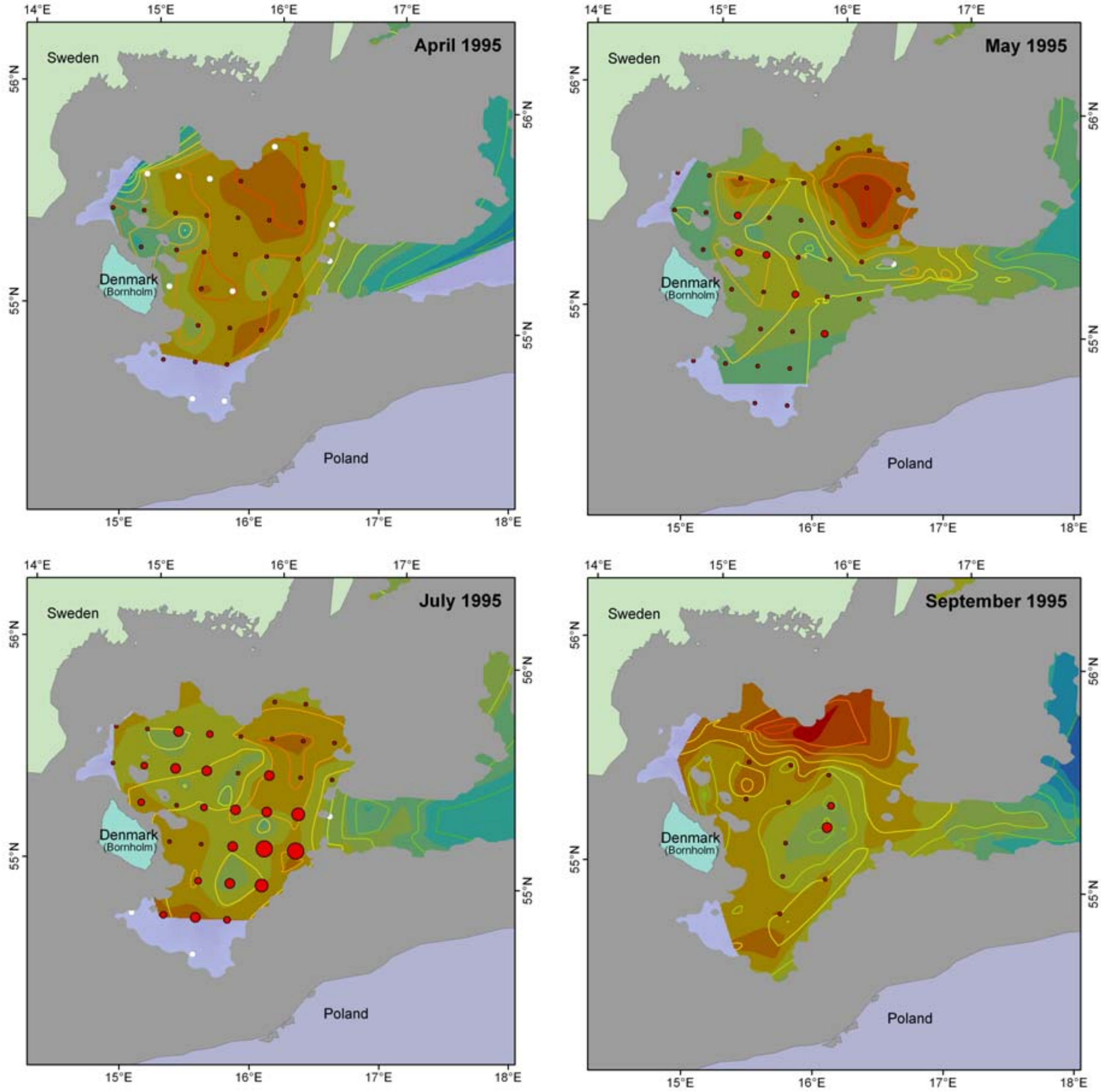


Fig. 11 *1995 April, May, July and September. Cod egg distribution in Bornholm Basin. Hydrographical data from ICES at depth of ca. 60 m. Salinity - isoclines and temperature – colour.*

In April the homogenous colouring at halocline depth across the Bornholm basin characterized by low oxygen content and highly saline water, signify the upper part of the permanent halocline (visible at this depth), which is recognized by these factors. To the east of the basin in the Slupsk Furrow, the winter water is occurring, which typical contain high oxygen and low salinity. Cod eggs are located in small amounts throughout the basin in April (Fig. 11).

In May salinity is high where oxygen concentration is low at the northeast edge of the basin, which could indicate a high degree of oxygen consumption by degradation. At this time the permanent halocline is no longer visible throughout the basin. Throughout the basin the oxygen concentration is low, but not critical, and the salinity is high. The winter water is still visible in the very eastern part of the Slupsk Furrow (Fig. 11). The abundance of cod eggs throughout the basin is higher than the previous month.



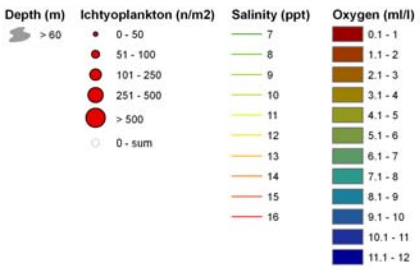


Fig. 12 *2003 April, May, July and August. Cod egg distribution in Bornholm Basin. Hydrographical model data is applied for estimation of salinity and oxygen at a depth of ca. 60 m. Salinity - isoclines and temperature – colour.*

The oxygen content is fairly low at the boundaries of the basin (3-4 ml/l) in July which probably is due to increased egg abundance and hence oxygen consumption. To the east in the Slupsk Furrow, oxygenated winter water can be observed (Fig. 11). The egg abundance is at its highest level throughout the basin, which indicates that July in 1995 is the peak spawning month for cod in the Bornholm Basin.

In September the oxygen concentration is rather homogeneous throughout the basin, though with very low concentrations (0.5-1 ml/l) to the north. It is mainly at the boundaries of the basin that the oxygen concentration is low and the salinity is high and this is probably due to the increased oxygen consumption in these regions (Fig. 11). In the central part of the basin where oxygen content is greatest, the salinity is very low compared to other months during the year and in this month the greatest abundance of cod eggs are found in the low saline, but fairly oxygenated water.

In April 2003 several stations were sampled with no occurrence of cod egg, which indicates a later beginning of spawning season compared to 1995. The highest abundance of cod egg in the Bornholm Basin occurs in July whereas in September a tendency is seen that the egg abundance is skewed more to the east near the Slupsk Sill and Furrow (Fig. 12).

The major inflow, which was detected in the Arkona Basin in February 2003, is observable just east-northeast of Bornholm. It is characterized by highly oxygenated and very saline water. To the east, at the beginning of the Slupsk Furrow, winter water is still visible - though it seems that it is getting pressed further east by the inflow water. Almost no eggs have been found throughout the basin in April.

The inflow water is still highly noticeable in the Bornholm basin in May. It has now moved further to the east and is passing through to the rest of the Baltic Sea. This is visible by the barrier that has started to form to the east of the basin at the beginning of the Slupsk Furrow (the Slupsk Sill). It is characterized by low saline winter water and highly saline inflow water. There is relatively low cod egg abundance throughout the basin in May (Fig. 12).

In July the effect of the inflow can still be seen on the hydrography in the Bornholm basin by the well oxygenated and saline water. To the east, a strong barrier has been formed at the beginning of the Slupsk Furrow (the Slupsk Sill) by the low saline winter water and the highly saline inflow water and it is indicated that it is moving further east passing into the rest of the Baltic Sea through the Slupsk Furrow. The egg abundance is at its highest, which indicates that July in 2003 as well is the peak spawning month for cod in the Bornholm Basin (Fig. 12).

Even in August the inflow can be detected in the eastern part of the basin. The barrier at the Slupsk Furrow (the Slupsk Sill) is not as prominent anymore, and it seems that the inflow water is gaining more access to the rest of the Baltic Sea through here. Cod eggs do still occur throughout the basin, though the greatest egg abundance is found to the east (Fig. 12).

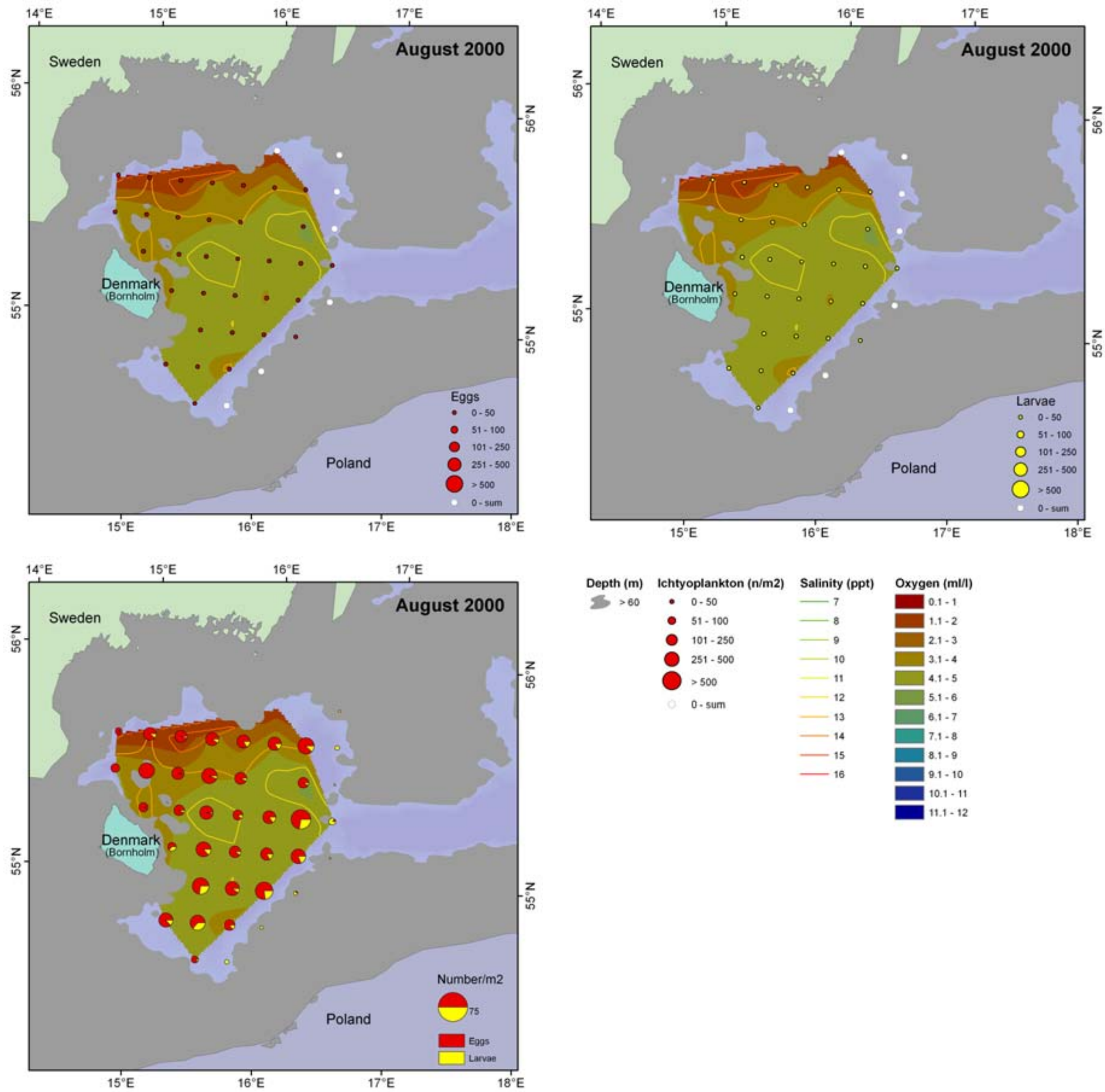


Fig. 13 *Cod egg and larvae distribution in Bornholm Basin in August 2000. Cod egg, larvae and combined egg/larvae abundance are mapped from the top left to the bottom left.*

In Fig. 13 the uppermost maps illustrates the egg and larval abundance in August 2000 separate whereas in the lower map larval and egg abundance has been joined and enlarged for visual purposes. The centre of the basin is fairly high in oxygen (4-5 ml/l) and salinity (12 psu), compared to the northern part of the basin, where the oxygen content of the water is low and saline high (oxygen consumption). There seem to be a trend in larval displacement to the edges of the basin, which could indicate larval movement towards nursing grounds.

Fig. 14 shows how the reproductive volume decreases from 2003, which was a year with a major inflow during the winter, to 2005 where stagnation almost was reached. The same trend is also seen when comparing reproductive volume in April and June from the three years (see Appendix 1 and Appendix 2).

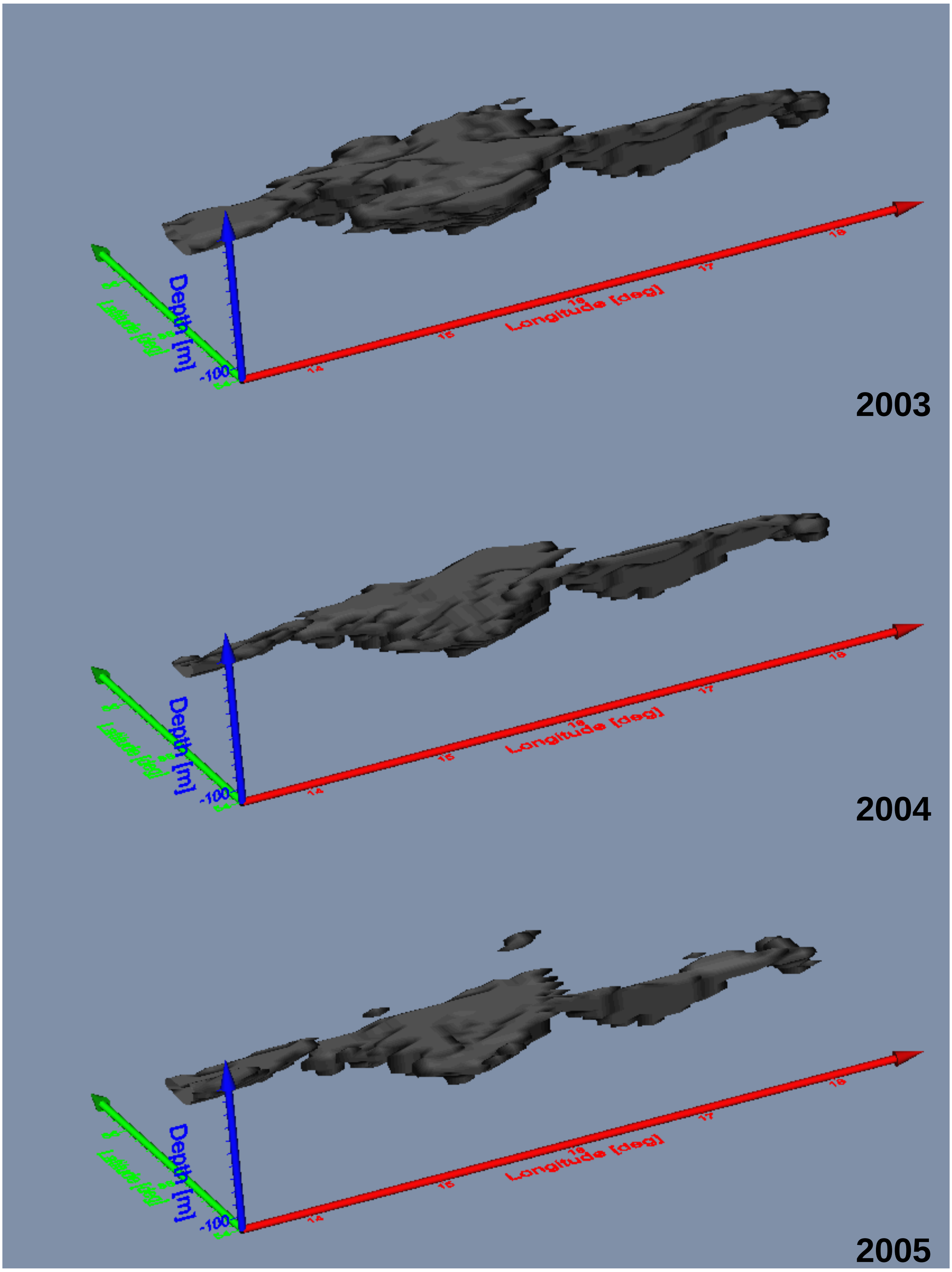


Fig. 14 Reproductive volume for cod in the Bornholm Basin and the Slupsk Furrow, 2003, 2004 and 2005 (from top to bottom). Hydrographical model data is used for mapping. Thresholds: Temperature > 1.5ºC, Salinity > 11 psu, Oxygen > 2 ml/l May.

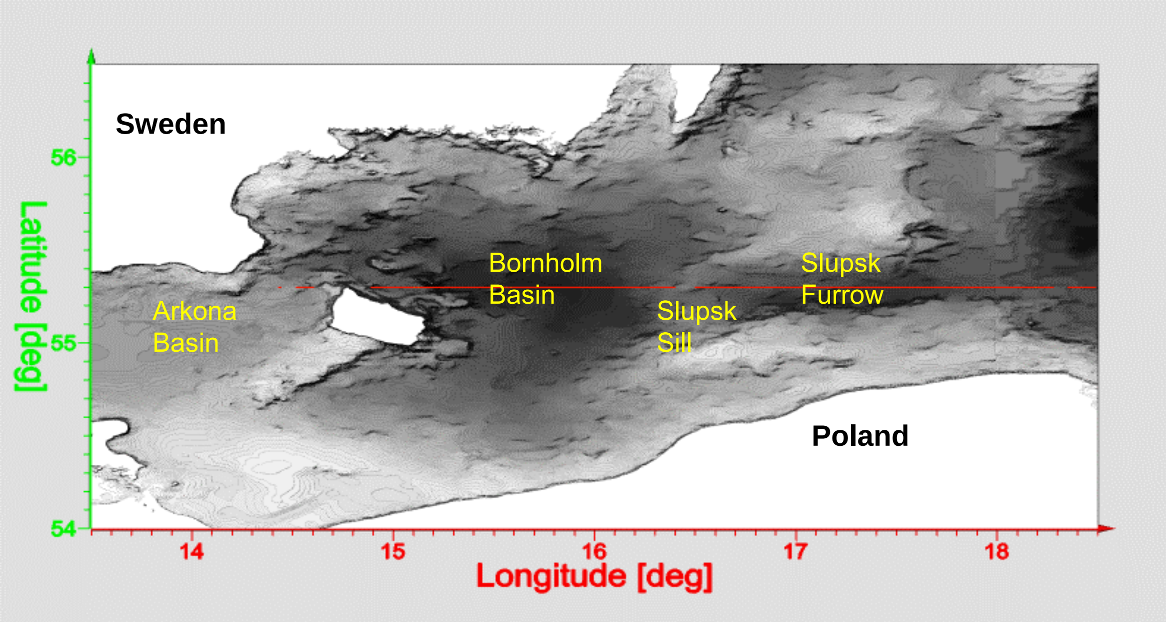


Fig. 15 *Bornholm Basin of the Baltic Sea - transect placement.*

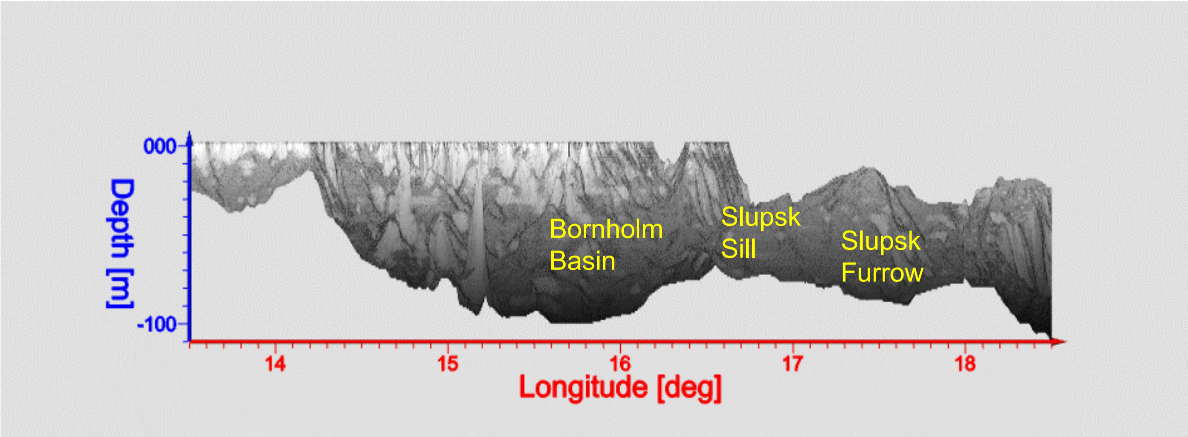


Fig. 16 *Bornholm Basin of the Baltic Sea – transversal cut of the transect placement.*

The transect maps of cod egg habitat, have been made in Voxler, and are visualizing transects through the deepest part of the Bornholm Basin just a little north-northeast of Bornholm and through the Slupsk Furrow leading into the Gdansk Deep.

