

8 The Baltic Sea

8.1 Ecosystem overview

8.1.1 Ecosystem components

Bottom topography, substrates, and circulation

The Baltic Sea is one of the largest brackish areas in the world. It receives fresh water from a number of larger and smaller rivers while salt water enters from the North Sea along the bottom of the narrow straits between Denmark and Sweden. This creates a salinity gradient from southwest to northeast and a water circulation characterized by the inflow of saline bottom water and a surface current of brackish water flowing out of the area.

The Baltic Sea is characterized by large areas (ca 30%) that are less than 25 m deep, interspersed by a number of deeper basins with a maximum depth of 459 m. The Gulf of Bothnia and the Gulf of Riga are internal fjords, while the Baltic Proper and the Gulf of Finland feature several deep basins separated by sills. The western and northern parts of the Baltic have rocky bottoms and extended archipelagos, while the bottom in the central, southern, and eastern parts consists mostly of sandy or muddy sediment.

Physical and chemical oceanography

The water column in the open Baltic is permanently stratified with a top layer of brackish water separated from a deeper layer of saline water. This separation limits the transport of oxygen from the surface and as a result the oxygen in the deeper layer can become depleted due to breakdown of organic matter.

A strong inflow of new saline and oxygen-rich water from the North Sea can lead to a renewal of the oxygen-depleted bottom water. Strong inflows can occur when high air pressure over the Baltic is followed by a steep air pressure gradient across the transition area between the North Sea and the Baltic. Such situations typically occur in winter. Strong inflows were frequent prior to the mid-1970s, but have since become rarer and as a result salinity has decreased over the last 25 years. Major inflows occurred, however, in 1976, 1983, and 1993. In 2003 an inflow of medium size (200 km³; ICES, 2004) introduced salty, cold, and well-oxygenated water into all main basins of the Baltic Sea, including the Gotland Deep, Figure 8.1.1.1. Since 2003 there have been no major inflow events, and the waters in the deep basins of the Baltic are returning toward the relatively stagnant conditions in the late 1990s and early 2000s. Since the winter and summer inflows in 2003 temperature and hydrogen sulfide have increased, and salinity and dissolved oxygen have decreased in all the deep basins. The bottom temperature in Bornholm Deep is now 1.8°C above the average 1970–1990 (7.96 vs 6.12), and at least 1°C greater in all the other basins except Gotland Deep (0.3°C warmer) (Helcom, 2006).

The Baltic receives nutrients and industrial waste from rivers, and airborne substances from the atmosphere. As a result the Baltic has become eutrophied during the 20th century. In general, nutrient concentrations in the Baltic Sea have not decreased since the mid-1990s. Through the first part of this decade nutrient levels have remained persistently high and may have been increasing further in the most recent years (Helcom 2003, 2006). Low oxygen conditions in deep water affect the amounts of nutrients in the water. Phosphorus is easily released from sediments under anoxic conditions. Nitrogen cycles in deep-water layers also change in anoxic conditions: mineralization eventually produces ammonium, and no oxidation occurs to form nitrates. Consequently, the process of denitrification, which needs oxygen from nitrates, will not occur. The resulting nutrient surplus in the deep-water layers is a potential source of nutrients for the surface layers, where primary production may be further increased (Helcom, 2003). This effect may counterbalance the decrease in nutrient input into some parts of the Baltic Sea. In addition a long-term decrease in silicate concentrations is apparent in most parts of the Baltic, and silicate has recently been limiting the growth of diatoms in the Gulf of Riga in spring. Silicate limitation changes the structure of the phytoplankton community rather than limiting the total production (Helcom, 2002, p. 181).

Furthermore, hypoxia in shallow coastal waters seriously affects biodiversity, and seems to be an increasing problem – especially in the archipelagos of the northern Baltic Sea. These irregular events are caused by local topography, hydrography, and drifting algal mats (Helcom, 2002, p. 166).

Contaminants

The Baltic Sea is severely contaminated, and contamination status is regularly assessed through Helcom (e.g., Helcom, 2002, 2003), where details are available. Whereas DDT pollution has decreased substantially, the decline of PCB and dioxin concentrations continues, but at a slow rate, suggesting that some input of these compounds continue (Helcom,

2002, 2006). Contaminant levels in northern Baltic herring and salmon are so high that consumption is being regulated (Helcom, 2002, 2004).

Broad-scale climate and oceanographic features and drivers

The oceanographic conditions in the Baltic are very much driven by meteorological forcing, influencing the inflow from the North Sea. Significant correlations have been demonstrated between the NAO and total fresh-water runoff, westerly winds, and salinity (Häninnen *et al.*, 2000), ice conditions (Koslowski and Loewe, 1994) and local circulation and upwelling (Lehmann *et al.*, 2002). Climate variability has been shown to affect the dynamics of many of the components of the Baltic ecosystem.

