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Integrated ecosystem assessments of seven Baltic Sea areas covering the last three decades

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Contents

1 Background

Key elements in supporting the ecosystem approach to management (EAM) of marine resources are assessment, monitoring, and scientific research. These elements provide a sound basis for identifying ecological and associated operational objectives, selecting indicators, and identifying reference points (ICES, 2005a). Furthermore, "Evaluating the Ecosystem Status" is one of the preconditions of the EAM and requires a description of the ecosystem, based on knowledge of ecosystem structure, function, and environmental quality (ICES, 2005a).

Integrated ecosystem assessments (IEAs; called the "aggregative approach" by Hall and Mainprize, 2004) consider the physical, chemical, and biological environment – including all trophic levels and biological diversity – and treat fish and fisheries as an integral part of the environment. Technically, IEAs are multivariate analyses of a large suite of indicators representing all biotic components of an ecosystem as well as their abiotic drivers. The first IEAs for marine ecosystems were developed by Link *et al.* (2002) for the Northeast US continental shelf and by Choi *et al.* (2005) for the eastern Scotian Shelf ecosystem off Canada. The first IEA for a European sea was conducted by the ICES Regional Ecosystem Study Group for the North Sea (REGNS; ICES, 2005b; Kenny *et al.*, 2009).

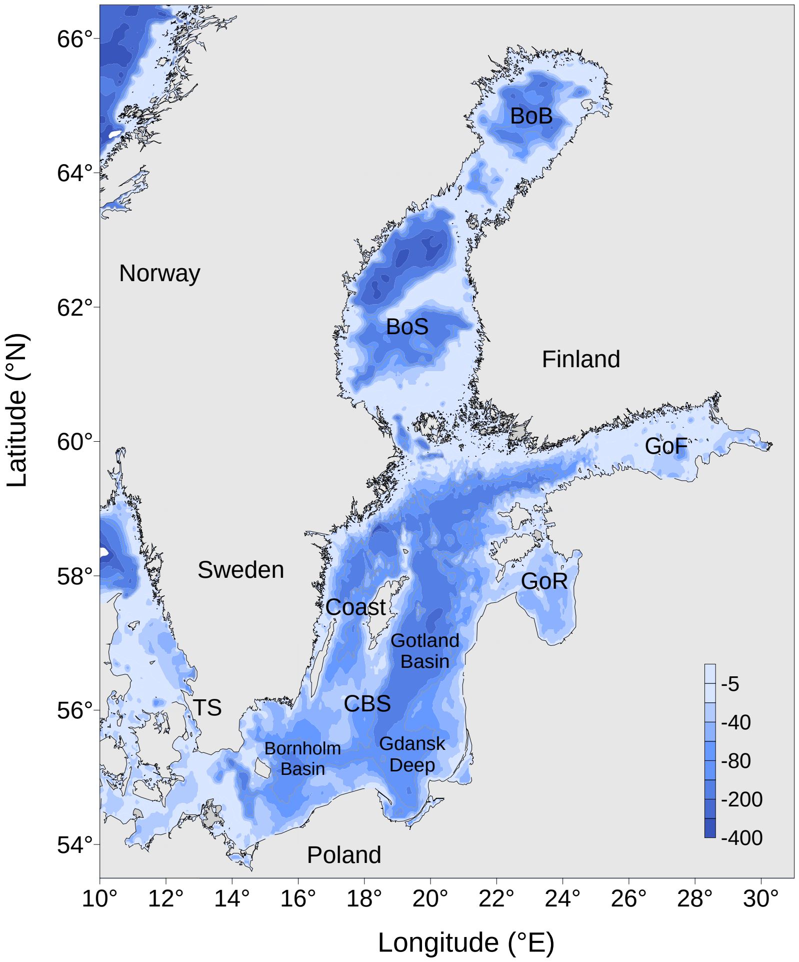


Figure 1.1. Map of the Baltic Sea with the seven sub-ecosystems investigated by WGIAB: TS = the Sound, CBS = central Baltic Sea (including Bornholm Basin, Gotland Basin, and Gdańsk Deep), GoR = Gulf of Riga, GoF = Gulf of Finland, BoS = Bothnian Sea, BoB = Bothnian Bay, and COAST = a coastal ecosystem in the Baltic proper.