The colour scale on the following maps (Voxler) represents percent survival of cod eggs in the given habitat calculated by using the cod egg survival function, but only if thresholds of temperature (>1.5ºC), salinity (> 7 psu) and oxygen (2 ml/l) are fulfilled. The lower vertical limit (red lines) of the cod egg habitat is primarily regulated by oxygen, while the upper vertical limit (red lines) is mainly controlled by salinity. Temperature is rarely a limiting factor.

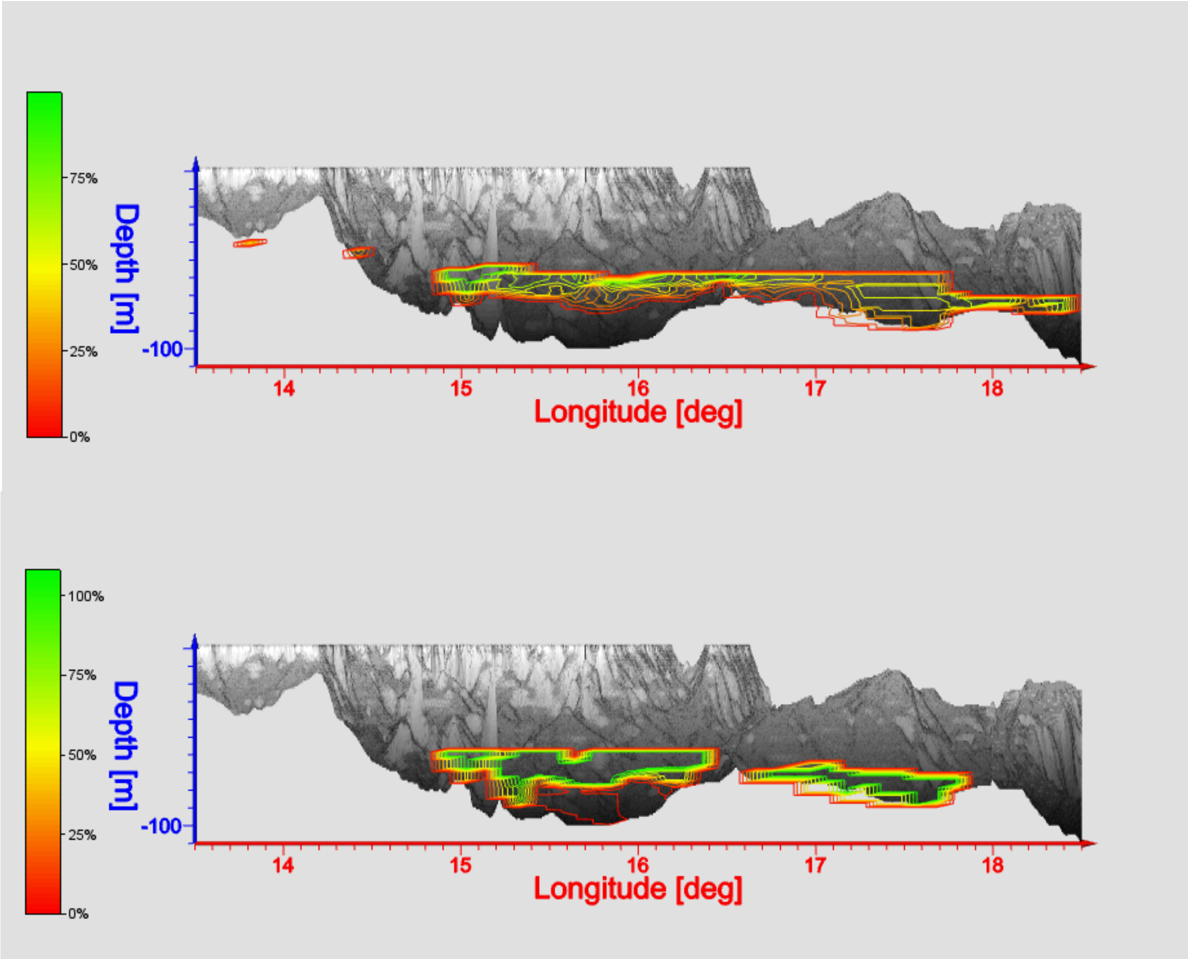


Fig. 17 *1995 May and July cod egg habitat in the Bornholm Basin and the Slupsk Furrow. ICES CTD and oxygen data is used for mapping. Percentage represents cod egg survival calculated from the oxygen related cod egg survival function with thresholds: Temperature > 1.5ºC, Salinity > 11 psu, Oxygen > 2 ml/l.*

Fig. 17 and Fig. 18 illustrate cod egg survival in percentage within the reproductive volume. It is visible that the habitat most suitable for cod egg survival in May 1995 is located is around 60 m depth in the Bornholm Basin, and it appears to stretch a little deeper in the Slupsk Furrow (Fig. 17).

In July 1995 the cod egg habitat has become gradually reduced longitudinally but has increased in the vertical distribution. This increase is probably due to summer inflow from the Arkona Basin, where the bottom water gets replenished with oxygen, even though oxygen consumption still is high. The best habitat for survival is located at around 60 m in Bornholm Basin. Furthermore there is an indication that there are favourable conditions at the same depth in the Slupsk Furrow (Fig. 17).

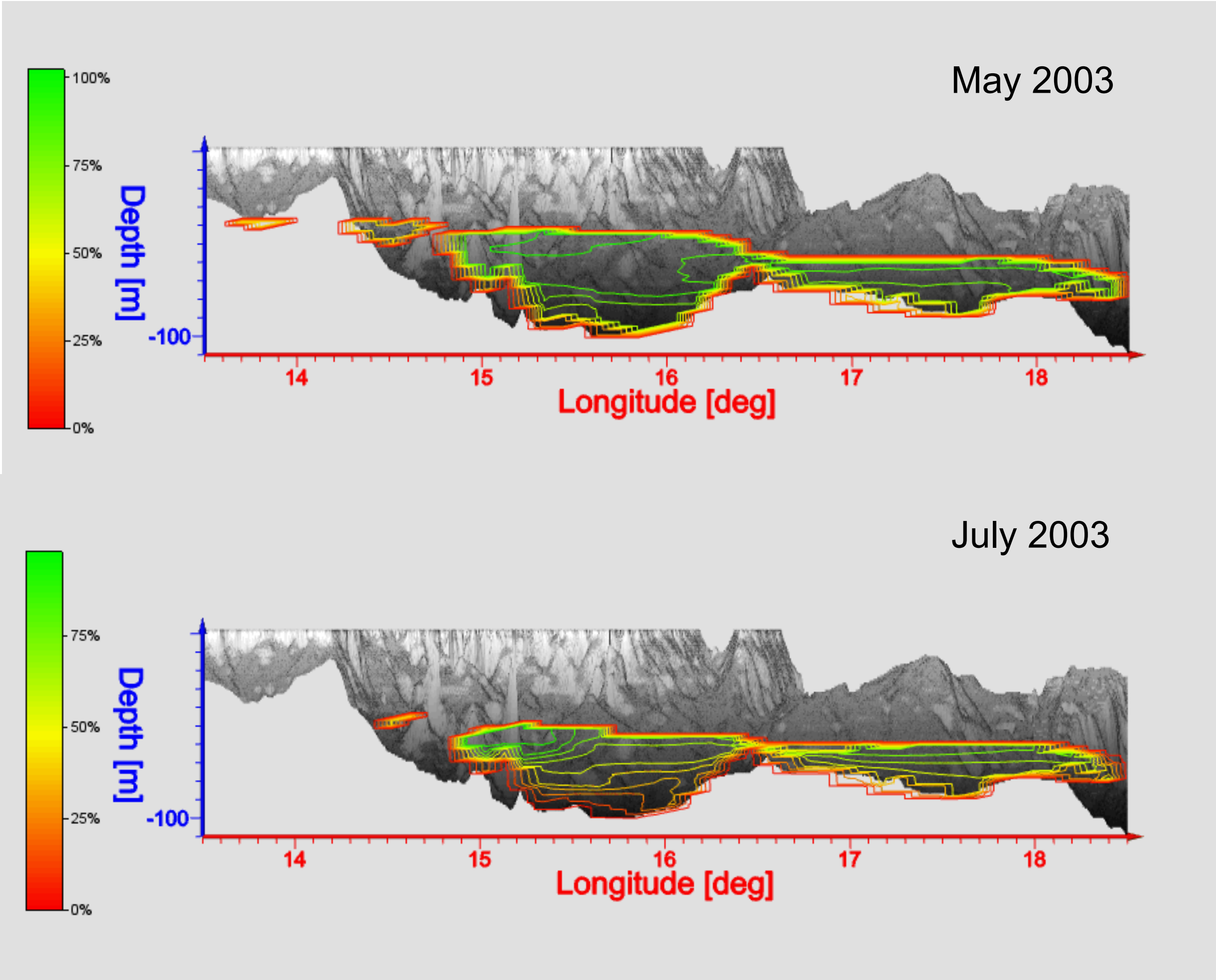


Fig. 18 *2003 May and July cod egg habitat in the Bornholm Basin and the Slupsk Furrow. Hydrographical model data is used for mapping. Percentage represents cod egg survival calculated from the oxygen related cod egg survival function with thresholds: Temperature > 1.5ºC, Salinity > 11 psu, Oxygen > 2 ml/l.*

May 2003 is after a major inflow event at the beginning of the year, and it is very clear (compared to 1995) that the cod egg habitat (with highest percent survival – given from the criteria) has increased significantly throughout the Bornholm Basin, as well as the Slupsk Furrow, and is now located between 50-70 m in the Bornholm Basin (Fig. 18).

The cod egg habitat is still greater in July 2003 compared to 1995, though it has decreased in magnitude from the previous month (Fig. 18). This indicates an effect of the inflow moving eastward together with oxygen consumption, which thereby creates a decrease in oxygen saturation, limiting the cod egg habitat.

4.2.2 Adult cod

The colour scale represents the oxygen saturation of the water in percent, where salinity is the only threshold (> 7 psu).

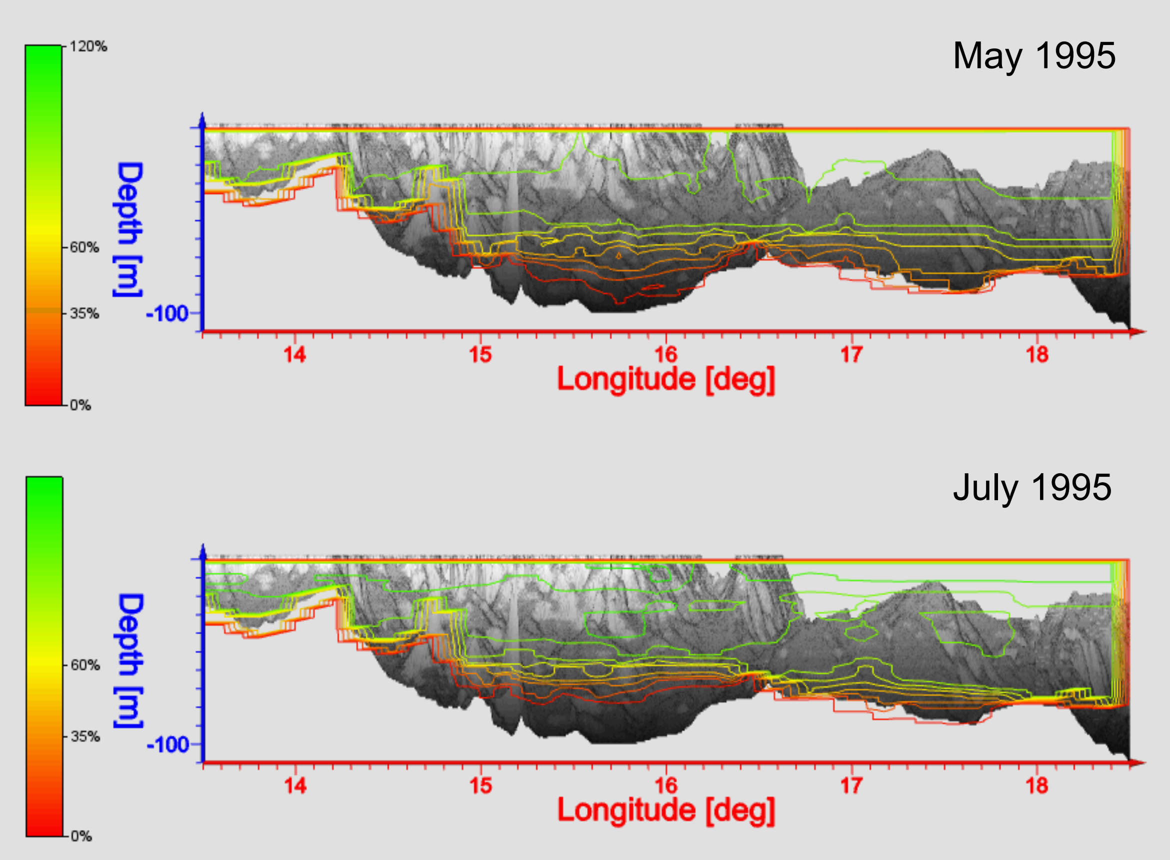


Fig. 19 *1995 May and July adult cod habitat in the Bornholm Basin and the Slupsk Furrow. Thresholds: Salinity > 7 PSU, oxygen 0-120%. ICES CTD and oxygen data is used for mapping.*

In May 1995 the adult cod are restricted by oxygen saturation, and Fig. 19 indicates that they are distributed above 20 m from the bottom in the Bornholm Basin where the oxygen concentration is above 34%, and only take short excursions to the near-bottom water layer for feeding. Cod distribution is even more limited in July 1995 compared to May of the same year, and in this month the optimal preferences are found above 30 m from the bottom (Fig. 19).

In May 2003 (compared to May 1995) the near optimum habitat is stretching almost all the way to the bottom of the Bornholm Basin, which is due to the major inflow has replenished the basin with oxygen rich water (Fig. 20). In July 2003 the aftermath of the inflow is still shown by the relatively large habitat reaching almost to the bottom (compared to July 1995). The reason for this is a positive trend of degradation, using oxygen, at the bottom which can be seen from May to July in 2003 (Fig. 20).

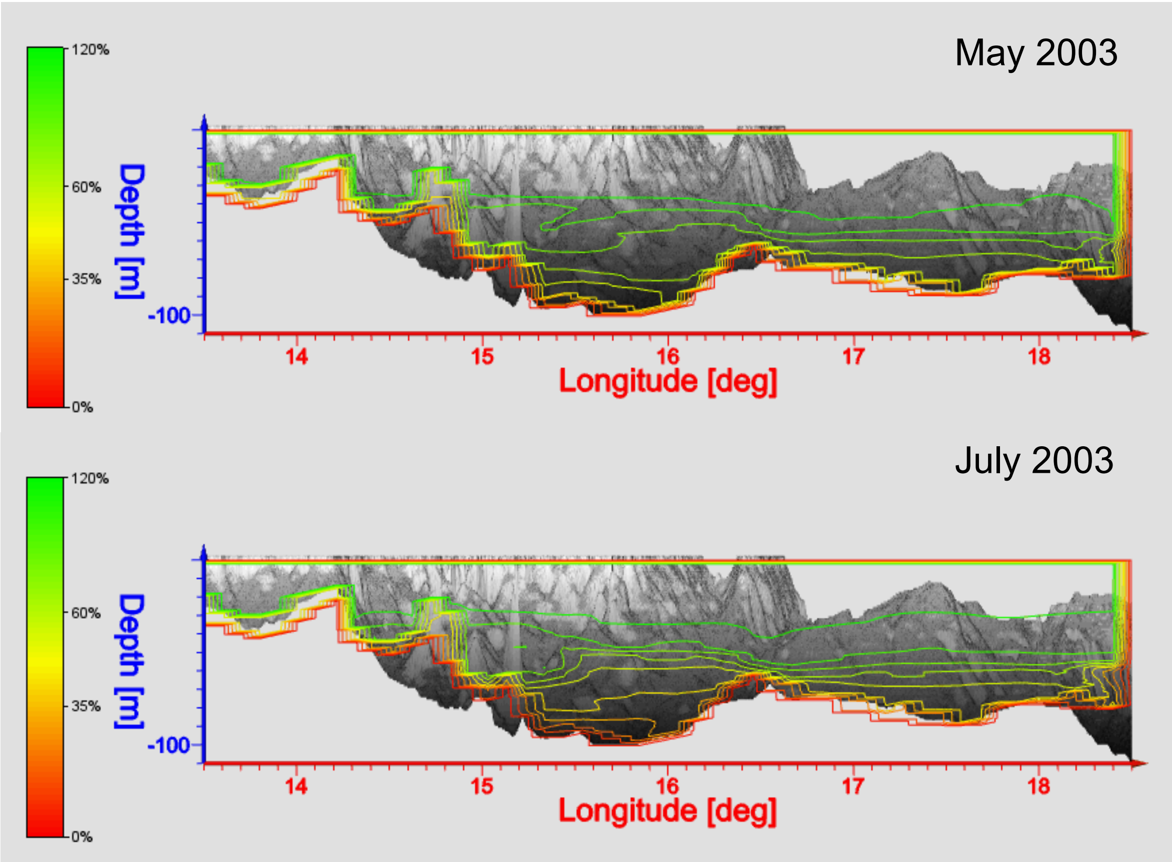


Fig. 20 *2003 May and July adult cod habitat in the Bornholm Basin and the Slupsk Furrow. Thresholds: Salinity > 7 PSU, oxygen 0-120%. Hydrographical model data is used for mapping.*

4.3 Sprat

Optimal sprat egg habitat in April, May and July 1995 appears in the intermediate water layer in the Bornholm Basin but the widest vertical distribution seem to be in May (45-70 m) whereas the narrowest range is seen in July (50-60 m) (Fig. 21). The upper depth limit for sprat egg distribution is deepest in April (55-70 m) which correspond to the fact that the density of sprat eggs are highest during April compared to later in the spawning season.