Phytoplankton

The species composition of the phytoplankton depends on local nutrients and salinity and changes gradually from the southwest to the northeast. Primary production exhibits large seasonal and interannual variability (Helcom, 2002, p. 182). Normally, an intense spring bloom starts in March in the western Baltic, but only in May–June in the Gulf of Bothnia. In the southern and western parts the spring bloom is dominated by diatoms, whereas it is dominated by dinoflagellates in the central and northern parts. Over the period from 1979 to 1999 downward trends were found for diatoms in spring and summer, whereas dinoflagellates generally increased in the Baltic proper, but decreased in the Kattegat. Chlorophyll *a*, a proxy indicator for total phytoplankton biomass, also increased in the Baltic proper (Wasmund and Uhlig, 2003).

Summer blooms of nitrogen-fixing cyanobacteria (“blue-green algae”) are normal in the central Baltic, Bothnian Sea, Gulf of Finland, and Gulf of Riga. Such blooms have occurred in the Baltic Sea for at least 7000 years, but their frequency and intensity seem to have increased since the 1960s. Mass occurrences of blue-green algae are often made up of several species. Since 1992 the relative abundance of the most common species has shown a clear trend in the Arkona Basin (southern Baltic) and in the northern Baltic Sea: the toxin-producing species *Nodularia spumigena* has become more abundant compared to the non-toxic *Aphanizomenon flos-aquae*. Red tides (dinoflagellate blooms) are regularly observed, including blooms of the toxic *Gymnodinium mikimotoi* (Helcom, 2002, 2003).

Zooplankton

The zooplankton of the Baltic Sea is dominated by calanoid copepod and cladocerans. The species composition is influenced by the salinity gradient. Generally marine species (e.g. *Pseudocalanus* spp.) prevail in the southern more saline part, while brackish species (e.g. *Eurytemora affinis* and *Bosmina longispina maritima*) dominate in the northern areas. Changes in the species composition of the zooplankton have been linked to changes in salinity and temperature. For the shallower northern areas of the Baltic Sea a decline of large neritic copepods and a increase of species with fresh-water origin, i.e. cladocerans has been related to a reduction of salinity caused by increased river runoff (Viitasalo *et al.*, 1995; Vuorinen *et al.*, 1998; Ojaveer *et al.*, 1998). In the Central Baltic deep basins the abundance and biomass of *Pseudocalanus* spp. has declined since the 1980s, whereas the abundance of *Temora longicornis* and *Acartia* spp. increased (Figure 8.1.1.2). The decrease in *Pseudocalanus* spp. is correlated to the decrease in deep-water salinity resulting from the reduced frequency of inflow events (Möllmann *et al.*, 2000, 2003a). Recent investigations indicate that the combination of low salinity and oxygen conditions in the halocline of the deep basins might have a detrimental effect on the viability of *Pseudocalanus* spp. eggs and nauplii (Schmidt *et al.*, 2003). The increase in *Acartia* spp. and *T. longicornis* during the 1990s is correlated with temperature (Möllmann *et al.*, 2000, 2003a), a result of the persistently strong positive state of the NAO (Alheit *et al.*, 2005; Möllmann *et al.*, 2005). Recent investigations indicate that temperature-dependent resting egg activation is the responsible process behind the temperature–*Acartia* spp. relationship (Alheit *et al.*, 2005). Information on long-term trends of macrozooplankton (e.g. mysids) and gelatinous zooplankton is generally insufficient.

Benthos

The composition of the benthos depends both on the sediment type and salinity, with suspension-feeding mussels being important on hard substrate while deposit feeders and burrowing forms dominate on soft bottoms. The species richness of the zoobenthos is generally poor and declines from the southwest towards the north due to the drop in salinity. However, species-poor areas and low benthos biomasses are also found in the deep basins in the central Baltic due to the low oxygen content of the bottom water. After major inflows a colonization of these areas can, however, be seen.

In the southwestern part of the Baltic the bivalve *Macoma balthica* characterizes the community found on shallow soft bottoms, while a community characterized by the bivalves *Abra alba* and *Arctica islandica* are found in the deeper parts. East of the Dars sill various polychaetes become important in the deeper parts. In the central areas the major parts of the hard bottoms are inhabited by communities of *Fucus vesiculosus* and *Mytilus edulis*, while the fauna of the main part of the soft bottoms has been classified as a *Macoma* community (Voipio, 1981). In the Bothnian Bay and the

central part of the Bothnian Sea the isopod *Saduria entomon* and the amphipod *Pontoporeia spp.* dominate the zoobenthos (Laine, 2003). In shallow areas seaweed and seagrass form important habitats (including nursery grounds) for many animals. The distribution of seaweed and seagrass has changed over time, in some cases in response to eutrophication (Helcom, 2003, p. 114).

Fish

The distribution of the roughly 100 fish species inhabiting the Baltic is largely governed by salinity. Marine species (some 70 species) dominate in the Baltic Proper, while fresh-water species (some 30–40 species) occur in coastal areas and in the innermost parts (Nellen and Thiel, 1996; cited in Helcom, 2002). Cod, herring, and sprat comprise the large majority of the fish community in both biomass and numbers. Commercially important marine species are sprat, herring, cod, various flatfish, and salmon. Sea trout and eel, once abundant, are of very low population sizes. Sturgeons, once common in the Baltic Sea and its large rivers are now extinct from the area. Recruitment failures of coastal fish, e.g. perch (*Perca fluviatilis*) and pike (*Esox lucius*) in Sweden have been observed along the Swedish Baltic coast (Nilsson *et al.*, 2004; Sandström and Karås, 2002). Further studies show that several species have failed in the outer archipelagos and that these failures correlate with low densities of zooplankton.