This *ICES Cooperative Research Report* is a publication of the ICES/HELCOM Working Group on Integrated Assessments for the Baltic Sea (WGIAB). The WGIAB was set up as a forum to develop and combine efforts to provide scientific advice for ecosystem-based management in the Baltic Sea region. Specifically, WGIAB adopted the approach for IEAs described above. The "WGIAB process" began in 2006 through the ICES/BSRP/HELCOM Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB; ICES, 2006a). The workshop was successful in bringing together expertise from the different scientific organizations in the area and produced the first ecosystem overview assessments for the central Baltic Sea and Gulf of Riga. The WGIAB (established in 2007) further developed the IEA framework (ICES, 2007a, 2008), which eventually resulted in IEAs for seven Baltic Sea sub-ecosystems: the Sound, central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Sea, and Bothnian Bay, and a coastal site (Kvädöfjärden) in Sweden (Figure 1.1).

The ecosystem overview documents in this report were prepared with the aim of delivering background ecosystem information to both ICES and HELCOM, specifically for ICES fish stock assessments (i.e. the Baltic Fisheries Assessment Working Group (WGBFAS) and Working Group on Baltic Salmon and Trout (WGBAST)), and to HELCOM's assessment of the effects of fishing on the Baltic ecosystem. This report describes the development of (i) hydroclimatic conditions; (ii) nutrients; (iii) phytoplankton; (iv) zooplankton populations; (v) for some basins, macrozoobenthos and top predators, such as seals; and (vi) major fish stocks and their fisheries for each sub-ecosystem. Additionally, multivariate analyses of all time-series within the different systems are presented, providing an integrated view of changes in ecosystem structure and functioning.

In addition to the new insight into the ecosystem structure and function of Baltic ecosystems, major outputs of WGIAB for future ecosystem-based management approaches are the impressive regional datasets on abiotic and biotic indicators (see Section 8). These have great potential for future ecosystem analyses and may serve as important information sources for ecosystem-based management efforts for the Baltic Sea.

2 Methods

Ecosystem states and developments are described by abiotic and biotic time-series, providing information about climate, hydrography, nutrients, phytoplankton, zooplankton, fish, and fisheries, plus, where available, data for benthos and top predators like seals. The selection of these variables was based on a number of criteria: (i) length of the investigated period, (ii) number of missing data points, (iii) representativeness for a specific ecosystem component, and (iv) low cross-correlation with other variables (ICES, 2007a). All dataseries were compiled to one value per year^{-1}, covering at maximum the period 1971–2008 (COAST). The type and number of variables available for each system differed, but their proportion was balanced as far as possible according to drivers and response variables.

The temporal development of selected variables was graphically displayed as anomalies from the overall mean. Subsequently, IEAs were performed on the area-specific time-series using a combination of exploratory ordination methods and inferential statistics. Initially, principal component analysis (PCA) was used as a time-series tool. For methodological reasons, missing values, although few, were replaced by the average of the four nearest datapoints. To improve linearity between variables, and to reduce the relationship between the mean and the variance, the biological time-series as well as nutrient values were $\ln(x+1)$ transformed. Subsequently, a standardized PCA based on the correlation matrix was performed on the transformed values of the full dataset, as well as of the explanatory and response variables separately. Variable loadings and year scores were displayed on the first factorial plane, and the years were connected in chronological order. Year scores along the two principal components, principal component 1 (PC1) and principal component 2 (PC2) were also plotted against time in order to visualize temporal relationships and the occurrence of abrupt ecosystem changes.

To illustrate systematic patterns in single time-series, the "traffic-light" framework applied in stock assessments (Link *et al.*, 2002; Choi *et al.*, 2005) was used. Raw values of each variable were categorized into quintiles, and the values in each quintile were assigned a specific colour: green in the lowest quintile, red in the highest quintile, and a gradation of colours in between. The variables were then sorted according to their loadings along the PC1 axis in order to obtain a temporal pattern.