4.3.1 Sprat egg

In the Slupsk Furrow the preferred habitat for sprat eggs in April 1995 (70-85 m) is located near the bottom while in May (60-70 m) and July (60-70 m) where the eggs are lighter the habitat has moved towards intermediate water (Fig. 21).

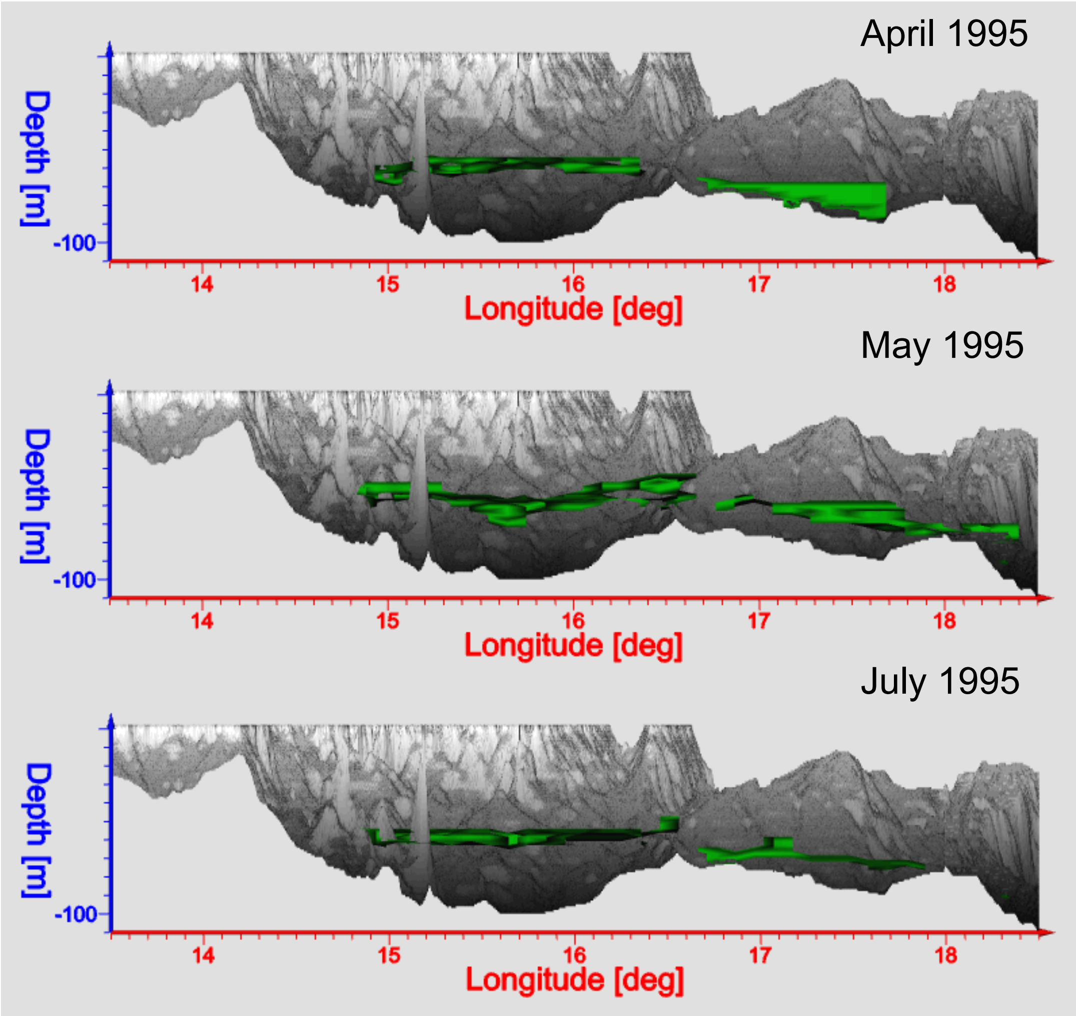


Fig. 21 *1995 April, May and July sprat egg habitat in Bornholm Basin and the Slupsk Furrow estimated from egg density expressed as σ (mg/cm³) in April ≥ 10.08 and ≤ 11.76 and in May and July 1995 ≥ 7.29 and ≤ 10.31. The applied hydrography is ICES CTD and oxygen data.*

In April, May and July 2003 the estimated sprat egg habitat in the Bornholm Basin is found in the intermediate water layer and as in 1995 the location of the habitat is deepest in April where the eggs are denser than in the following months (Fig. 22). Comparing with 1995 the eggs have a tendency to occur at shallower depths in 2003 which may be due to the inflow in 2002-2003 of cold water with high salinity as the preferred temperature for egg hatching is > 5.1ºC and the water becomes denser because of the increase in salinity.

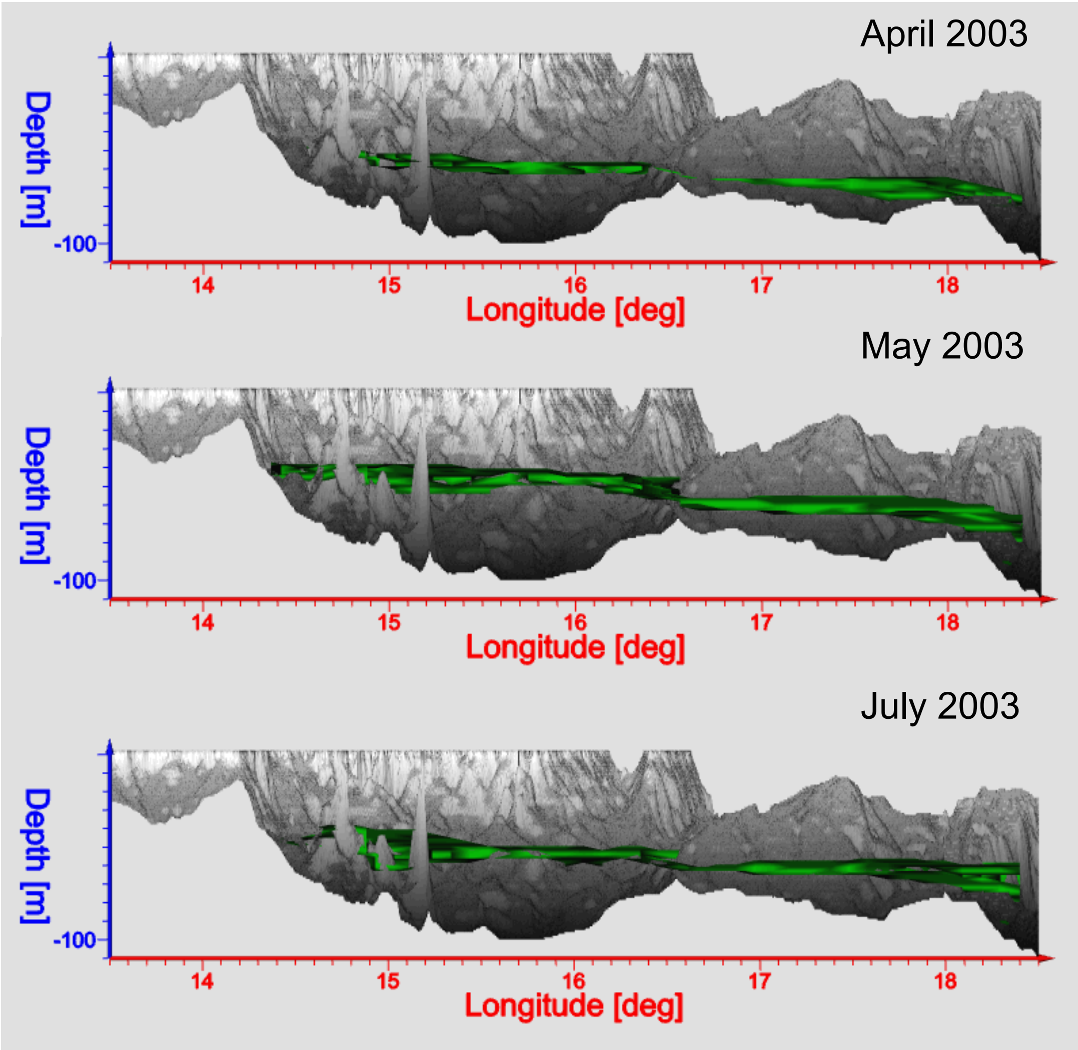


Fig. 22 *2003 April (top), May (mid) and July (bottom) sprat egg habitat in Bornholm Basin and the Slupsk Furrow estimated from egg density expressed as σ (mg/cm³) in April ≥ 10.08 and ≤ 11.76 and in May and July ≥ 7.29 and ≤ 10.31. The applied hydrography is hydrographical model data.*

In the Slupsk Furrow the sprat egg habitat is closest to the bottom in April (70-80 m) where the egg density is highest. As in May and July 1995 the habitat is placed in the intermediate water layer but at shallower depths in 2003 which also could be caused by the inflow - resulting in a lower temperature near the bottom and a higher density of the water (Fig. 22).

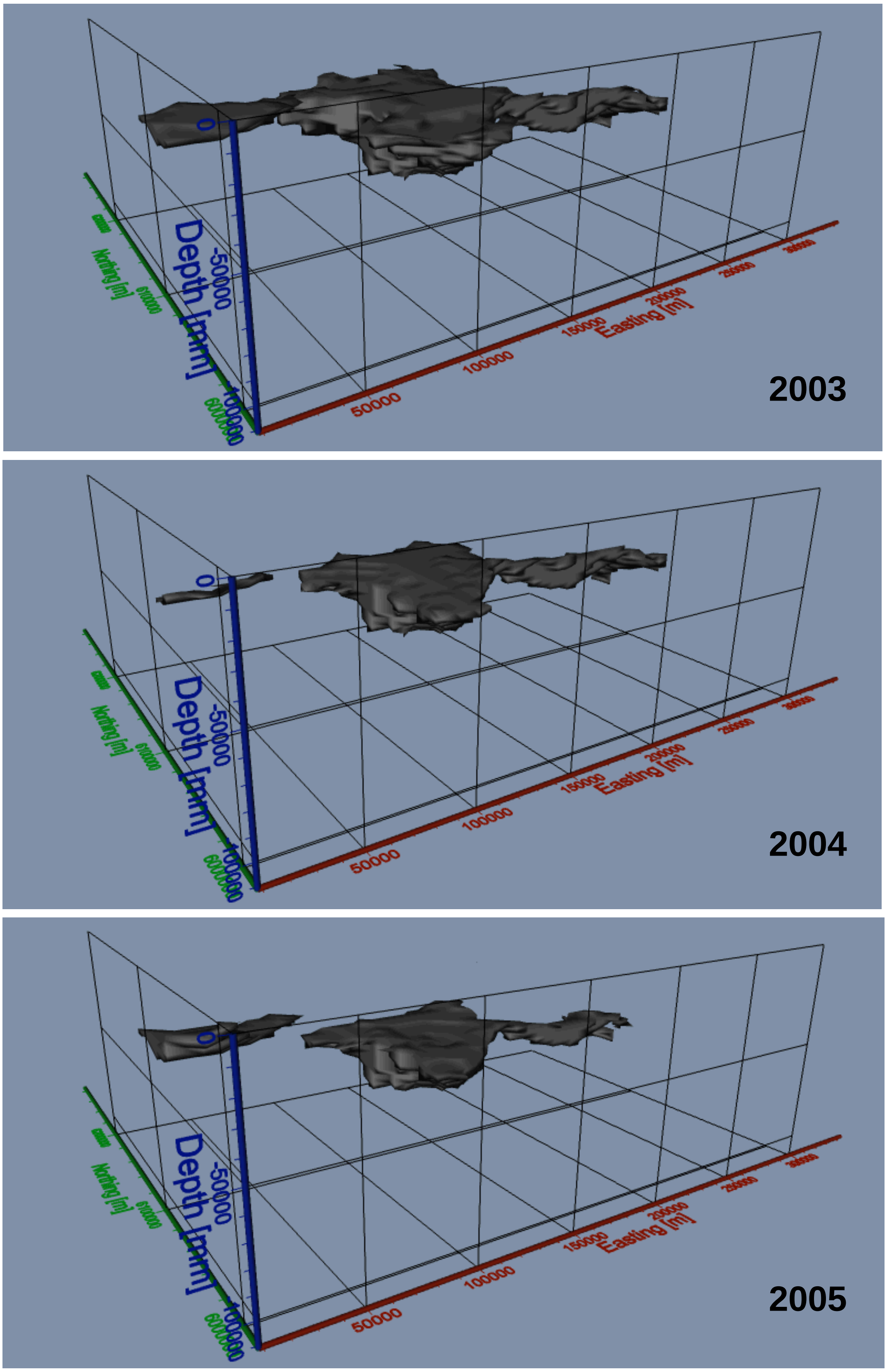


Fig. 23 *2003, 2004 and 2005 May - sprat egg habitat in the Bornholm Basin and the Slupsk Furrow estimated from egg density expressed as σ (mg/cm³) in April ≥ 10.08 and ≤ 11.76 and in May and July ≥ 7.29 and ≤ 10.31. The applied hydrography is hydrographical model data.*

On the 3D maps of sprat egg habitat (Fig. 23) the widest area suitable for sprat egg survival occur in 2003 which is just after an inflow. A rather large decrease of the habitat is seen in the two following years 2004 and 2005, but no considerable difference appears between 2004 and 2005. The same trend is also seen in April and June 2003-2005 (see Appendix 3 and **Fejl! Henvisningskilde ikke fundet.**).

4.3.2 Adult sprat

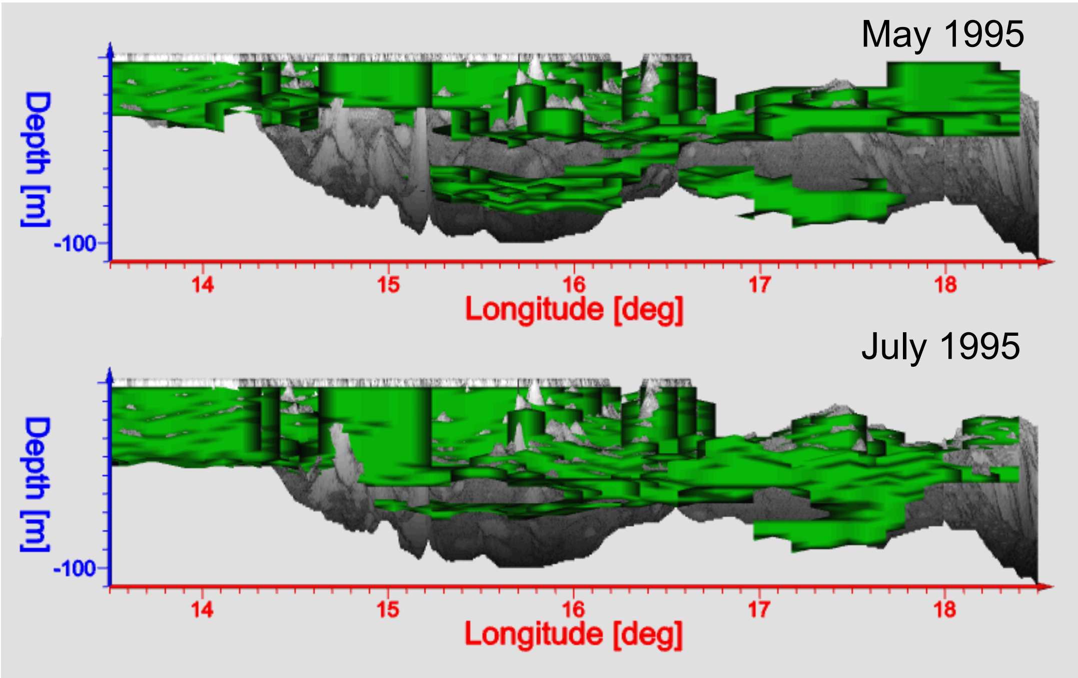


Fig. 24 *1995 May (top) and July (bottom) – adult sprat habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is ICES CTD and oxygen data. Thresholds: Temperature >5.1°C, oxygen > 1ml/l.*

The suitable habitat for adult sprat in 1995 is widespread in the Bornholm Basin and the Slupsk Furrow but the bottom water (from the bottom and approximately 20 m up) does not seem to be an appropriate region for adult sprat (Fig. 24). In July the distance from the bottom to the habitat appears to be larger than in May. In May an area in the intermediate water layer which contains cold winter water at approximately 45-60 m depth in both Bornholm basin and the Slupsk Furrow is not suitable for sprat (Fig. 24) while the area with non-favourable conditions has decreased in July to a depth of 55-65 m and only appears in the Bornholm Basin (Fig. 24). Furthermore the water masses that fulfil the requirements for adult sprat habitat are more abundant in July both in the Bornholm basin and the Slupsk Furrow than in May 1995 but are located more to the upper water layers in the Bornholm Basin (Fig. 24). This indicates that in May sprat are limited mainly by temperature whereas in July mostly oxygen seems to be the limiting factor.