Cod is the main predator on herring and sprat, and there is also some cannibalism on small cod (Köster *et al.*, 2003a). Herring and sprat in the central Baltic prey on cod eggs, and sprat are cannibalistic on their eggs, although there is seasonal and inter-annual variation in these effects (Köster and Möllmann, 2000a). The trophic interactions between cod, herring, and sprat may periodically exert a strong influence on the state of the fish stocks in the Baltic. To accommodate predator–prey effects in the assessment (e.g., predation by cod on herring and sprat) multispecies models are used to estimate the natural mortality of herring and sprat. Due to the coastal spawning of herring, it is also subject to interactions with fresh-water species in the coastal zone. For example, pikeperch predation on young herring can decrease local herring production considerably (Hansson *et al.*, 1997). Immature cod are also commonly found in shallower areas (Baranova, 1995), but the relative importance of its interactions with coastal dwelling species remains unclear.

Climate-driven changes in the salinity, temperature, and oxygen content of the water affect the recruitment of cod, and the growth and recruitment of herring and sprat. The reduction in salinity and oxygen and the increase in temperature caused by the high NAO index in the 1990s resulted in a reduction of the growth rate of herring, and sprat growth declined during the 1980s and 1990s, probably due to changes in the zooplankton composition and abundance (Rönkkonen *et al.*, 2004; Möllmann *et al.*, 2005) and as a result of increases in food competition (Casini *et al.*, 2006), while the recruitment of herring in the Gulf of Riga and sprat in the entire Baltic increased during the 1990s (MacKenzie and Köster, 2004).

In the past the eastern cod stock spawned in the Bornholm, Gdansk, and Gotland Deeps (Figure 8.1.1.3), but since the end of the 1980s the salinity and oxygen conditions have in general only allowed successful spawning, egg fertilisation, and egg development in the Bornholm Deep (MacKenzie *et al.*, 2000). Cod eggs can only develop successfully if the oxygen concentration is larger than $2 \text{ ml} \cdot \text{l}^{-1}$ and the salinity is higher than 11 psu, and the volume of water where this is fulfilled, the so-called “reproductive volume”, has generally been very low or zero since the mid-1980s in the Gotland and Gdansk Deeps (Figure 8.1.1.4) (MacKenzie *et al.*, 2000). It increased somewhat following the 2003 inflow but has declined towards very low values in most recent years. Furthermore, recruitment to the cod stock declined as the spawning stock was reduced by heavy fishing, the decline in the biomass of *Pseudocalanus spp.* reduced the available food for cod larvae, and the increase in the sprat biomass meant increased predation on cod eggs by sprat.

Hydrographic-climatic variability (i.e., low frequency of inflows from the North Sea, warm temperatures) and heavy fishing during the past 10–15 years have thus led to a shift in the fish community from cod to clupeids (herring, sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.*, 2000) and subsequently generating favourable recruitment conditions for sprat (Köster and Möllmann, 2000a; Köster *et al.*, 2003a; MacKenzie and Köster, 2004).

Birds and mammals

The marine mammals in the Baltic consist of grey (*Halichoerus grypus*), ringed (*Phoca hispida*), and harbour seals (*Phoca vitulina*), and a small population of harbour porpoise (*Phocoena phocoena*). Seals and harbour porpoise were much more abundant in the early 1900s than they are today (Elmgren, 1989; Harding and Härkönen, 1999) where their fish consumption may have been an important regulating factor for the abundance of fish (MacKenzie *et al.*, 2002). Baltic seal populations – harbour seals, grey seals, and ringed seals – are generally increasing. Little is known about recent changes in the abundance of the harbour porpoise (Helcom, 2001).

The seabirds in the Baltic Sea comprise pelagic species like divers, gulls, and auks, and benthic-feeding species like dabbling ducks, sea ducks, mergansers, and coots (ICES, 2003). The Baltic Sea is more important for wintering (c. 10

million) than for breeding (c. 0.5 million) seabirds and sea ducks. The common eider exploits marine waters throughout the annual cycle, but ranges from being highly migratory (e.g. in Finland) to being more sedentary (e.g. in Denmark). Population trends for seabirds breeding within the different countries of the Baltic Sea show an overall decrease for nine of the 19 breeding seabird species. Black-headed gulls are assessed as decreasing throughout the Baltic Sea, whereas the eight other species are considered decreasing in parts of the Baltic Sea. The status of other species, which predominantly breed in the archipelago areas, like common eider, arctic skua, Caspian tern, and black guillemot, is uncertain, and populations of these species may be decreasing in parts of the archipelago areas (ICES, 2003).