In order to identify the years in which the largest shifts in the mean value of the time-series occurred, two independent types of discontinuity analysis were used. The first was a clustering technique capable of grouping sequential years on the basis of the time-variable matrix (chronological clustering; Legendre *et al.*, 1985). To demonstrate the most important breakpoints in the dataset, the significance level (α), which can be considered as a clustering-intensity parameter, was set to 0.01 and the connectedness level to 50%. In accordance with the use of the correlation coefficient in the PCA, data were first normalized, and then the Euclidean distance function was calculated to determine similarity between years. The second was the sequential regime shift analysis (STARS) developed by Rodionov (2004), which was applied to the PCs derived by the previous PCAs. The test is based on a sequential t-test, and the two parameters controlling the magnitude and scale of the regimes to be detected need to be set. Accordingly, the significance level (α) was set to 0.05, after which the cut-off length (l) was set to 8 years. The latter defines the minimum length of the time period (regime) to be identified by the test. However, shifts with a high magnitude can still be detected for shorter periods. The average value of the regimes is also affected by the handling of outliers. For this, Huber's weight parameter, which controls the identification and weights assigned to outliers, was set to 2. This means that, if the deviation of a measurement from the expected regime average normalized by the standard deviation for the respective section is larger than 2, its weight is inversely proportional to the distance from the expected mean value of the new regime. No pre-whitening procedure to remove red-noise components from the time-series was used because the overall length of the time-series and the embedded regimes makes this correction generally problematic (Rodionov, 2006).

Tables detailing all the time-series used in the analysis, together with relevant metadata, are given in Section 8.

3 Hydroclimatic changes

Like other areas of the world ocean, the Baltic Sea region has experienced pronounced changes in atmospheric forcing. In the past century, sea surface temperature (SST) increased by >0.7 °C, which is greater than the global mean increase of 0.5 °C. Sequentially, other variables, such as river run-off, ice coverage and thickness, and salinity conditions changed, and projections indicate a further increase in temperature and decrease in salinity (BACC Author Team, 2008).

Atmospheric forcing in the Baltic Sea region can be described by the Baltic Sea Index (BSI). This index correlates well with the North Atlantic Oscillation index (NAO; Lehmann *et al.*, 2002) and was generally negative during the 1970s and 1980s, although it turned positive during the late 1980s (Figure 3.1). This change in the index from negative to positive values was associated with a greater frequency of westerly winds, warmer winters, and eventually a warmer climate over the Baltic area. This is demonstrated by the strong correlation between the BSI and the maximum ice extent in the Baltic ($r = 0.84$). Generally, the BSI can be interpreted as a common driver for the different sub-ecosystems investigated.

In addition to its direct influence on temperature, climate also affects salinity conditions in the Baltic Sea. Increased precipitation, together with increased westerly winds, negatively affected surface salinity. Additionally, during the high BSI period since the late 1980s, only two major Baltic inflow events were recorded. These are identified by the large amount of highly saline water (>17 psu) across the Darss and Drodgen sills and are quantified by the inflow intensity parameter Q_{96} as a function of the duration of the inflow and the mean salinity of the inflowing water (Fischer and Matthäus, 1996). It has been hypothesized that the low frequency of major inflow events into the Baltic since the 1980s, although unpredictable to date, is related to the high NAO (BSI) period (Hänninen *et al.*, 2000). Increased run-off leading to sea-level variations may have additionally hindered major inflow events (Matthäus and Schinke, 1999). During the long "stagnation periods" since the early 1980s, virtually no high-salinity, oxygen-rich waters were transported into the eastern basins, resulting in largely unfavourable conditions for marine species in deeper water and near-bottom layers. Although the size of hypoxic areas (i.e. <2 ml l^{-1} O_2) in the Baltic Sea decreased considerably during and after the strong inflow event in 1993, it has increased nearly continuously since then, reaching a maximum extent of ca. 75 000 km^2 in 2005 (Figure 3.1, top right; Hansson *et al.*, 2009). Deep-water salinity conditions, demonstrated by the depth of the 11-psu isocline in the Gotland Basin, also degraded since the early 1980s until the major inflow in 1993, when the halocline was located at a depth of ca. 200 m. Afterwards, conditions improved considerably and, more recently, the halocline was found at a depth of ca. 100 m (Figure 3.1, bottom left).