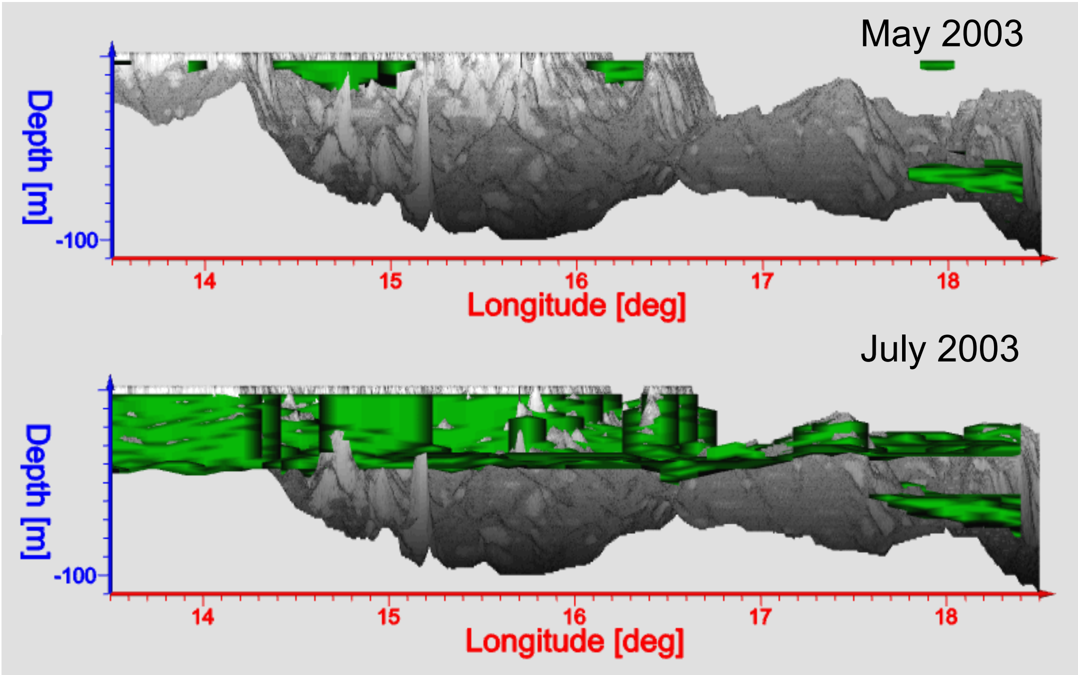


Fig. 25 *2003 May and July – adult sprat habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is hydrographical model data. Thresholds: Temperature >5.1ºC, oxygen > 1ml/l.*

In May 2003 the adult sprat habitat is restricted to the surface water down to 20 m depth in the Bornholm Basin while the preferred hydrographic conditions in the Slupsk Furrow appear only in the eastern part at 55-75 m depth (Fig. 25). The favourable conditions are still limited to the surface layer but have increased to a depth of 50 m in the Bornholm Basin continuing into the Slupsk Furrow where another suitable region is found to the east at 60-80 m depth (Fig. 25). By comparing May and July 2003 the hydrographic conditions in July are more optimal for adult sprat than in May (Fig. 25). Temperature seem to be the limiting factor in this year as the water is replenish by a major inflow in 2002-2003 with cold oxygen-rich water.

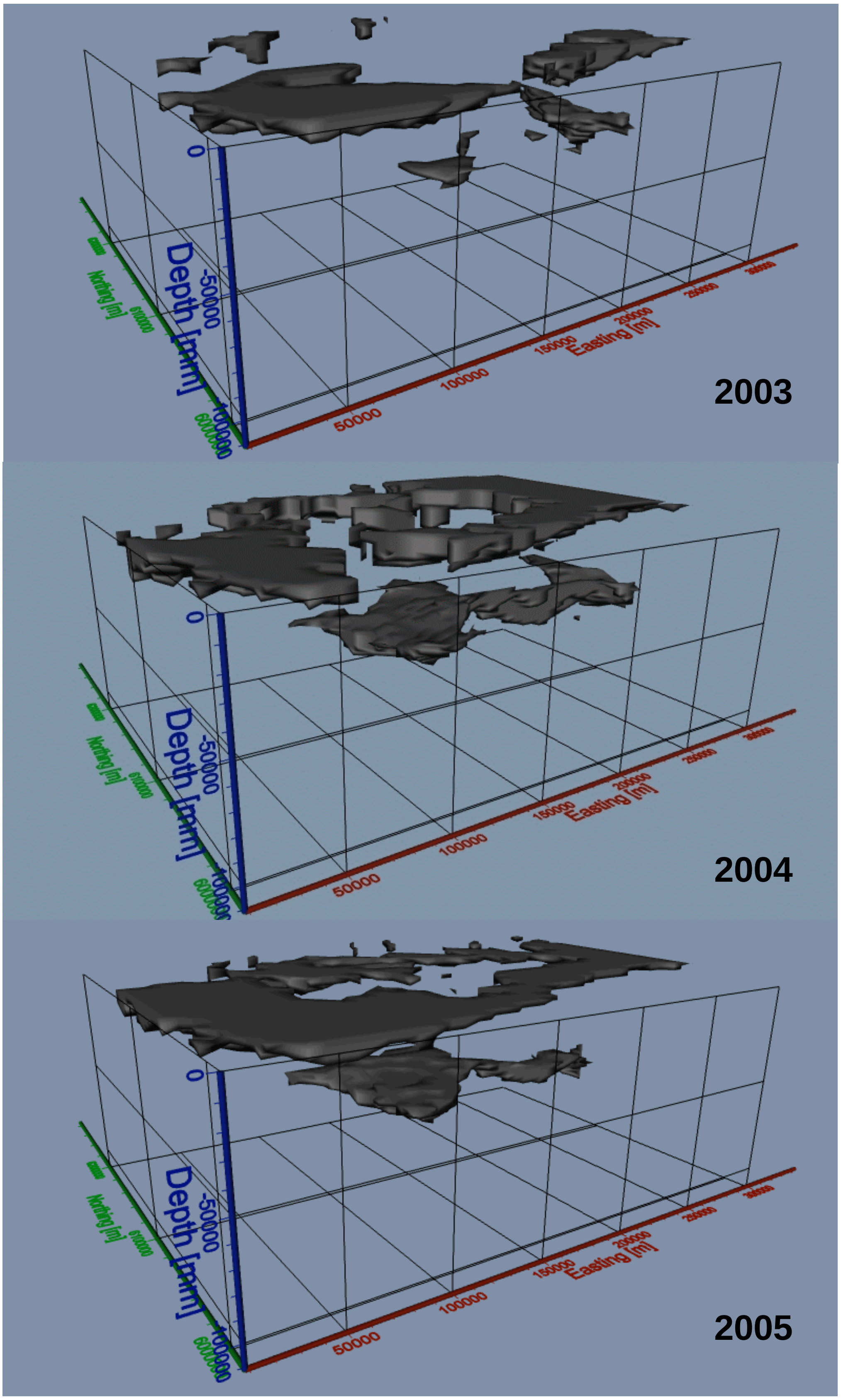


Fig. 26 *2003, 2004 and 2005 May- adult sprat habitat in the Bornholm Basin and the Slupsk Furrow. The applied hydrography is hydrographical model data. Thresholds: Temperature > 5.1ºC and oxygen saturation > 1 ml/l.*

According to the 3D maps of adult sprat habitat (Fig. 26) it is mainly restricted to the surface layer in 2003 whereas two suitable layers occur in 2004 and 2005 – one in the surface water layer and one in the intermediate water layer. The optimal habitats in 2003 are limited compared with 2004 and 2005 while no considerable differences between these two years are observed. For further information about adult sprat habitat in April and June 2003 – 2005 see Appendix 5 and Appendix 6.

4.4 Combined maps

The 2D maps shown are originally 3D maps (made in Voxler) and can therefore conceal some of the cod habitat within the sprat habitat and the other way around.

4.4.1 Cod egg and sprat egg

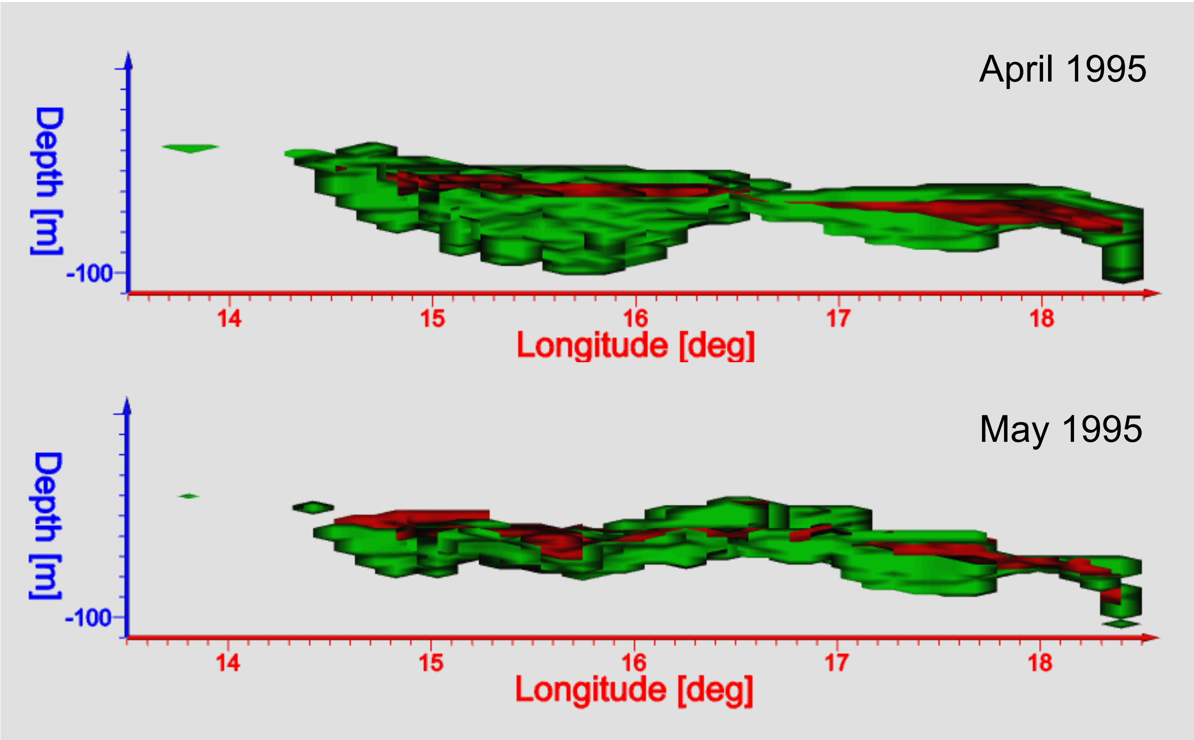


Fig. 27 *1995 April and May – cod egg (green) and sprat egg (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is ICES CTD and oxygen data.*

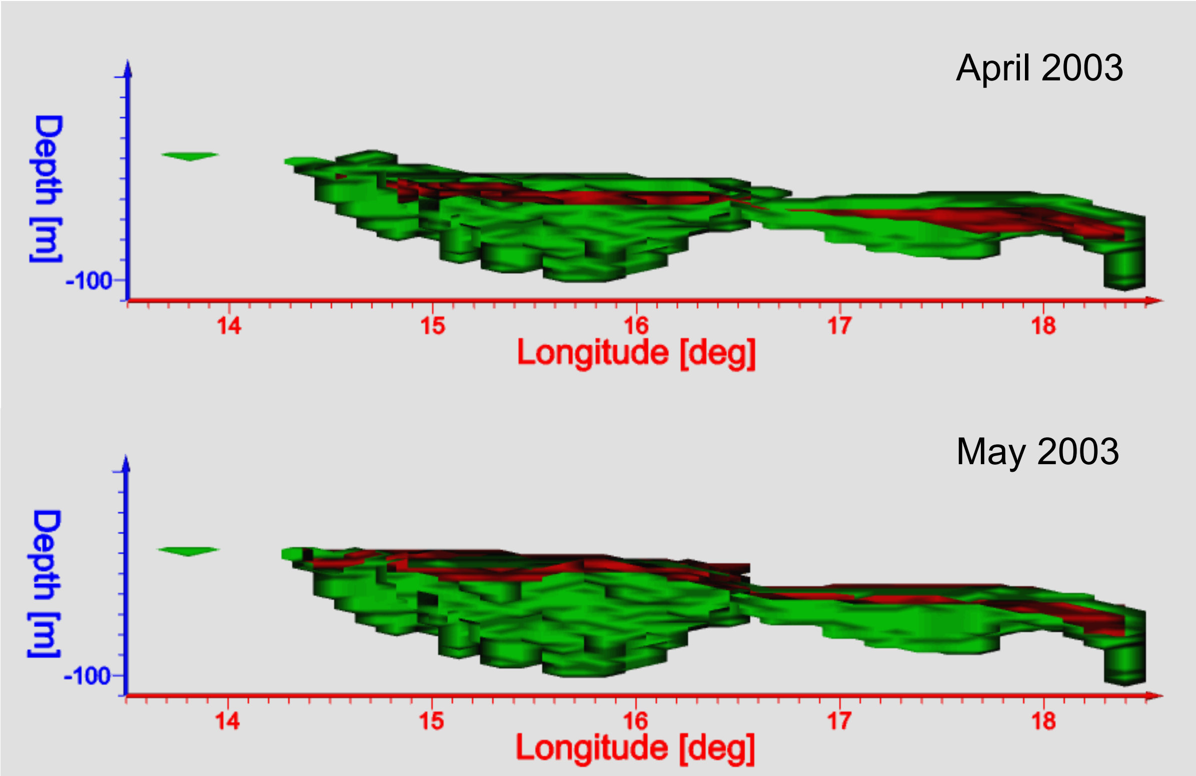


Fig. 28 *2003 April and May – cod egg (green) and sprat egg (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is hydrography model data.*

In April 1995 and 2003 the cod egg habitat is abundant throughout the Bornholm Basin and the Slupsk Furrow below 50 m, starting just above the permanent halocline, and extending all the way to the bottom of the basin. The sprat egg habitat is placed below 50 m as well and is situated in the middle of the cod egg habitat, but do not reach the bottom in April of 1995 and 2003 (Fig. 28).

In May of 1995 the cod egg habitat is greatly reduced and some of this habitat is now found above 50 m in the Bornholm Basin, but is not to be found below 80 m. In the Slupsk Furrow it is situated between 35 – 95 m. The sprat egg habitat is placed in the same region as in April of 1995, just below 50 m and above the permanent halocline. In May 2003 the sprat egg habitat has extended above 50 m and has seemingly increased in volume as has the cod egg habitat, which still extends to the bottom of the basin. The sprat egg habitat does not seemingly lie below 80 m (at the end of the Slupsk Furrow) and is mainly situated above 50 m in the Bornholm Basin (Fig. 28).

4.4.2 Cod egg and adult sprat

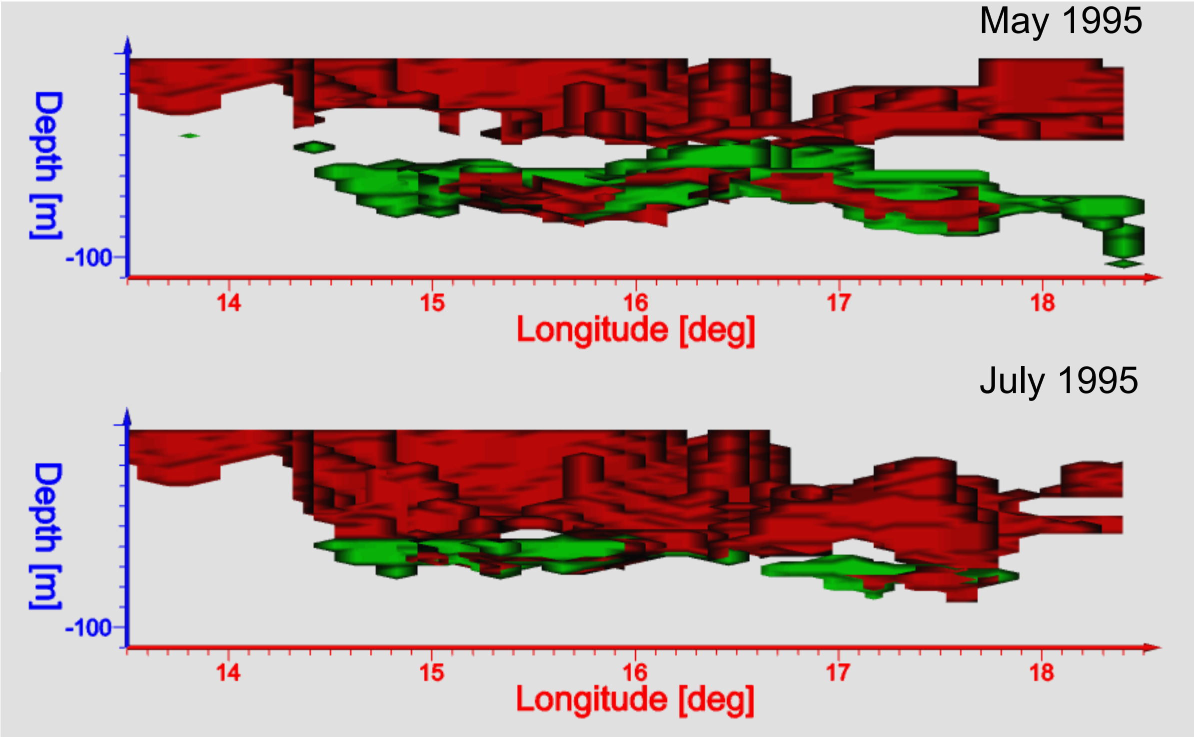


Fig. 29 *1995 May and July – cod egg (green) and adult sprat (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is ICES CTD and oxygen data.*

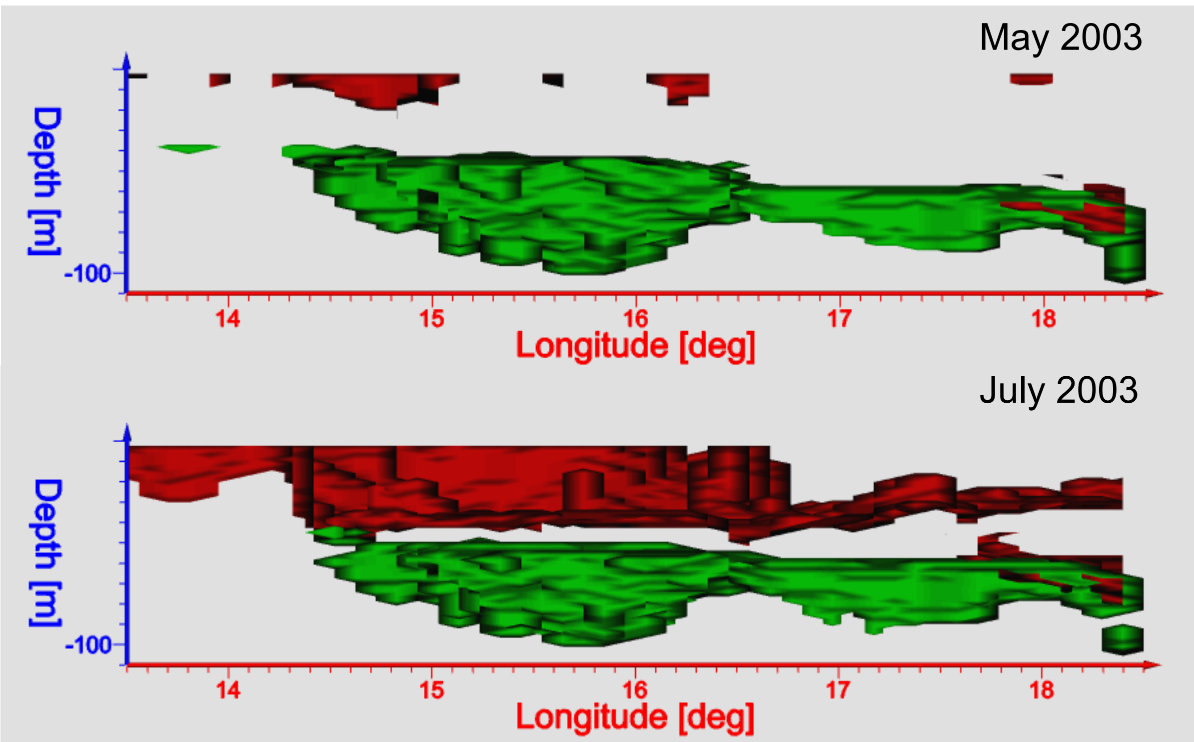


Fig. 30 *2003 May and July – cod egg (green) and adult sprat (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is hydrography model data.*

In May 1995 the adult sprat are mainly located in the surface layer, but are also found in the intermediate water layer, where the cod eggs are located. In July of the same year, the adult sprat habitat volume has increased and is now found down to 70 m in the Bornholm Basin and it is still located in the same area as the cod eggs. It is worth to notice that the cod egg habitat has decreased in volume from May to July. In May 2003 the adult sprat are sparsely distributed in the surface water layer of the Bornholm Basin and it looks like they only interact with cod eggs in the Slupsk Furrow which could be due to the cold winter water layer. The cod egg habitat in May 2003 is of greater volume than in the same month of 1995. In July of 2003 adult sprat are to be found in the surface and intermediate water layers of the Bornholm Basin and the Slupsk Furrow, where they have minimal interaction with cod eggs, which are found below 50 m (Fig. 30).