8.1.2 Major environmental influences on ecosystem dynamics

Variations in the abiotic environment of the Baltic Sea are strong and depend on climate forcing. Populations of fish are directly affected by this variability with respect to growth and recruitment and also indirectly affected through changes in the zooplankton community

The changes in the Baltic Sea abiotic environment and the food web have been synthesized by the Working Group on Integrated Assessments of the Baltic Sea (ICES, 2008) in Integrated Ecosystem Assessments (IEA) conducted for seven sub-regions of the Baltic Sea: i) the Sound (ÖS), ii) the Central Baltic Sea (CBS), encompassing the three deep basins, Bornholm Basin, Gdansk Deep, and Gotland Basin; iii) the Gulf of Riga (GoR), iv) the Gulf of Finland (GoF), v) the Bothnian Sea (BoS), vi) the Bothnian Bay (BOB), and vii) a coastal site at the Swedish east coast (Subdivision 27) (COAST). The IEA are multivariate analyses of time-series of the physical, chemical, and biological environment – including all trophic levels and biological diversity – and socio-economic factors and treats fish and fisheries as an integral part of the environment.

All seven sub-regions displayed pronounced structural changes (i.e. regime shifts) in the last two to three decades, related to climate, fisheries, and eutrophication. Regime shifts were identified in all multivariate datasets (Table 8.2.1.1). The major period of reorganization in the Baltic sub-regions is at the end of the 1980 (mainly between 1987 and 1988). Several sub-regions (Central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Bay) experienced structural change also during the middle of 1990s, probably related to the major inflow in 1993. Indications exist that a recent shift in ecosystem organization occurred in some sub-regions (Central Baltic Sea, Gulf of Finland, coastal area in SD 27) in the early years of the present century.

Table 8.2.1.1 Summary of the Regime Shifts detected in the 7 ecosystems investigated. Regime shifts were identified from the whole data set for each ecosystem using chronological clustering (with $\alpha=0.01$).

System	Period covered	Regime shift 1	Regime shift 2	Regime shift 3	Regime shift 4
Sound	1979–2005		1987/88	1995/96	
Central Baltic Sea	1974–2006		1987/88	1994/95	
Gulf of Riga	1974–2006		1988/89	1997/98	
Gulf of Finland	1979–2007		1988/89	1995/96	2002/03
Bothnian Sea	1979–2006	1982/83	1988/89		
Bothnian Bay	1979–2006		1987/88	1993/94	
Coastal area in SD 27	1971–2006	1976/1977	1987/88		2004/05 ¹⁾

¹⁾ When using a time-series that covers 1989–2006, Regime shift 4 in the coastal area is identified to be 2003/04.

The Central Baltic Sea showed two relatively stable periods, 1974–1987 and 1994–2006. The first period was characterized by comparatively high cod and herring SSB and recruitment, and high abundances of *Pseudocalanus acuspes*, whereas in the current period the system is sprat-dominated with high abundances of *Acartia* spp. and *Temora longicornis*. Between the two shifts identified, there was a transition period of highly variable climatic and hydrographic conditions and no major inflow events, resulting in low salinity and high temperature values (Figure 8.1.1.5). Whereas the hydrographic conditions, although still variable, are currently similar to the situation in the 1970s, the ecosystem switched to the above-described new state with an abrupt change in 1990. Even though the other investigated systems are characterized by different conditions and are either more influenced by North Sea water (Sound) or by river runoff and fresh-water conditions (e.g. Gulf of Finland, Bothnian Bay), they all underwent a similar shift in the late eighties and reached new ecosystem states.

These changes in the abiotic environment and the food web have affected fish growth and recruitment. The growth rate of herring and sprat diminish with reduced salinity in the eastern and northern part of the Baltic (Flinkman *et al.*, 1998; Cardinale *et al.*, 2002; Möllmann *et al.*, 2003a; Cardinale and Arrhenius, 2000). The recruitment of herring in the Gulf

of Riga and sprat in the entire Baltic are positively related to spring temperatures and the North Atlantic Oscillation index (MacKenzie and Köster, 2004).

The recruitment of the eastern cod stock depends primarily on the volume of water with sufficient oxygen content and salinity available in the deeper basins (Sparholt, 1996; Jarre-Teichmann *et al.*, 2000; Köster *et al.*, 2003a). The present hydrographic situation in the central basins of the southern Baltic suggests that during the spawning season in 2006, the most favourable conditions for cod egg survival are still expected to be restricted to the Bornholm Basin and the Slupsk Furrow, and not in the more eastern basins.

The main drivers of the observed ecosystem changes vary somewhat between sub-regions, but they all include the increasing temperature and decreasing salinity. These are influenced by large-scale atmospheric processes illustrated by the Baltic Sea Index (BSI), a regional calibration of the North Atlantic Oscillation index (NAO) (Lehmann *et al.*, 2002). The change from a generally negative to a positive index in the late eighties was associated with more frequent westerly winds, warmer winter, and eventually a warmer climate over the area. Further, the absence of major inflow events has been hypothesized to be related to the high NAO period (Hänninen *et al.*, 2000). An indication of this is that only two major inflows to the Baltic Sea have been recorded during the high BSI-period since the late 1980s (Fig. 8.1.1.5).

In addition to temperature and salinity, fishing pressure was identified as an important driver for the Central Baltic Sea and Bothnian Sea. For the highly eutrophicated Gulf of Finland, also nutrient loads were found to be an important driver. Trends in nutrient concentration and loading vary between the sub-regions; the concentrations of DIN and DIP decreases in the Sound and Central Baltic Sea, whereas in Gulf of Riga and Gulf of Finland DIP concentration is increasing because of internal loading. In the Bothnian Sea and Bothnian Bay DIN concentration is increasing. In the Bothnian Bay and coastal region the total DIP loading from run-off is also increasing. Although the long-term decrease in salinity is apparent in all sub-regions, the recent trends in salinity differ. In the Gulf of Riga and the Central Baltic Sea, salinity has increased since 2003. In the coastal region of Subdivision 27 salinity is continuing to decrease due to the increased fresh-water input from runoff.