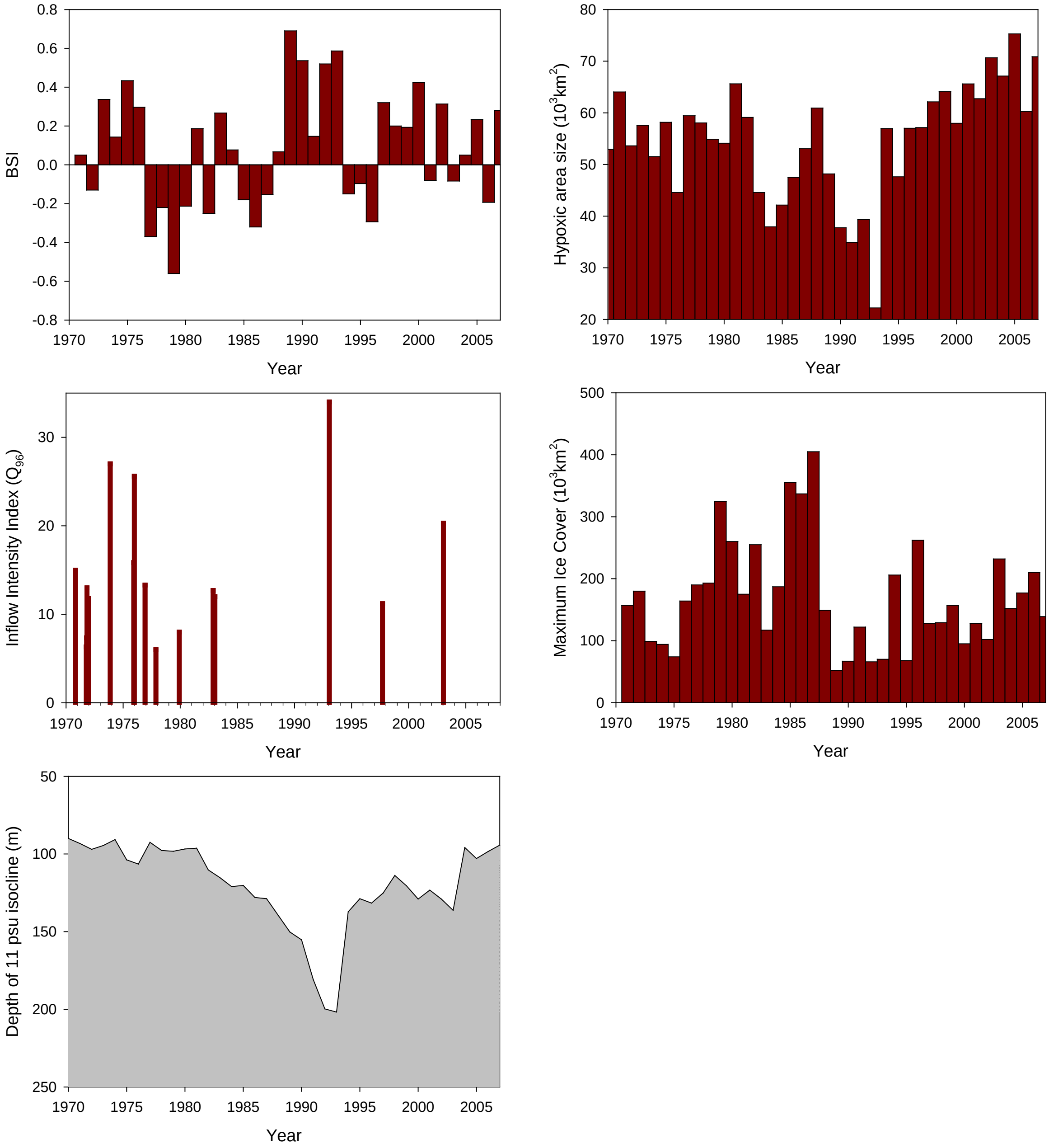


Figure 3.1. Long-term hydroclimatic changes in the Baltic Sea indicated by (from left to right): the Baltic Sea Index (BSI); the maximum ice extent (in km^2); the inflow intensity parameter (based on Matthäus, 2006; Feistel *et al.*, 2008); the extent of hypoxic areas (≤2 ml l^{-1} O_2) in the Baltic (in km^2); and the depth of the 11-psu isocline in the Gotland Basin (in metres).

4 Integrated ecosystem assessments

Seven sub-ecosystems of the Baltic Sea were investigated: the Sound, central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Sea and Bothnian Bay, and a coastal site (Kvädöfjärden) in the western part of the central Baltic Sea. A detailed description of the state and development of each system is given in the following subsections. Each is based on the best knowledge of WGIAB participants and, as far as possible, covers information about all key ecosystem components (i.e. relevant hydrographic, nutrient, phytoplankton, zooplankton, fish, and fisheries time-series) plus, where available, data for benthos and for top predators, such as seals. In addition to the trends of single variables, the multivariate dataset was subsequently analysed according to the IEA framework, giving indications about the ecosystem structure and development as a whole. Ordination techniques and discontinuity analyses provide information about abrupt ecosystem changes (here termed "regime shifts"), the relevant drivers, and the past state of, and future consequences for, ecosystem states.

4.1 The Sound

The Sound is a strait, 118 km long and 4–28 km wide, that separates Denmark and Sweden in a west–east direction and connects the Kattegat with the Baltic Sea from north to south. In general, the northerly surface current transports brackish water from the Baltic proper northwards, whereas highly saline bottom water, originating in the North Sea, flows south. This results in a strong, permanent halocline at a depth of 10–12 m.