4.4.3 Adult cod and adult sprat

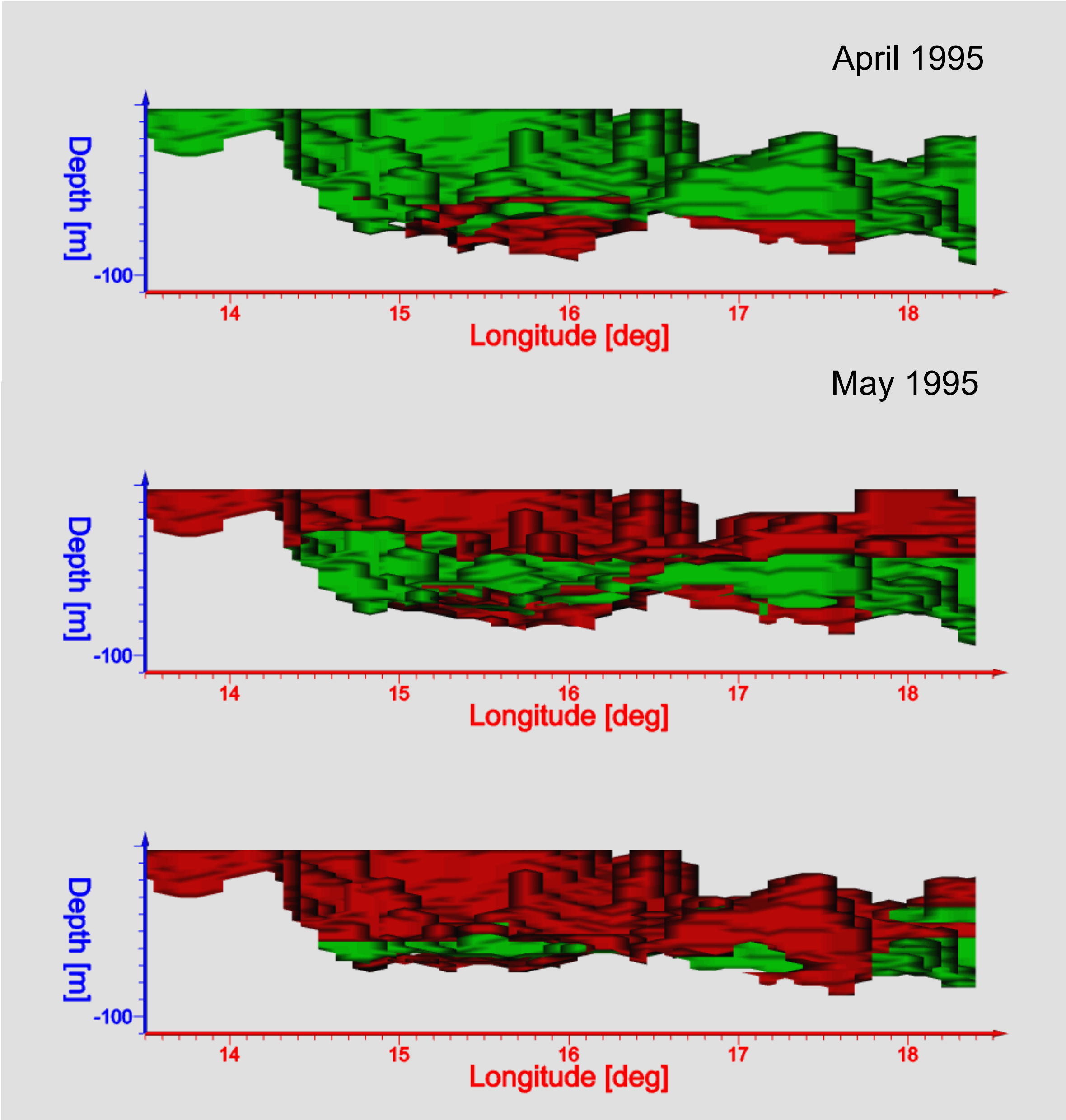


Fig. 31 *1995 April, May and July – adult cod (green) and adult sprat (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is ICES CTD and oxygen data.*

In April 1995 adult cod are found in almost the entire Bornholm Basin and the Slupsk Furrow, though none are found below 80 m. In the same month the adult sprat habitat is situated in the warmer intermediate and bottom water layers, between 50-80 m. In May of 1995 adult cod are found between 30-70 m in the Bornholm basin and the Slupsk Furrow, while the adult sprat habitat extends throughout most of the basin and the Slupsk Furrow down to about 85 m. In July of 1995 adult cod are found in the surface and intermediate water layers of the Bornholm Basin and the Slupsk Furrow, but not below 70 m. Adult sprat are dispersed throughout the basin and the Slupsk Furrow, and also they do not journey below 70 m in the Bornholm Basin (Fig. 31).

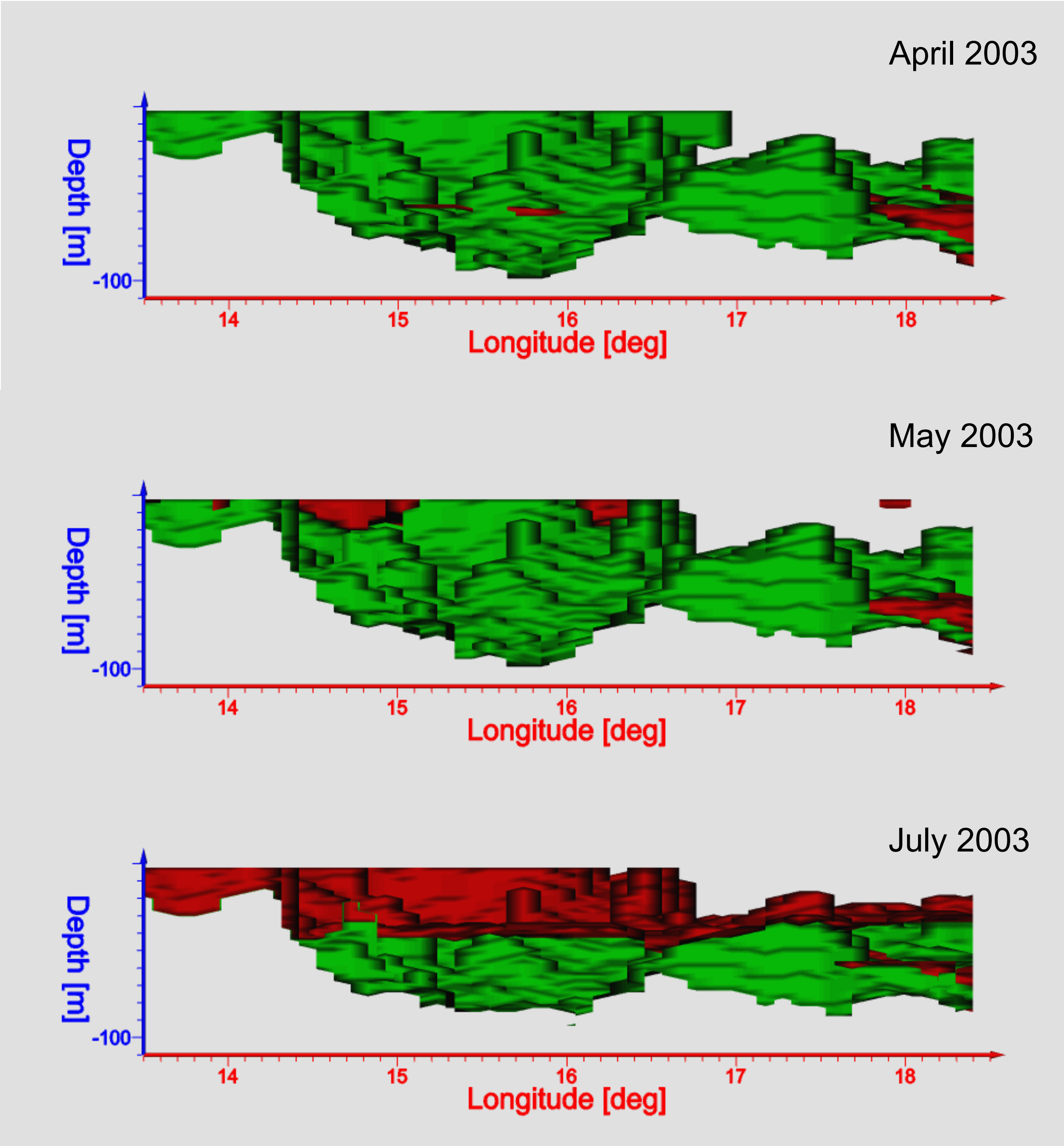


Fig. 32 *2003 April, May and July – adult cod (green) and adult sprat (red) habitat in the Bornholm Basin and the Slupsk Furrow. Applied hydrography is hydrographical model data.*

April 2003 looks different than the same month in 1995, adult cod are again distributed throughout the basin and the Slupsk Furrow but now their habitat stretches all the way to the bottom, while adult sprat are only found in the warmer water around and below the permanent halocline (60 m) in the same area.

In May of 2003, compared to the same month in 1995, the adult cod habitat has dispersed throughout the entire Bornholm Basin and the Slupsk Furrow, stretching all the way to the bottom, while the adult sprat are sparsely distributed in the surface layer of the Bornholm

Basin and in the bottom water layer of the Slupsk Furrow (close to Gdansk Deep). Compared to July of 1995, the adult cod aggregate between 30 – 90 m of depth in the Bornholm Basin in July of 2003, and the same takes place in the Slupsk Furrow. Adult sprat, compared to May 2003, are now keeping to the more surface layers from 0 – 40 m of the Bornholm Basin and a little deeper (60 m) in the Slupsk Furrow.

5 MANAGEMENT IMPLICATIONS

Mapping of essential fish habitats can be an important element for bringing ecological relevant maps into a spatial planning and thus bridge the gap between fisheries management and marine spatial planning. According to the US Magnuson-Stevens Act, an *essential fish habitat* (EFH) is defined as "*those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity*" (Magnuson-Stevens Act 16 U.S.C. 1801 et seq). This report demonstrates the use of two- and three-dimensional mapping of individual life stages spatial and temporal distribution for the definition of an Essential Fish Habitat. In the following the results from this approach will be discussed with respect to their impact on our understanding of physical and biological processes. The application of such ecologically relevant habitat maps and their importance for marine spatial planning and management in the Baltic Sea will also be discussed.

5.1 Spatial management of Cod in the Baltic Sea

A summer ban (end of May to 1 September) has since 1994 been enforced for cod-directed fisheries in the Baltic Sea in order to reduce fishing mortality. In addition, the closure of a central part of the main spawning area in the Bornholm Deep has been enforced for all fisheries during the main spawning seasons since the mid-1990s to enable undisturbed spawning. In 2005 the closed area was extended to a year round closure of central part of the main spawning area in the Bornholm Basin and smaller areas in the Gotland and Gdansk basins (see figure 33). In 2006 the area closures were enforced from 1 May to 31 October, while the closed period for cod-directed fisheries was scheduled from 15 June to 14 September, with 27 days extra closure to be distributed individually by the member states. In the western Baltic the seasonal closure covered the period from 15 March to 14 May and an additional 30 days of closure, to be allocated individually by the member states (Anon 2005; ICES 2006a).

In this report, it has been demonstrated that the habitat distributions of most life stages of cod and sprat are strongly related to the hydrographic conditions and therefore subject to extensive spatial and temporal variability. Together with other evaluation studies (e.g. Hinrichsen et al. accepted), this report therefore indicates that the 1995-2003 closed area for fishing in the Bornholm Basin did not necessarily ensure undisturbed spawning in all years, although the position of the closure in the centre of the basin was to some degree adequate, although too small in size (ICES 2004). In addition, closure of the area in May might in some cases be too late, as pre-spawning concentrations of cod will gather earlier, increasing the catchability of cod in spring months in both the targeting fishery and as by-catch in the pelagic fishery (ICES 2004)

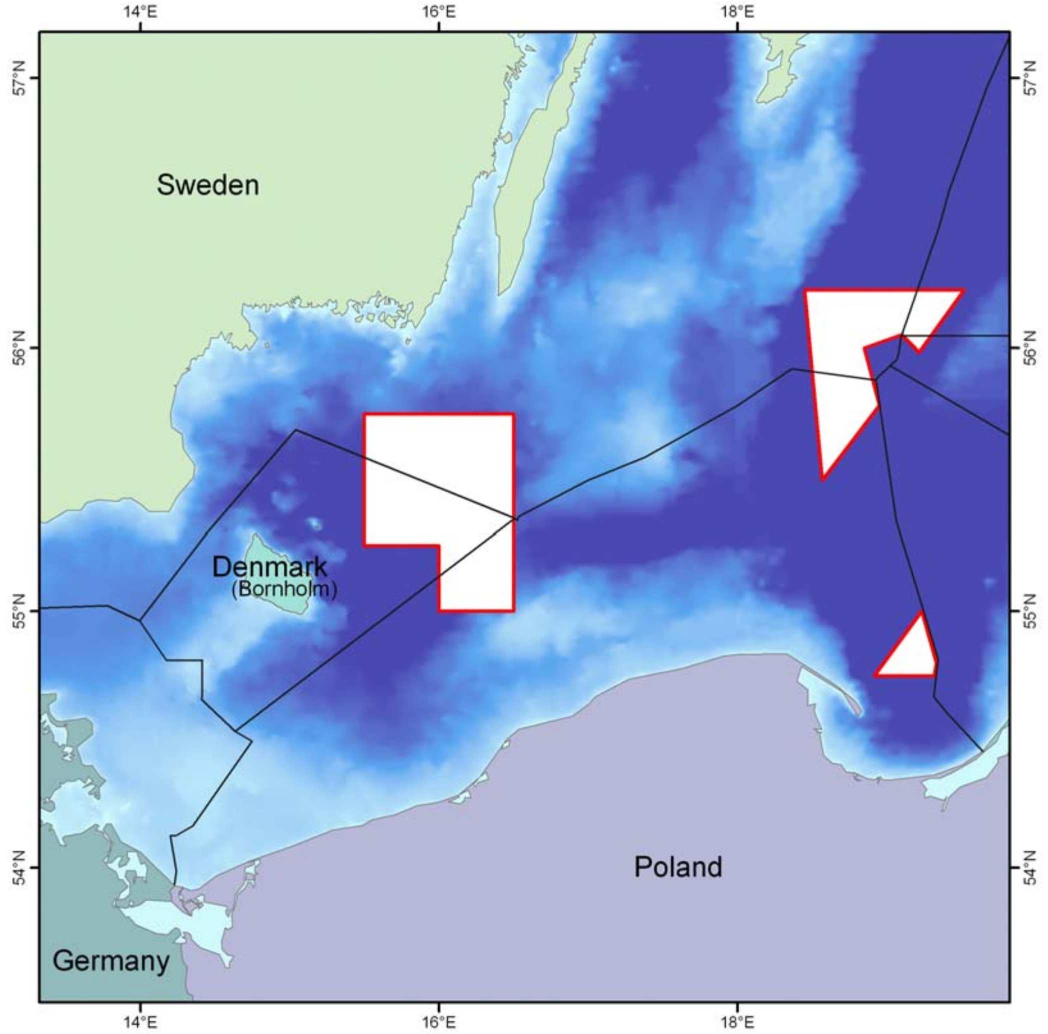


Fig. 33 Current Baltic cod spawning closure. The black lines show the EEZ

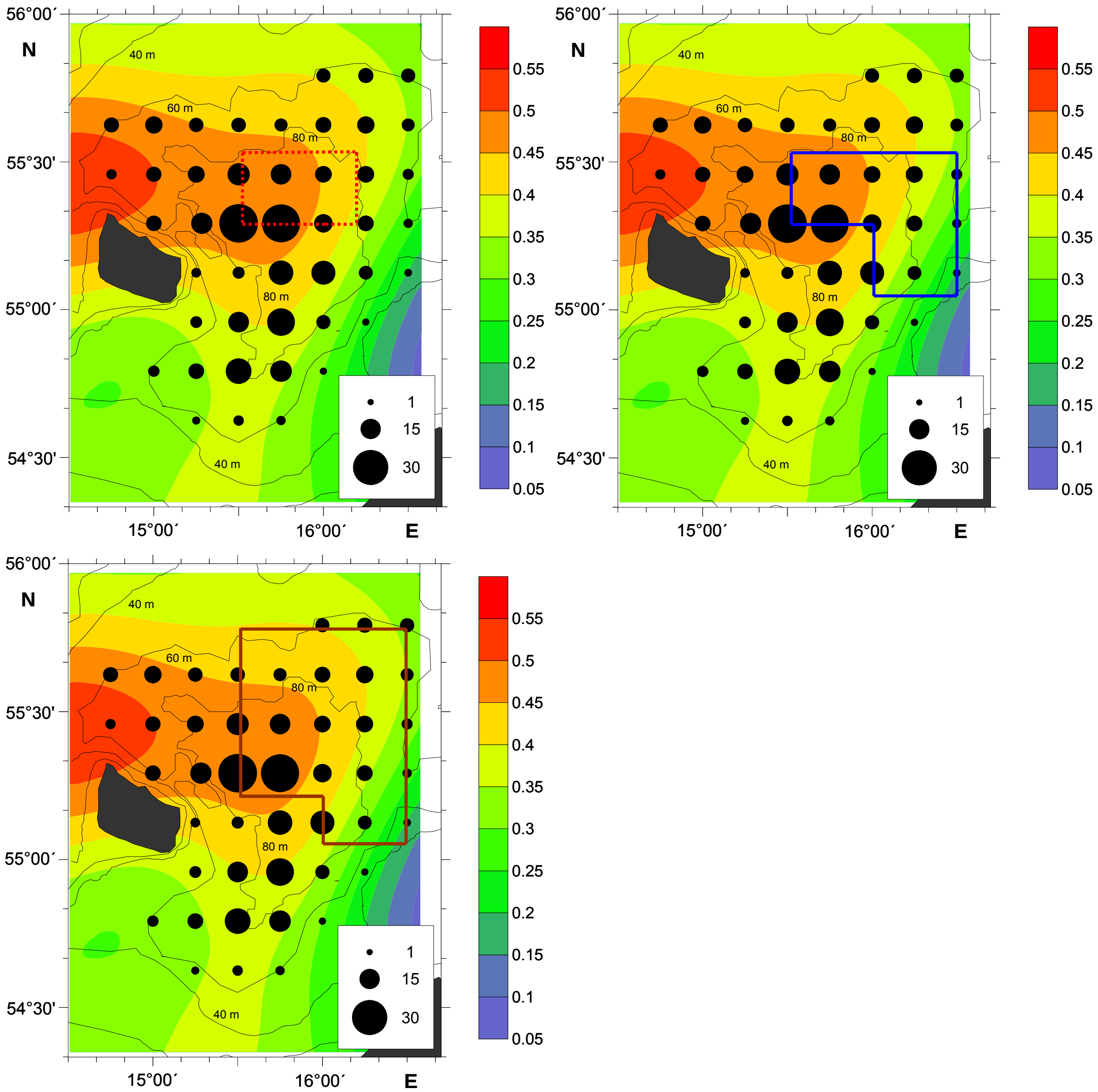


Fig. 34 *Evolution of Bornholm Basin cod spawning closure. Red dotted line enforced May-Aug 1995-2003; blue line enforced May-Aug 2004; brown line enforced year-round in 2005, from 2006 May–Oct. Background colour scale and dots represent mean egg survival.*

Figure 34 shows the evolution of the closed areas in relation to the abundance of cod eggs. It indicates that the area extension conducted in 2004 into eastern slope areas did not cover areas of highest egg abundances and can thus be considered as having limited effect. The area extension in 2005 into northern slope areas suffers from the same shortcoming. Based on the information available it can therefore be argued that, in order to achieve the objective of ensuring undisturbed spawning and to avoid increased catchability and by-catch of Baltic cod in the Bornholm Basin during spawning months, a fixed closure should probably be enlarged spatially and extended temporally. Such an extended spatial closure was proposed by the EU Commission in 2004 (but not implemented), covering the majority of the potential reproductive volume based on historical values (figure 35).