8.2 Human impacts on the ecosystem

8.2.1 The major effects of fishing on the ecosystem

In the Central Baltic cod and sprat spawn in the same deep basins and have partly overlapping spawning seasons. However, their reproductive success is largely out of phase. Hydrographic-climatic variability (i.e., low frequency of inflows from the North Sea, warm temperatures) and heavy fishing during the past three decades have led to a shift in the fish community from cod to clupeids (herring, sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.*, 2000) and subsequently generating favourable recruitment conditions for sprat, thereby resulting in increased clupeid predation on early life stages of cod (Köster and Möllmann, 2000b; Köster *et al.*, 2003b; MacKenzie and Köster, 2004). The shift from a cod- to a sprat-dominated system may thus be explained by differences in the reproductive requirements of both species in a changing marine environment. Additionally, the dominance shift was supported by the continued high fishing pressure on cod (Jarre-Teichmann, 1995).

Coastal commercial and recreational fisheries have also influenced ecosystem structures (Hansson *et al.*, 1997). This impact is generally more local than that of the offshore fishery, however, since most of the coastal fish species are relatively stationary.

8.2.1.1 Bycatch of fish

The total bycatch of fish in the Baltic fisheries is presently unknown. The EU has supported several very recent studies of bycatch, the results of which have been compiled by ICES (2000). These studies primarily concern the major fisheries for cod, herring, and sprat and these have low bycatches. The less important smaller fisheries can have a high proportion of bycatch (Helcom, 2002).

The occurrence of lost nets has been surveyed in areas where gillnet fishing is practiced and lost nets are frequent (www.fiskeriverket.se/miljofragor/pdf/okt-rapp_webb.pdf). Lost gillnets in the Baltic cod fishery are most likely of concern for cod fishing mortality since 30–50% of the landings originate from the net fishery. Experiments show that during the first 3 months, the relative catching efficiency of “lost” nets decrease by around 80%, thereafter stabilizing around 5–6% of the initial level (Tschernij and Larsson, 2003).

8.2.1.2 Bycatch of seabirds and mammals

Fishing nets, in particular set nets, have caused considerable mortality for long-tailed ducks (*Clangula hyemalis*), velvet scoters (*Melanitta fusca*), eiders (*Somateria mollissima*), and black scoters (*Melanitta nigra*). There are also reports of guillemot and razorbill (*Alca torda*) mortality in the driftnet fishery for salmon (Helcom, 2003).

Reports suggest that fisheries bycatches amount to 0.5–0.8% of the porpoise population in the southwestern part of the Baltic Marine Area each year, and 1.2% of the porpoise population in the Kiel and Mecklenburg Bays and inner Danish waters (Kock and Behnke, 1996). Estimates of the harbour porpoise population are uncertain, however, and the number of porpoises bycaught in fisheries is probably underestimated. The loss of porpoises to fishery in the Baltic Marine Area may be too high to sustain the population (ICES, 1997).

Seals have been recorded caught in fyke nets, set nets, and salmon driftnets, but although the recorded data almost certainly underestimate the total number of bycaught seals, the added mortality does not appear to restrain the seal populations from increasing (Helander and Härkönen, 1997).

8.2.1.3 Other effects of fishing on seabirds and mammals

Fishing activities will also affect the seabird community through the discarding of unwanted catch and fish offal. Studies indicate, for example, that over 50% of the offal discarded in the Baltic Marine Area will be consumed by seabirds (ICES, 2000).

8.2.2 Other effects of human use of the ecosystem

Human society uses the Baltic for many purposes including shipping, tourism, and mariculture. Overviews are given in Helcom (2002, 2003) and Frid *et al.* (2003). Shipping may pose threats due to transport and release of hazardous substances (e.g., oil) and non-indigenous organisms. The former would likely have only relatively short-term effects (e.g., direct mortality of individuals in a restricted time and area), whereas the latter are more likely to have longer-term and more widespread effects (e.g., influences on energy flows or species interactions in food webs).

8.2.3 Conclusions

8.2.3.1 Short term

The WG was unable to identify strong environmental signals likely to have implications for short-term management advice.

8.2.3.2 Medium term

The primary driving forces for the observed regime shift in all sub-regions are decreasing salinity and increasing temperature. Both are consequences of climate change. For the Baltic Sea region, future climatic change is expected to involve decreased frequency of inflow of saline water from the North Sea and increasing run-off due to precipitation. Both of these have contributed, and will continue to contribute to the decreasing salinity in the Baltic Sea. The changes in the Baltic ecosystem identified by WGIAB (ICES, 2008) can be expected to continue.

Depletion of cod in the Baltic has contributed to a shift in the trophic structure from a cod-dominated system to a clupeoid-dominated system. This has been accompanied by shift in zooplankton and phytoplankton, which may be related to a reduced inflow of saline water, higher average temperatures, and to increased precipitation due to a consistently high NAO in the 1990s. There is no evidence to suggest that the current situation will reverse, given the low level of cod biomass and lack of major inflow events.