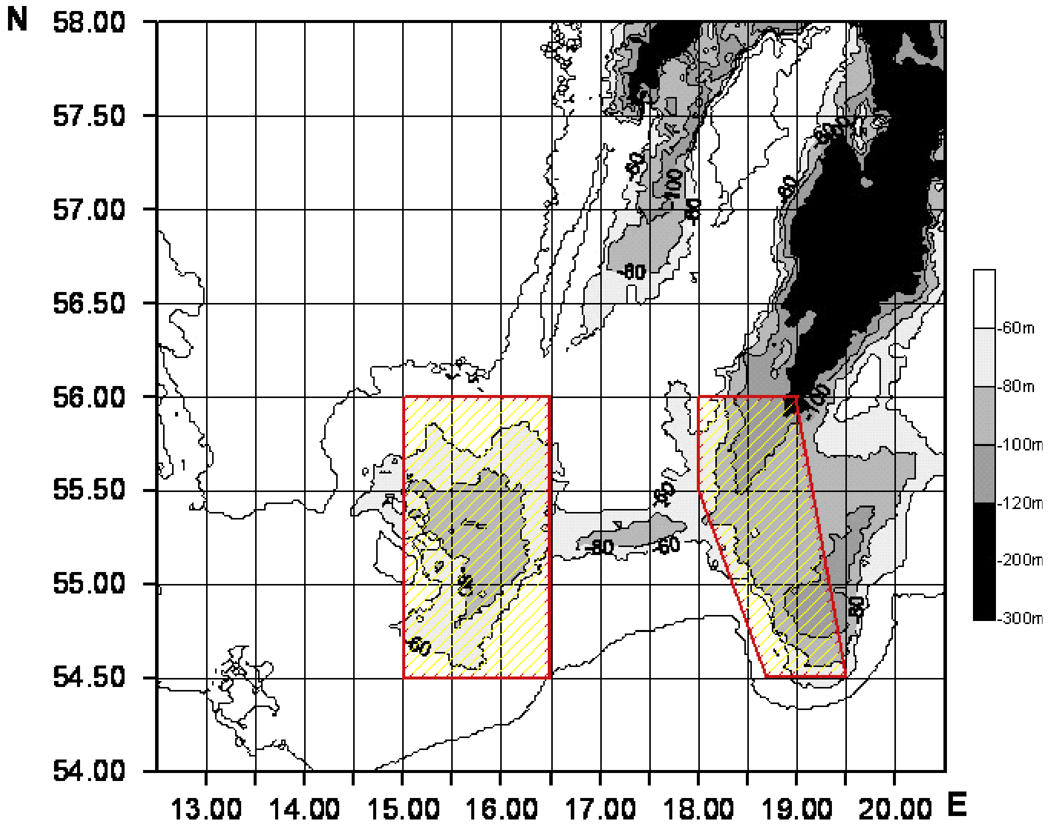


Fig. 35 *Area proposed by the EU Commission (in 2006) for closure of the Bornholm Basin to ensure undisturbed spawning and reduced by-catch of pre-spawning cod concentrations.*

5.1.1 Baltic Essential Fish Habitats: Gaps in knowledge - The juvenile stage

In the Baltic Sea, there are still some issues to be resolved before an Essential fish habitat concept for cod and sprat may become applicable. One of these issues is the lack of knowledge regarding the distribution of juvenile stages. Within the BALANCE project, initiatives have been taken to resolve this lack of knowledge.

Demersal juvenile cod (Fig. 36) maximise their survival by inhabiting complex bottom habitats consisting of e.g. gravel, cobble, rocky reefs or seagrasses in areas surrounding the Bornholm Basin as well as in many other areas of the Baltic Sea (e.g., Hinrichsen et al. submitted). Consequently, such nursery habitats should be considered essential to the species in the Baltic and managed accordingly.

As a result of monitoring efforts, the knowledge base regarding the distribution of cod eggs, larvae and adult cod is relatively solid. In comparison, not much is known regarding the distribution of juvenile cod in the Baltic Sea. A recent analysis of data from the Baltic Sea International Trawl Survey (BITS) indicates that small juvenile cod (5-10 cm) can be found in many parts of the central Baltic (pers. comm. R. Nielsen, DIFRES). The analysis indicates that there is much variation between the distributions of juveniles in individual quarters and years, but there is a tendency in the first three months of the year for juveniles to be distributed in areas north and south of Bornholm and to a degree also to the east of the island, i.e. in areas surrounding the Bornholm Basin. This indicates that juveniles are likely to be the result of spawning events within the basin, a hypothesis confirmed by back-tracking juvenile drift with a hydrodynamic model (CORE 1998).

Fig. 36 *Juvenile cod (Photo from:* http://www.fishbase.de/Photos/ThumbnailsSummary.php?ID=69, last accessed 21/1- 2008)

There are regular reports of large bycatches of juvenile cod by Baltic fishermen, and a field study was therefore conducted by DIFRES on the island of Bornholm, where five experienced fishermen (employing different gears) were interviewed and asked to identify areas in which (Danish) fishermen, on a regular basis, encounter large numbers of "small" (sizes of up to a few cm) cod. Known sites were drawn onto maps and additional information regarding e.g. seasonal variation was gathered.

The results of the exercise are shown in figure 37. It should be noted that the map indications are in no way exclusive, i.e. they are based on the activities and knowledge of only a small number of fishermen. Furthermore, there are other, more systematic, scientific processes and surveys that have attempted to document distributions of small, juvenile cod. Not included in the map is the general view among the fishermen that small juvenile cod could be found on most slopes in the central Baltic.

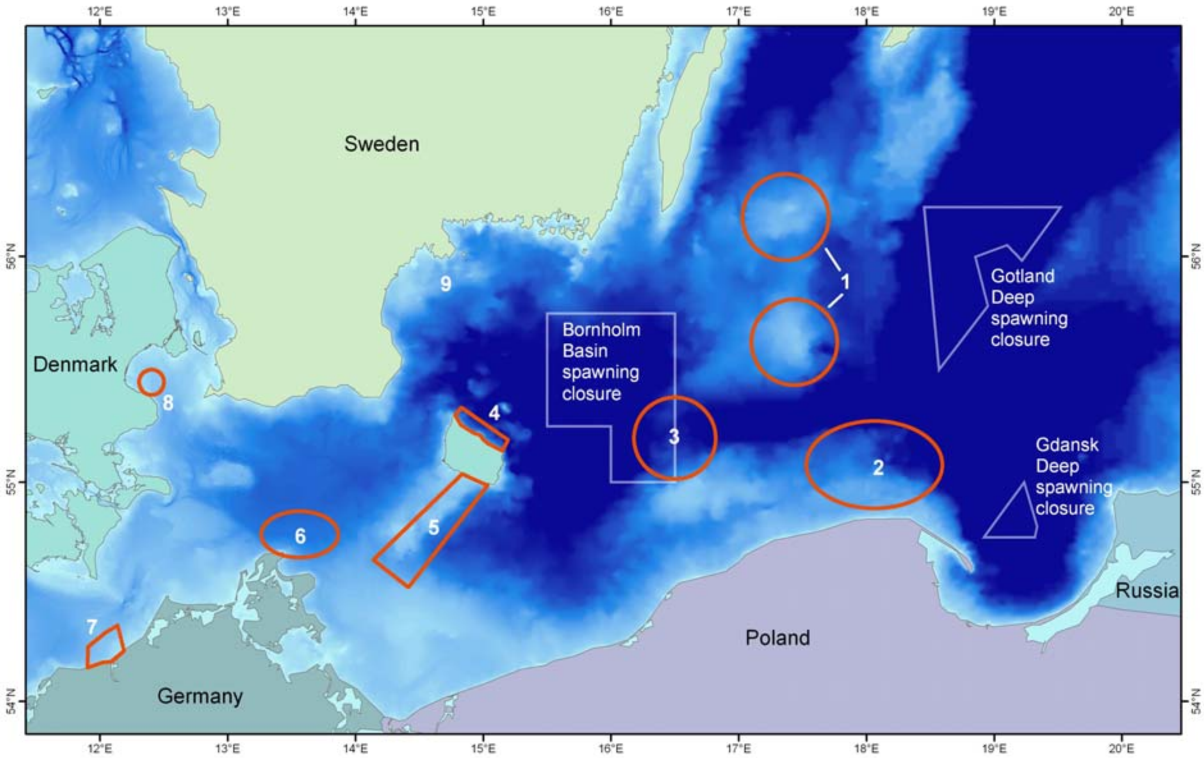


Fig. 37 *Map of areas with abundant juvenile cod, based on interviews with fishermen of Bornholm (pers. comm.).*

1. Middelbanke consists of the northern and southern Midsjö banks. Three of five interviewed fishermen identified these shallow banks as areas where many juvenile cod gather, especially in the autumn months. In addition, bottom trawlers experience good catches of larger cod in the deeper area between the two banks.

2. 90 mile is a fishing area 90 nautical miles from the harbour of Nexø. Two fishermen identified this area as an area where juvenile cod are often encountered (no season mentioned).

3. 42 mile is a fishing area 42 nautical miles from the harbour of Nexø. Two fishermen identified this area as an area where juvenile cod are often encountered (no season mentioned).

4. This area along the northern coast of Bornholm was identified by one fisherman as an area where there were many small juvenile cod in the winter months. Another stated that this might be due to an abundance of shrimp near the shore.

5. The slopes of the bank Rønne banke were identified by four out of five as an area where large numbers of juvenile cod can generally be found, although the juveniles were said to be particularly abundant in winter and autumn months.

6. & 7. These areas to the north of Cape Arkona (Rügen) and near Rostock, respectively, were said by one fisherman to host an abundance of juvenile cod in autumn months.

8. The area Sønakken in Køge Bight is consistently abundant with small, juvenile cod in the spring. According to one fisherman, adult cod found near the east coast of Zealand (DK) begin to migrate eastward, with fishermen following close behind.

9. This area in Hanö Bight in Swedish waters was not mentioned by the interviewed Danish fishermen, but surveys (ICES 2004) indicate that the general area is inhabited by many juvenile cod. This also applies to areas such as the Gdansk Bay, which is outside of the map area.

The impact of closing certain areas for fisheries on the neighbouring areas is still not resolved. By protecting the earliest life stages in the Central Baltic, other life stages may suffer from increased fishing pressure. Therefore, this mapping of juvenile cod habitats should be intensified in the future in order to ascertain the optimal management of the species.

5.2 Future perspectives

5.2.1 Management of Baltic fish stocks based on the essential fish habitat concept

This report indicates that the mapping of the reproductive volume, egg survival and adult distribution in relation to hydrographic conditions is a valuable tool for the definition of potential MPA's and may serve as tool in the definition of essential habitats for the species. However, except for the immobile egg stage data quality on habitat preferences and threshold values is not sufficient, to fully implement the essential habitat approach. In the future, however, the essential habitat mapping approach may prove useful with respect to a range of management initiatives such as real-time area management and vertical zonation.

Real time spawning closures

In contrast to the relatively fixed boundaries and time periods of the present area closures, it can be imagined that a more flexible and effective system of area based management measures, i.e. real-time closures, may be utilised to ensure both undisturbed cod spawning as well as protection of juvenile cod in other areas.

The cod reproductive volume in the Central Baltic is highly dynamic and varies in both size and distribution between years, and a rigid closure is therefore not likely to be an optimal method to ensure undisturbed spawning. In years where the reproductive volume is small in scale and distribution in the Bornholm Basin or even non-existent in the Gdansk Deep and the Gotland Basin, a large-scale closure in the former and any closure in the latter areas may unnecessarily impose strict regulations on fishermen targeting both cod and other species in the area. In contrast, when the reproductive volume is large in scale due to major inflow events, the present fixed closure may prove too small to protect the successfully spawning cod.

Saline inflows into the Baltic are monitored using hydrographic observations in the Western Baltic. As it takes some time for the inflow to impact the deep basins further east, these conditions can be sufficiently evaluated in March/April (after the winter inflow period) and utilised to make qualitative forecasts of potential areas with high egg survival probability in the coming spawning season (ICES 2004). The results of such forecasts may provide the basis for a more science-based, realistic and flexible annual determination of the closures..

Real-time closures for juvenile cod
In regard to the protection of nursery areas (see e.g. Fig. 37, based on interviews with fishermen of Bornholm, real-time closures have largely proven effective in waters surrounding e.g. Iceland or the Faroe Islands. The Faroe Islands introduced a spatial- and fisheries effort-based system of fisheries management in the mid-1990's, including temporal all-gear closures during spawning periods, as well as permanent spatial closures to trawl gear types. However, most relevant to the protection of juvenile cod are real-time closures where fishing is banned for 1-2 weeks if the number of small cod, saithe or haddock constitutes more than 30% of catches. In the Icelandic system, cod spawning areas are closed for several weeks in late winter and extensive nursery grounds are permanently closed for fishing. In addition, the Directorate of Fisheries, together with the Marine Research Institute, may over radio broadcasts temporarily close areas where there are a large number of juveniles at short notice (i.e. hours).

The implementation of such real-time closures to prevent bycatch and discarding of juvenile cod may be a successful strategy, but it requires 1) knowledge about the distribution of juveniles and its variability in space and time, which is at present insufficient and 2) rapid procedures and short routes between science and implementation of policy. The Faroe Islands and Iceland (as well as Norway, where similar strategies are in place) all control the waters within their respective exclusive economic zones, greatly simplifying management of fisheries including implementation of real-time closures.

Several interviewed Bornholm fishermen expressed a wish to implement real time closures in the Baltic (pers. comm.). For most fishermen, a trawl full of juvenile cod represents a sour loss of larger cod in following years, and voluntary reporting of the locations of large numbers of juveniles takes place regularly on an informal basis. However, as the fisheries management regulating most fishing grounds in and adjacent to the Bornholm Basin is determined by the EU Commission, no instruments or jurisdiction are in place locally to enforce any such closures in time for them to be effective.

Vertical zoning of the water column
Adhering to the BALANCE strategy of describing marine spatial planning concepts with real life illustrations from case study areas, the following will demonstrate a purely hypothetical concept for vertical zonation of the water column in the Bornholm Basin, based on the actual respective distributions in the water column of sprat and cod.

Vertical zoning is best known as a tool to protect sensitive benthic species and habitats in relation to vertical structures at seamounts, e.g., Tasmanian Seamounts Marine Reserve in Australia (Commonwealth of Australia 2002, Fig. 38). Vertical zoning is a topic which is gaining momentum in marine spatial planning in European waters, partly fuelled by discoveries of sea mounts and cold water corals as well as the gradual evolution and implementation of an ecosystem-based approach to European fisheries management, where adverse effects of fisheries on the ecosystem and benthic habitats are to be avoided.

There has often been a tendency to regard "commercial fishing" as a uniformly definable activity. However, fishing takes place where the target species is found, and in many cases the target species is a pelagic one that inhabits parts of the water column that are far above the sea floor. In the competition for space in European seas, tools must be developed where possible that can disentangle some of the activities that by tradition alone represent conflicts, such as e.g. nature conservation and fisheries.

Although usually applied to protect the benthos from damage from bottom trawling, the following investigates whether vertical zoning in theory could be applied as a tool to manage two potentially conflicting fisheries in the Bornholm Basin and adjacent areas, namely the large meshed cod fishery and the small meshed sprat fishery.