8.2.4 References

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Intensity of major Baltic inflows 1946-2003

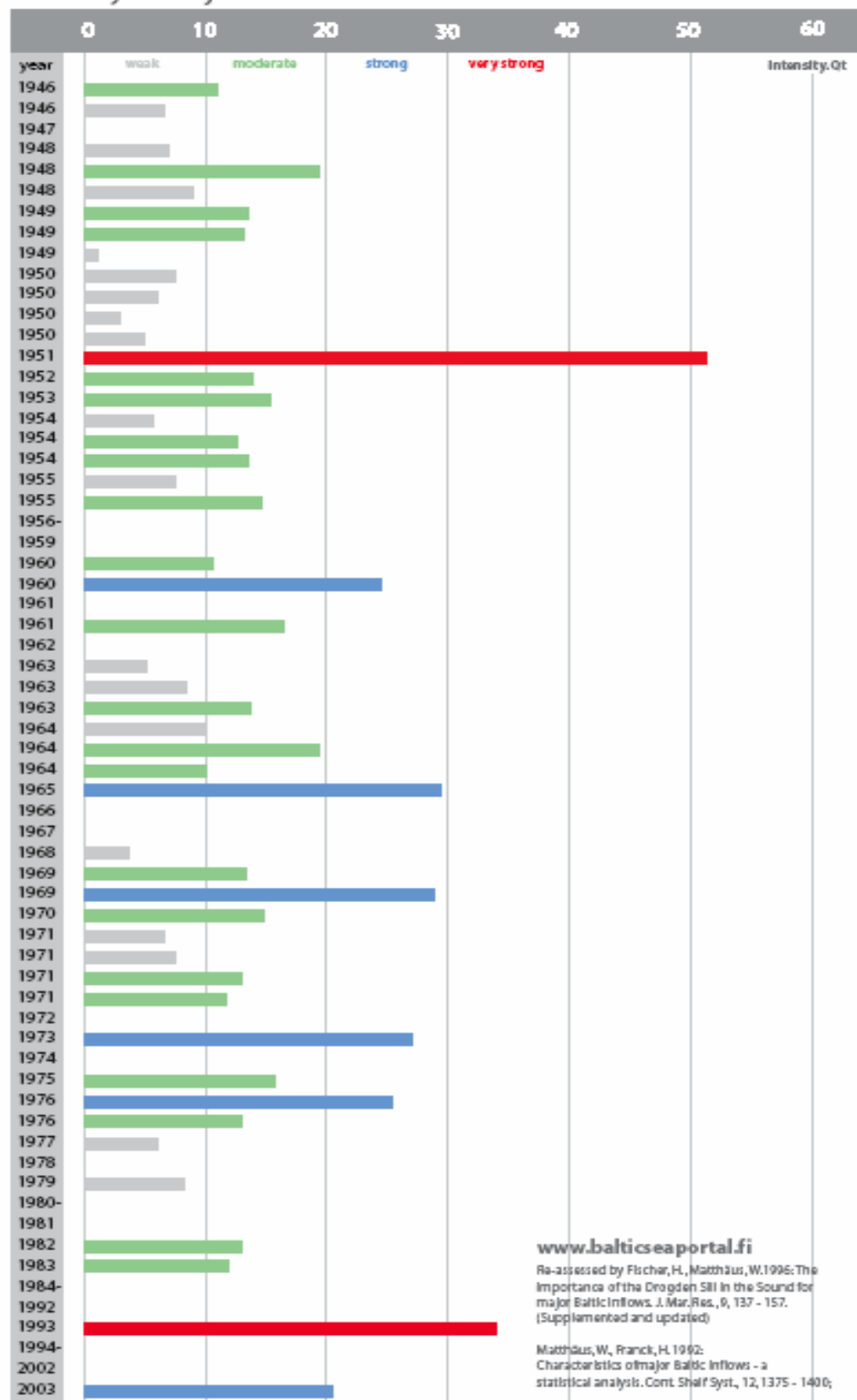


Figure 8.1.1.1 Intensity of inflows to the Baltic, 1946–2003.

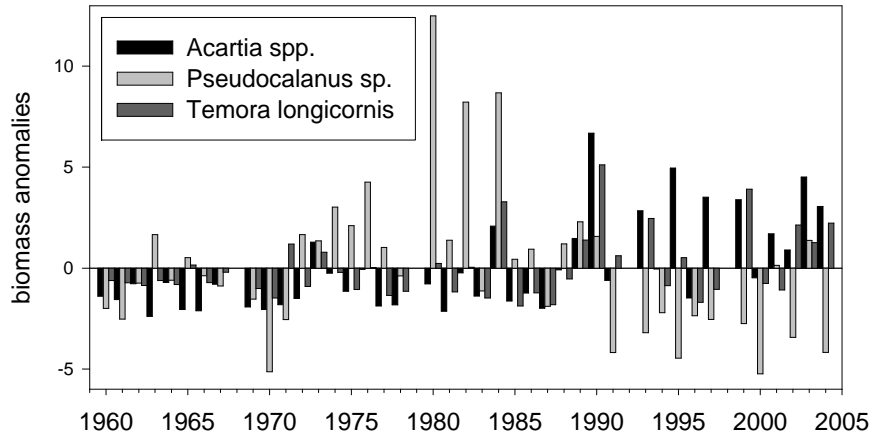


Figure 8.1.1.2 Time-series on spring biomass ($\text{mg}\cdot\text{m}^{-3}$) anomalies for the dominant mesozooplankton species in the Eastern Baltic, i.e. the calanoid copepods *Acartia* spp., *Pseudocalanus* spp., and *Temora longicornis*; data are from the Latvian Fish Resource Agency LatFRA in Riga.

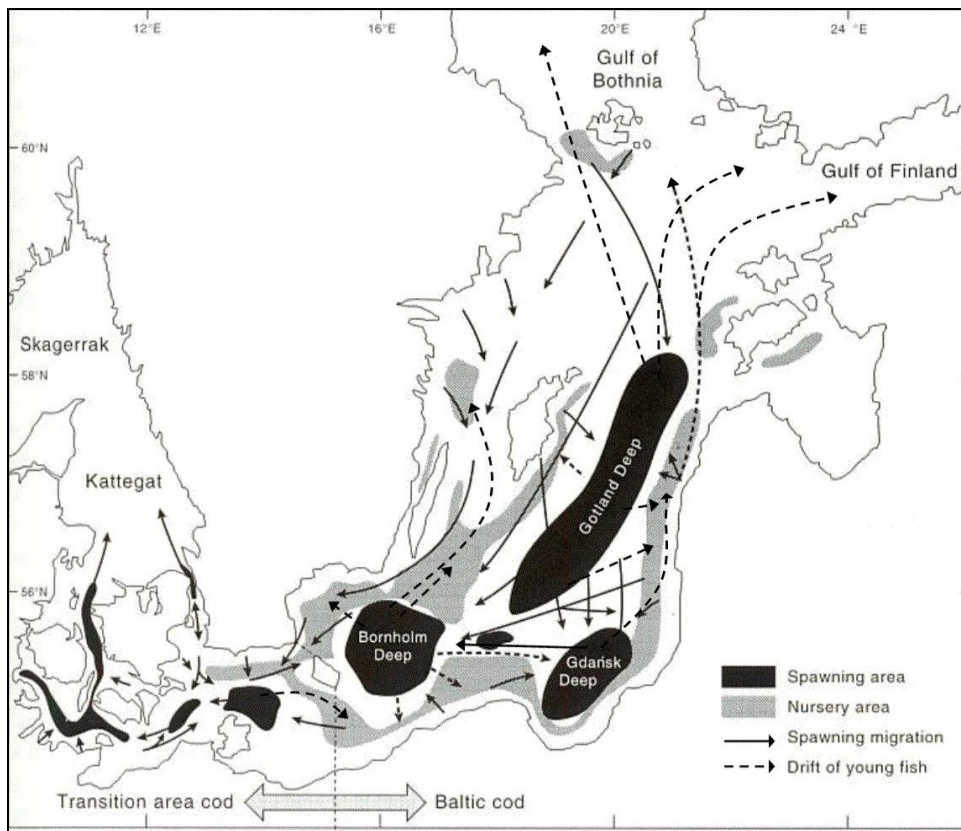


Figure 8.1.1.3 Historical spawning areas for cod in the Baltic Sea. From Bagge, O., Thurow, F., Steffensen, E., Bay, J. 1994. The Baltic Cod. Dana Vol. 10:1–28, modified by Aro, E. 2000. The spatial and temporal distribution patterns of cod (*Gadus morhua callarias*) in the Baltic Sea and their dependence on environmental variability – implications for fishery management. Academic dissertation. University of Helsinki and Finnish Game and Fisheries Research Institute, Helsinki 2000.