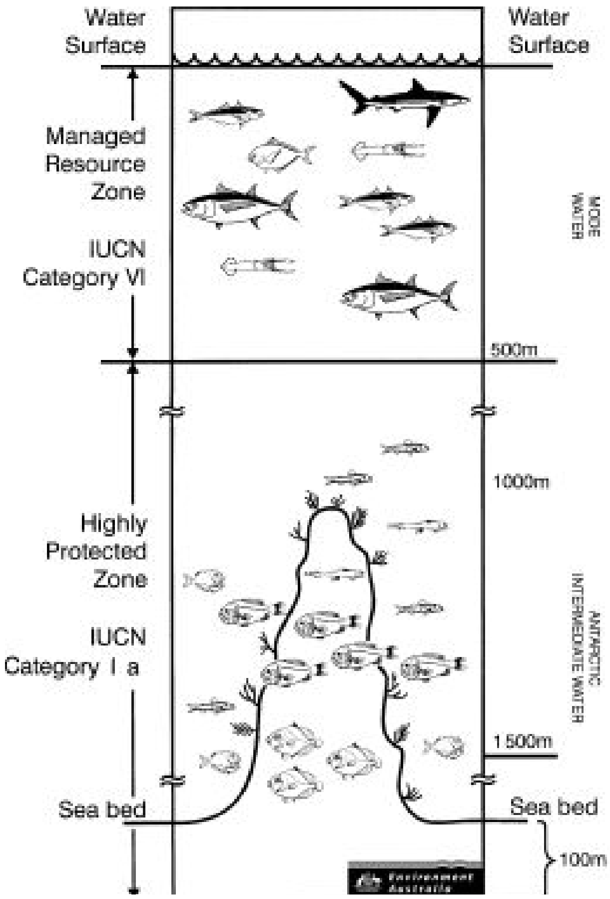


Fig. 38 *Vertical zoning to protect benthic, deep-sea habitats in Tasmania (Source: Commonwealth of Australia 2002).*

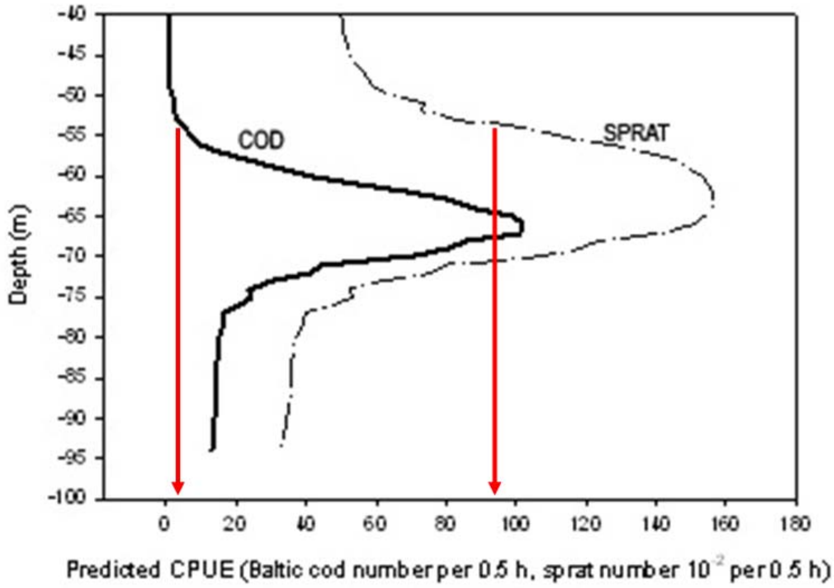


Fig. 39 *Predicted vertical distributions for cod and sprat in the Bornholm basin during spawning. CPUE is relatively high for sprat in the upper part of the water column, where cod CPUE is negligible. Modified from Neuenfeldt & Beyer (2003).*

Due to the small mesh trawls used in fishing for sprat, the fishery is currently not permitted inside the spawning closures in the Bornholm, Gdansk and Gotland Basins from May to October, as pelagic spawning cod may be caught as bycatch in the fishery for sprat. However, as can be seen from the catch per unit effort data depicted in figure 39, in summer months (from June onwards) sprat inhabit shallower parts of the water column than cod. Cod catches remain negligible down to depths of approximately 50 meters, where overlap between the distributions of the two species begins to become more apparent.

It can therefore in theory be imagined that a sprat fishery could take place in the upper 50 meters of the water column without significant risk of cod bycatch (Fig. 40). Transferred into the real world, our distribution maps (Fig. 29-32) generally confirm the differences in vertical zoning between cod and sprat, with sprat being located higher up in the water column compared to cod. However, there is a strong seasonal and inter-annual variation in the patterns with the overlap being stronger during late winter / early spring when sprat tends to move away from the cold, mixed intermediate winter water layer into the warmer deep waters. Similarly, the overlap between both species varies between years e.g. being influenced by inflow water masses, which can either extend the cod habitat into shallower layers due a rise of the halocline or modify the sprat habitat due to changes in water temperature. Similar to horizontal, spatial management measures or real time closures vertical zoning would need to be flexible to account for changes in the vertical extent of habitats as a consequence of changes in water masses (inflows, winter convection) rather than fixed layers. As the detailed changes in vertical habitat patterns are even more difficult to predict than in the horizontal plane the concepts of vertical zoning appears at least for the case of Eastern Baltic cod and sprat hardly applicable.

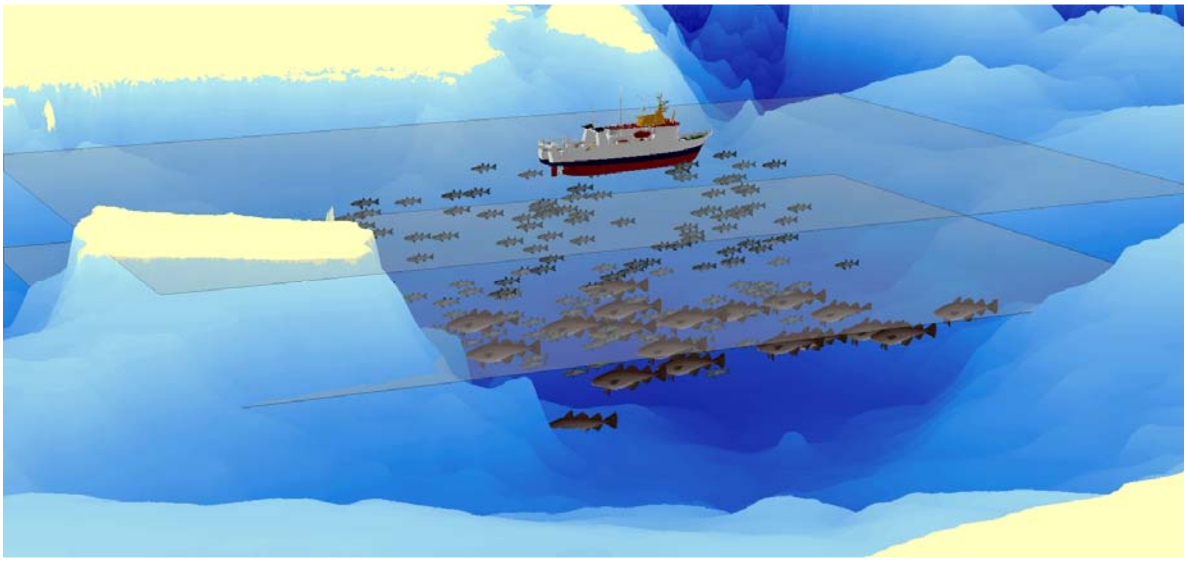


Fig. 40 *The Bornholm basin to the east of Bornholm. Cod spawn in areas below 50 meters, while sprat are also relatively abundant in the upper 50 meters of the water column. Indicated are conceptual vertical fishing zones based on the distribution of cod and sprat in the water column (Based on data from Neuenfeldt & Beyer 2003). ©DIFRES*

There are a number of other very serious caveats that would prevent such a zoning scheme from being applicable in situ. Firstly, biological systems tend to have also a mesoscale horizontal pattern and are never as clearly stratified and definable as they are depicted in figure 40. Thus, significant bycatches of spawning cod in the small mesh sprat fishery cannot be avoided completely even if the general vertical distribution pattern is correctly considered. Secondly, there is the issue of compliance. As can be seen in figure 39, although there are plenty of sprat to be caught in the upper 50 meters of the water column, the catch per unit effort peaks at a depth of approximately 60-65 meters (Neuenfeldt & Beyer 2003). First reactions from both fishermen and fisheries biologists to a presentation of a vertical zoning scheme was that it would be naïve to assume that depth limits for sprat fishing would be respected, given the temptation to lower trawls into depths with higher sprat densities.

6 CONCLUSION AND RECOMENDATIONS

Pelagic habitat maps are a useful tool for broad-scale management of the pelagic marine environment, which has hitherto been difficult to define and describe in spatial terms. These maps contribute to the attainment of insight and a broader perspective on how different marine species co-occur and interact with their ecosystem and variable environment. In addition, 3D-visualisation of elements of the marine ecosystem can be important aids in disseminating and promoting understanding in fisheries management, fisheries ecology, marine spatial planning, science-stakeholder interactions, education, etc.

Results presented in this report are preliminary by nature. The maps are based on data collected for various purposes and have thus not been specifically collected for the mapping of pelagic habitats. As a consequence, the quality of maps for different species and developmental stages varies, depending on the quality and suitability of data for habitat mapping purposes. Whereas the science and data base used to derive habitat thresholds of early life stages of fishes is probably as good as we can get at present, habitat maps for adult stages are on the other hand based on a much weaker foundation, due to a lack of highly spatially and temporally resolved distribution data.

These limitations have a number of implications for the interpretation and use of these maps in zoning and marine spatial planning:

- Meta-databases should be openly accessible to the scientific community and managers to optimise the data collection process in connection with other mapping and spatial planning exercises.

- Maps should not be used for management purposes without consideration of the quality of the underlying data. For instance, pelagic habitat mapping requires high resolution data and is therefore not recommendable in environments for which data is poor.

- Seasonal dynamics of ecosystem components and key species must be captured in development of habitat maps and must be taken into consideration when maps are applied in relation to management. In addition, long term fluctuations in marine systems caused by e.g. climate change may require maps to be updated regularly to ensure that they reflect the system under management.

- To maximise results of mapping efforts and their application, 3-D visualisation software must be tailored for its specific purposes (e.g. pelagic habitat mapping).

- Marine spatial planning requires high quality spatial habitat information, providing a major challenge for the design of effective spatial management strategies. Designated sampling programs and process studies are therefore needed to accomplish this, incl. better co-ordination of existing monitoring efforts (national and international).

- The concept of pelagic habitat mapping should be further developed and integrated into the ecosystem approach to fisheries management, i.e. integrating spatial aspects into management procedures. However, mapping of habitats for overall management of specific species implies the inclusion of those habitats used by the species in respective stages of its entire life cycle (incl. e.g. nursery areas).

- Pelagic habitat mapping may assist in identification and sustainable management of *hot spots* in the water column, i.e. where overlapping distributions of different species might constitute a hazard in relation to e.g. fisheries bycatch of non-target fish or other vulnerable species.

7 ACKNOWLEDGEMENTS

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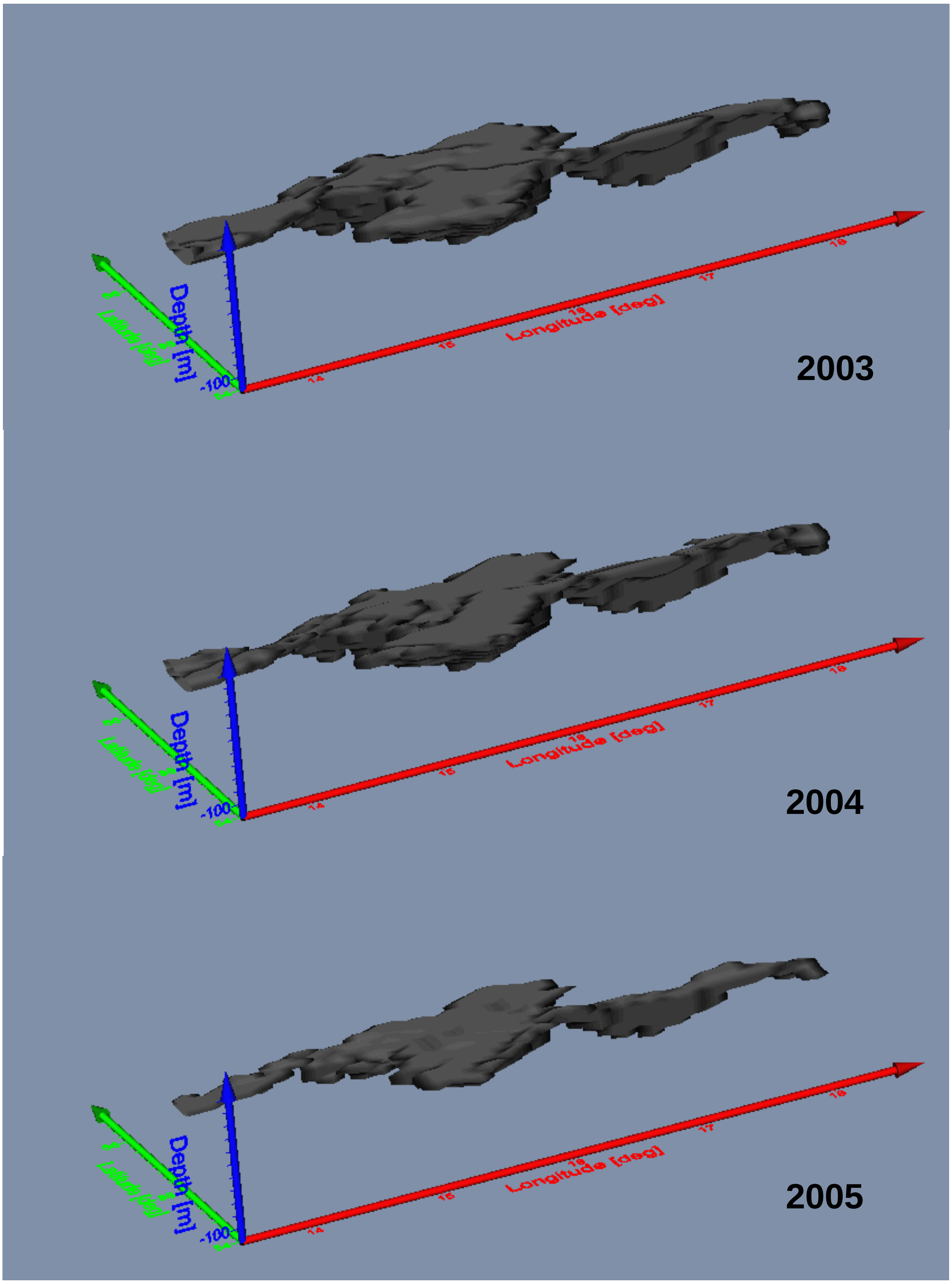
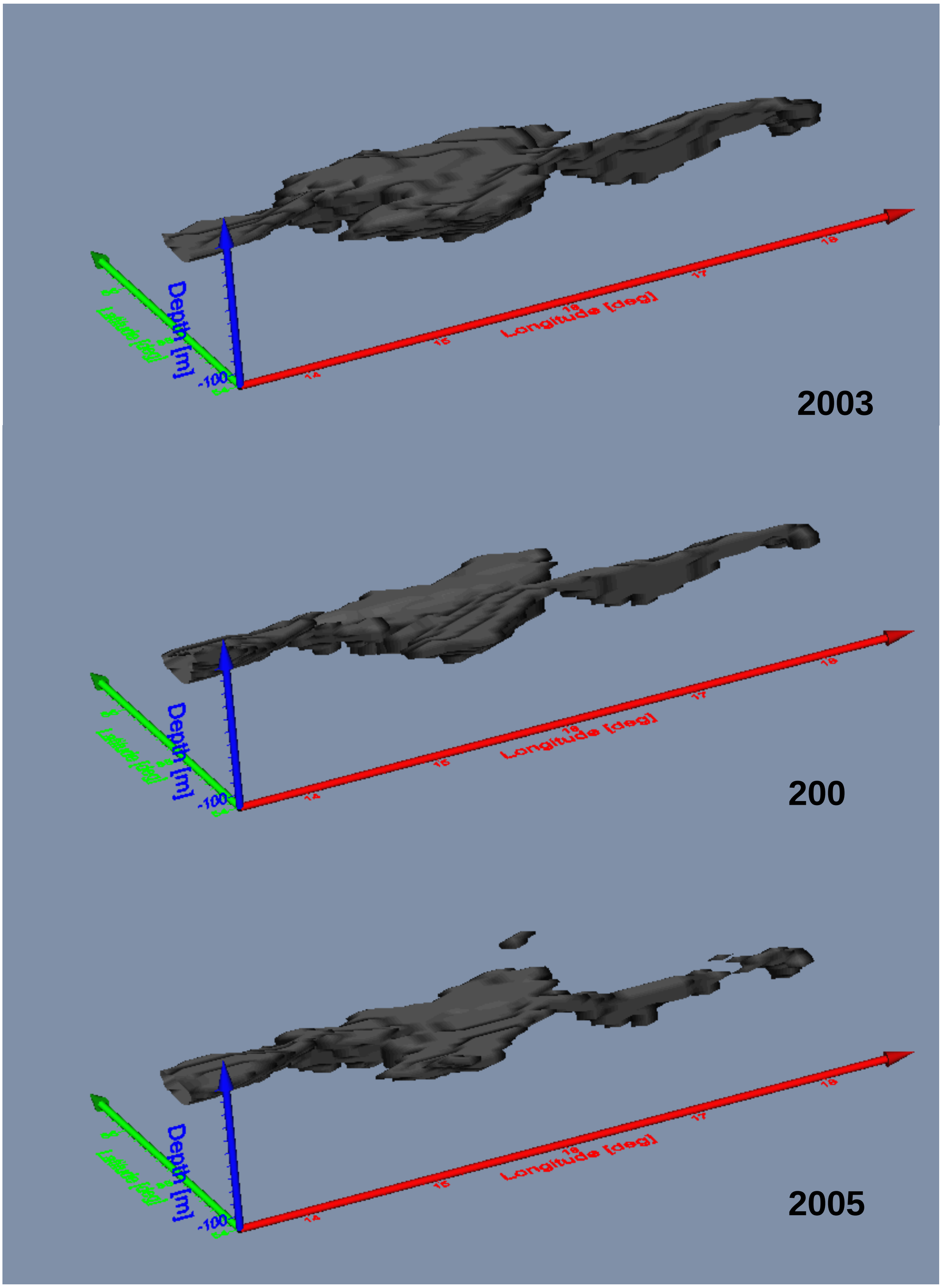
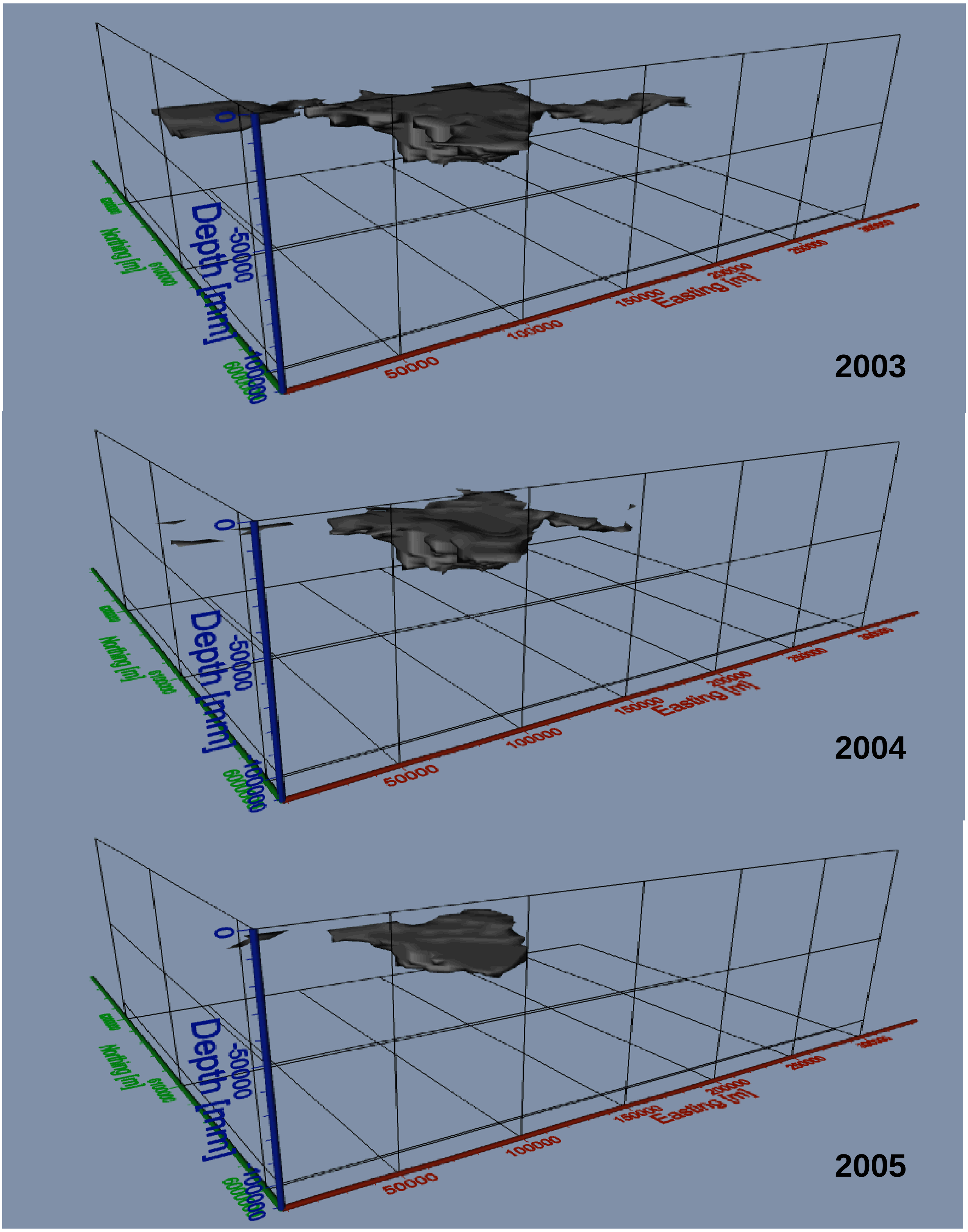
9 APPENDIX