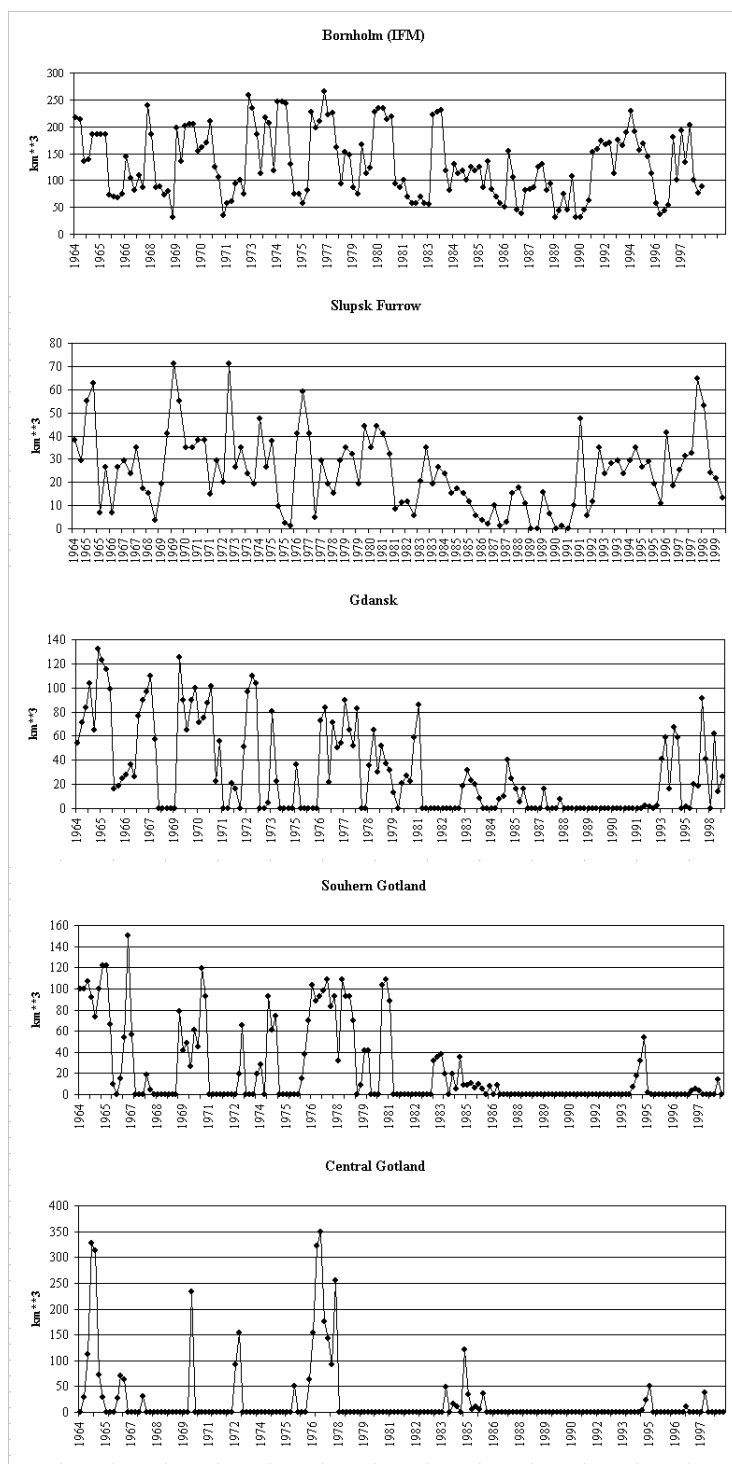


Figure 8.1.1.4 Time-series of reproductive volume for each spawning site. From MacKenzie, B. R., Hinrichsen, H-H., Plikshs, M., Wieland, K., and Zezera, A. 2000. Quantifying environmental heterogeneity: estimating the size of habitat for successful cod *Gadus morhua* egg development in the Baltic Sea. [Marine Ecology Progress Series 193: 143-156](#). With updates by Maris Plikshs (Pers. Comm.).

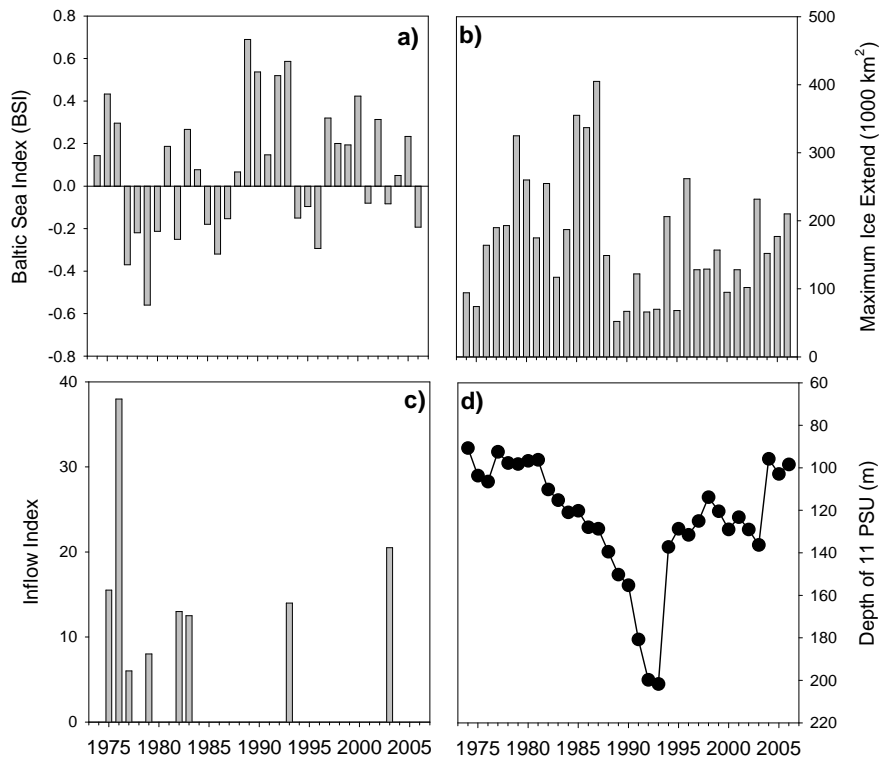


Figure 8.1.1.5 Climate effects on the Central Baltic Sea ecosystem: a) the Baltic Sea Index (BSI), b) Maximum Ice Extend, c) Inflow index, and d) depth of the 11 psu isoline in the Gotland Basin.