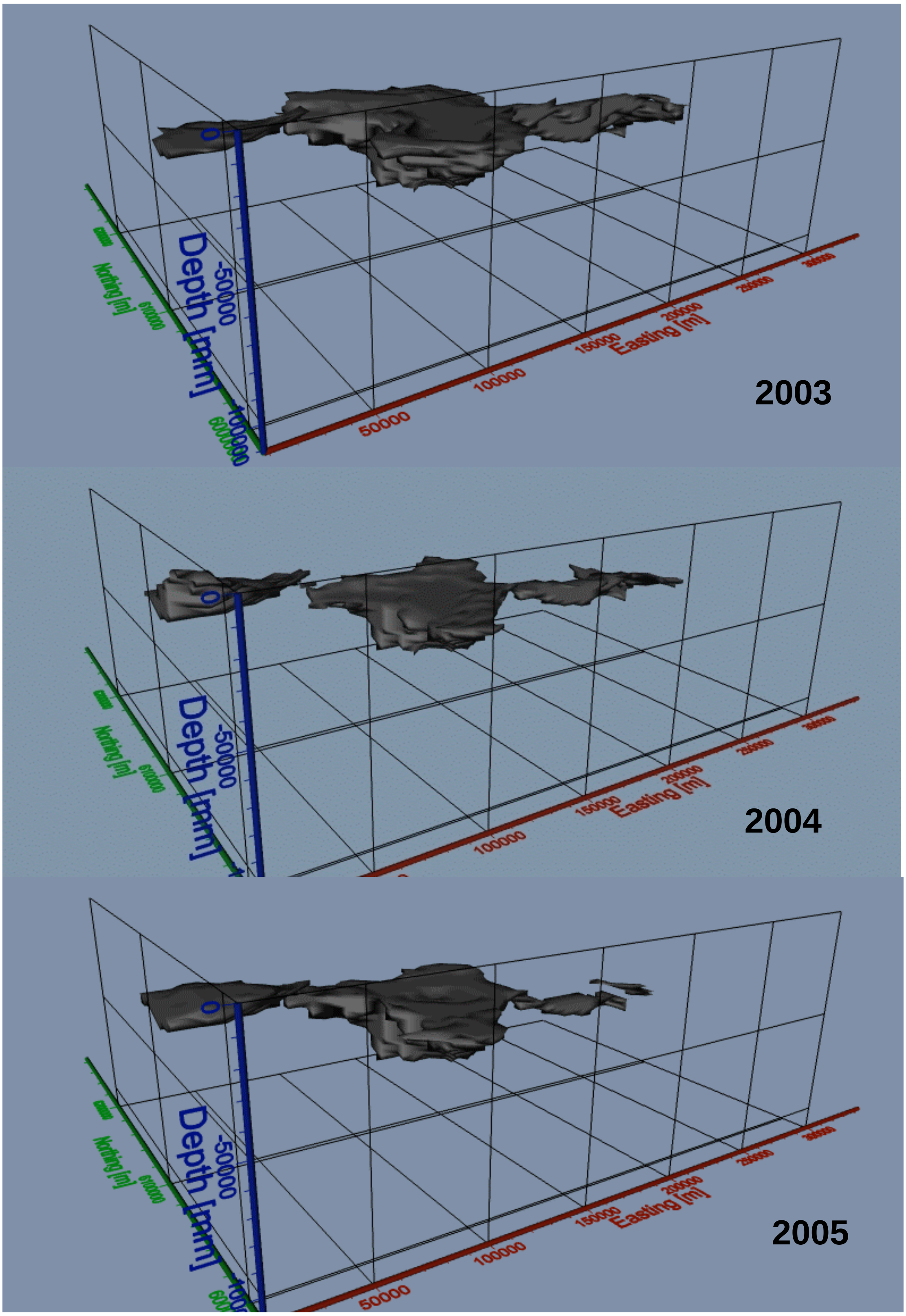
Appendix 1 *Reproductive volume for cod in the Bornholm Basin and the Slupsk Furrow, 2003, 2004 and 2005 (from top to bottom). Hydrographical model data is used for mapping. Thresholds: Temperature > 1.5 ◦C, Salinity > 11 psu, Oxygen > 2 ml/l April.*



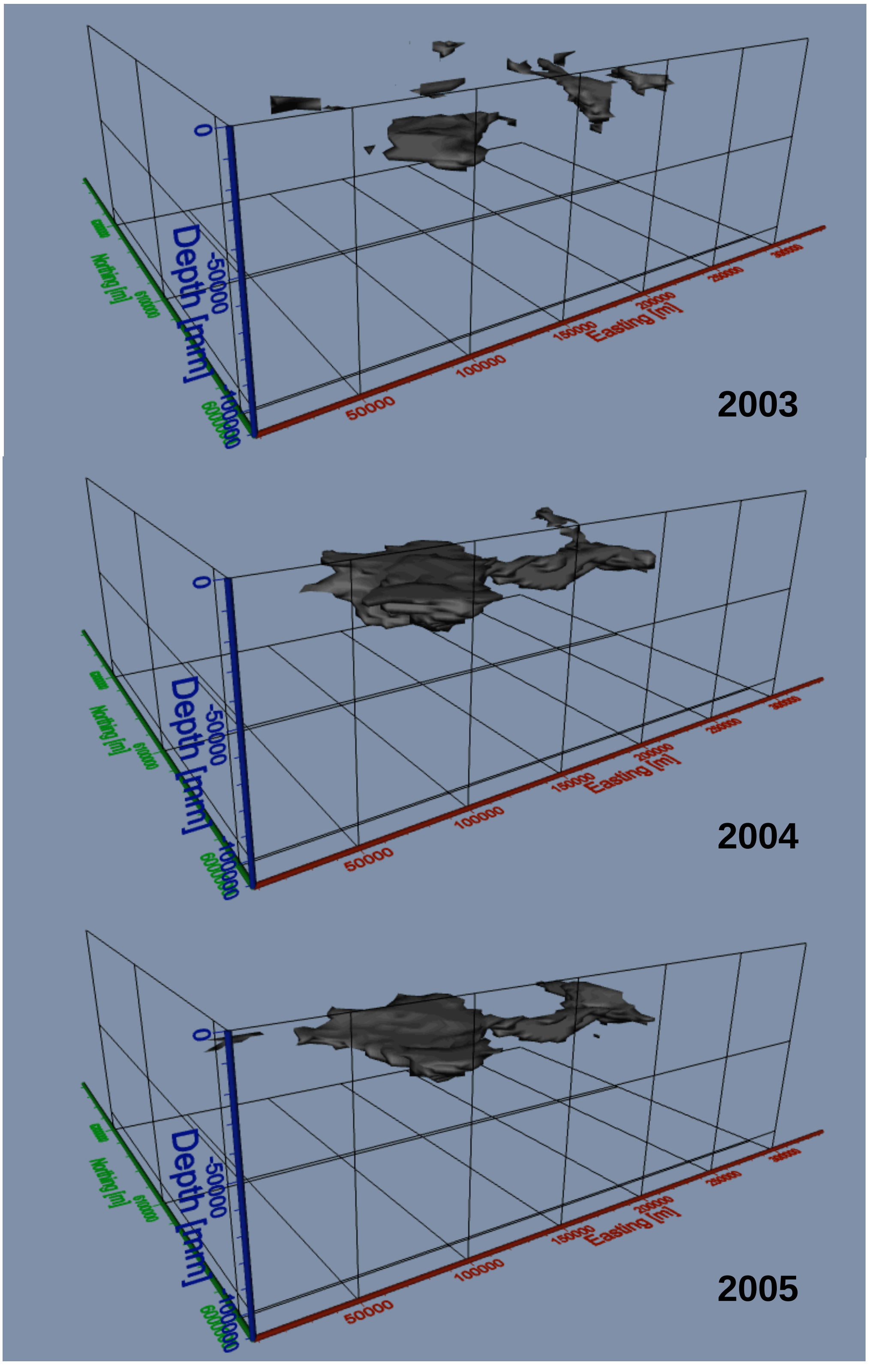
Appendix 2 *Reproductive volume for cod in the Bornholm Basin and the Slupsk Furrow, 2003, 2004 and2005 (from top to bottom). Hydrographical model data is used for mapping. Thresholds: Temperature > 1.5◦C, Salinity > 11 psu, Oxygen > 2 ml/l June.*



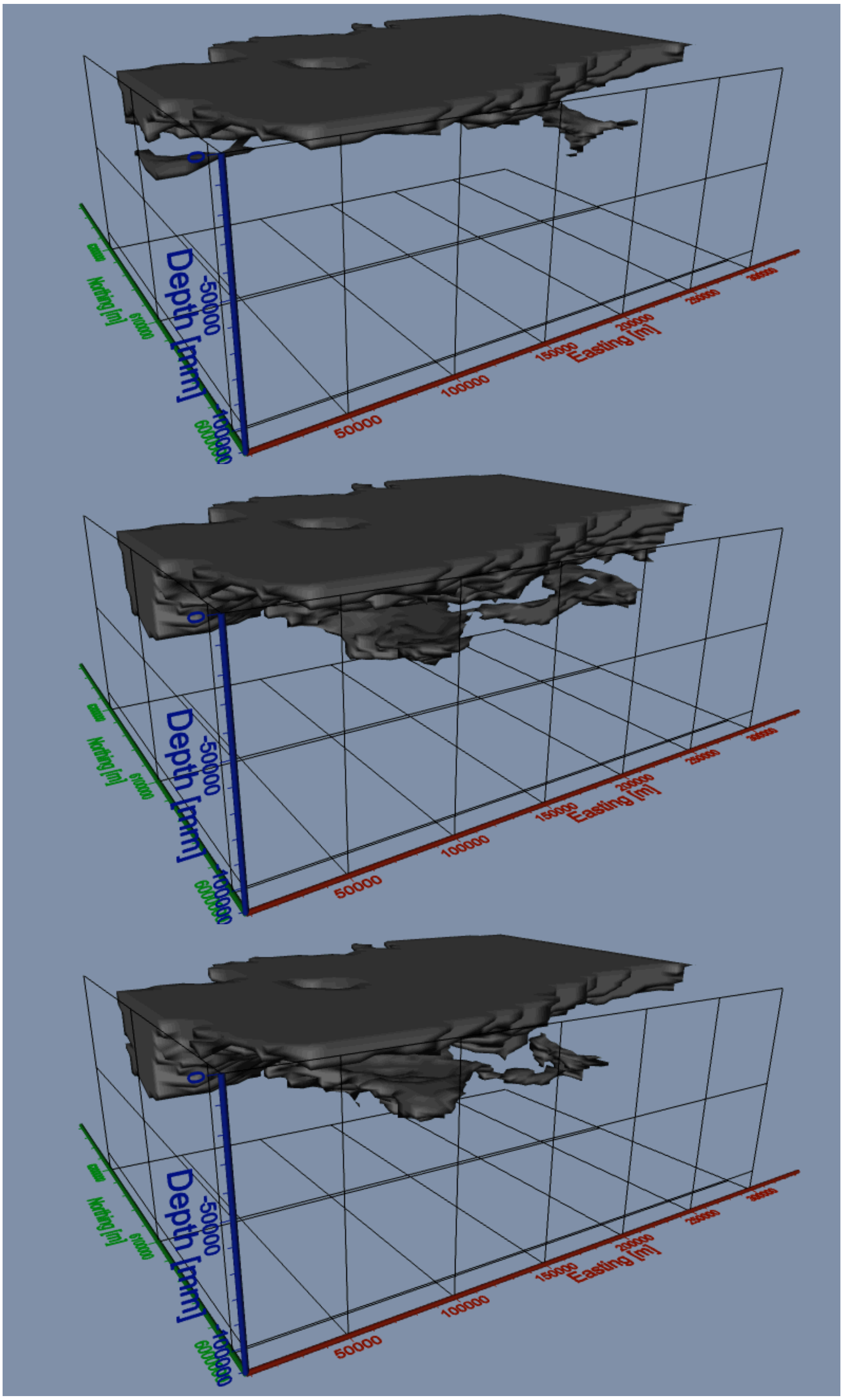
Appendix 3 *2003, 2004 and 2005 April - sprat egg habitat in the Bornholm Basin and the Slupsk Furrow estimated from egg density expressed as σ (mg/cm^3) in April ≥ 10.08 and ≤ 11.76 and in May and July ≥ 7.29 and ≤ 10.31. The applied hydrography is hydrographical model data.*



Appendix 4 *2003, 2004 and 2005 June - sprat egg habitat in the Bornholm Basin and the Slupsk Furrow estimated from egg density expressed as σ (mg/cm³) in April ≥ 10.08 and ≤ 11.76 and in May and July ≥ 7.29 and ≤ 10.31. The applied hydrography is hydrographical model data.*



Appendix 5 *2003, 2004 and 2005 April - adult sprat habitat in the Bornholm Basin and the Slupsk Furrow. The applied hydrography is hydrographical model data. Thresholds: Temperature > 5.1ºC and oxygen saturation > 1 ml/l.*



Appendix 6 *2003, 2004 and 2005 June - adult sprat habitat in the Bornholm Basin and the Slupsk Furrow. The applied hydrography is hydrographical model data. Thresholds: Temperature > 5.1ºC and oxygen saturation > 1 ml/l.*

About the **BALANCE** project:

The BALANCE project aims to provide a transnational marine management template based on zoning, which can assist stakeholders in planning and implementing effective management solutions for sustainable use and protection of our valuable marine landscapes and unique natural heritage. The template will be based on data sharing, mapping of marine landscapes and habitats, development of the blue corridor concept, information on key stakeholder interests and development of a cross-sectoral and transnational Baltic zoning approach. BALANCE thus provides a transnational solution to a transnational problem.

The work is part financed by the European Union through the development fund BSR INTERREG IIIB Neighbourhood Programme and partly by the involved partners. For more information on BALANCE, please see www.balance-eu.org and for the BSR INTERREG Neighbourhood Programme, please see www.bsrinterreg.net

The **BALANCE Report Series** includes:

BALANCE Interim Report No. 1	Delineation of the BALANCE Pilot Areas
BALANCE Interim Report No. 2	Development of a methodology for selection and assessment of a representative MPA network in the Baltic Sea – an interim strategy
BALANCE Interim Report No. 3	Feasibility of hyperspectral remote sensing for mapping benthic macroalgal cover in turbid coastal waters of the Baltic Sea"
BALANCE Interim Report No. 4	Literature review of the "Blue Corridors" concept and its applicability to the Baltic Sea
BALANCE Interim Report No. 5	Evaluation of remote sensing methods as a tool to characterise shallow marine habitats I
BALANCE Interim Report No. 6	BALANCE Cruise Report – The Archipelago Sea
BALANCE Interim Report No. 7	BALANCE Cruise Report – The Kattegat
BALANCE Interim Report No. 8	BALANCE Stakeholder Communication Guide
BALANCE Interim Report No. 9	Model simulations of blue corridors in the Baltic Sea
BALANCE Interim Report No. 10	Towards marine landscapes of the Baltic Sea
BALANCE Interim Report No. 11	Fish habitat modelling in a Baltic Sea archipelago region
BALANCE Interim Report No. 12	Evaluation of remote sensing methods as a tool to characterise shallow marine habitats II
BALANCE Interim Report No. 13	Harmonizing marine geological data with the EUNIS habitat classification
BALANCE Interim Report No. 14	Intercalibration of sediment data from the Archipelago Sea
BALANCE Interim Report No. 15	Biodiversity on boulder reefs in the central Kattegat
BALANCE Interim Report No. 16	The stakeholder – nature conservation's best friend or its worst enemy?
BALANCE Interim Report No. 17	Baltic Sea oxygen maps
BALANCE Interim Report No. 18	A practical guide to Blue Corridors
BALANCE Interim Report No. 19	The BALANCE Data Portal
BALANCE Interim Report No. 20	Pelagic habitat mapping: A tool for area-based fisheries management in the Baltic Sea
BALANCE Interim Report No. 21	Mapping of marine habitats in the Kattegat
BALANCE Interim Report No. 22	E-participation as tool in planning processes
BALANCE Interim Report No. 23	The modelling of *Furcellaria lumbricalis* habitats along the Latvian coast
BALANCE Interim Report No. 24	Towards a representative MPA network in the Baltic Sea
BALANCE Interim Report No. 25	Towards ecological coherence of the MPA network in the Baltic Sea
BALANCE Interim Report No. 26	What's happening to our shores?
BALANCE Interim Report No. 27	Mapping and modelling of marine habitats in the Baltic Sea
BALANCE Interim Report No. 28	GIS tools for marine planning and management
BALANCE Interim Report No. 29	Essential fish habitats and fish migration patterns in the Northern Baltic Sea
BALANCE Interim Report No. 30	Mapping of Natura 2000 habitats in Baltic Sea archipelago areas
BALANCE Interim Report No. 31	Marine landscapes and benthic habitats in the Archipelago Sea
BALANCE Interim Report No. 32	Guidelines for harmonisation of marine data
BALANCE Interim Report No. 33	The BALANCE Conference

In addition, the above activities are summarized in four technical summary reports on the following themes 1) Data availability and harmonisation, 2) Marine landscape and habitat mapping, 3) Ecological coherence and principles for MPA selection and design, and 4) Tools and a template for marine spatial planning. The BALANCE Synthesis Report *TOWARDS A BALTIC SEA IN BALANCE* integrates and demonstrates the key results of BALANCE and provides guidance for future marine spatial planning.