Geographically, the Sound consists of shallow bays, with bottoms of soft sand, and a central area, with depths of 30–50 m, with bottoms consisting mostly of clay/silt. The dominant vegetation on the soft sandy bottoms is eelgrass (*Zostera marina*), whereas macroalgae dominate the hard substrata. Ecologically, the Sound is situated in an ecotone between the high-diversity ecosystems of Atlantic origin and the brackish-water, low-diversity ecosystem of the Baltic Sea. Furthermore, its benthic fauna is diverse and includes several different communities, characterized by molluscs (*Macoma baltica*, *Abra alba*, *Mytilus edulis*), echinoderms (*Amphiura filiformis*), and crustaceans (*Haploops tubicola*). The fish community comprises ca. 30 species, many of which have important spawning or nursery grounds in the area. The commercially important species, such as cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and flounder (*Platichthys flesus*), demonstrate remarkably high densities and a large size-at-age and size-at-maturity compared with neighbouring areas (Svedäng *et al.*, 2004). This is attributed to the trawling ban that has been imposed in the Sound since 1932.

The catchment area of the Sound is heavily populated and includes vast agricultural and industrial areas. Eutrophication was a prominent feature in past decades, but the implementation of efficient wastewater treatment has subsequently greatly reduced nutrient loads and improved water quality (more information is available online at http://www.oresundsvand.dk/English/).

4.1.1 Trend analysis

4.1.1.1 Hydrography

Hydrographic conditions in the Baltic Sea area are influenced by the large-scale atmospheric processes illustrated by the BSI. The change in the BSI, from generally negative to positive values in the late 1980s, resulted in higher than average water temperatures (Figure 4.1.1). In addition, large-scale changes in ocean circulation also affected salinity and dissolved oxygen (DO) conditions in the Sound (Figure 4.1.1), with greater DO and salinity when the inflow of North Sea water was pronounced. However, variable long-term trends are ambiguous.

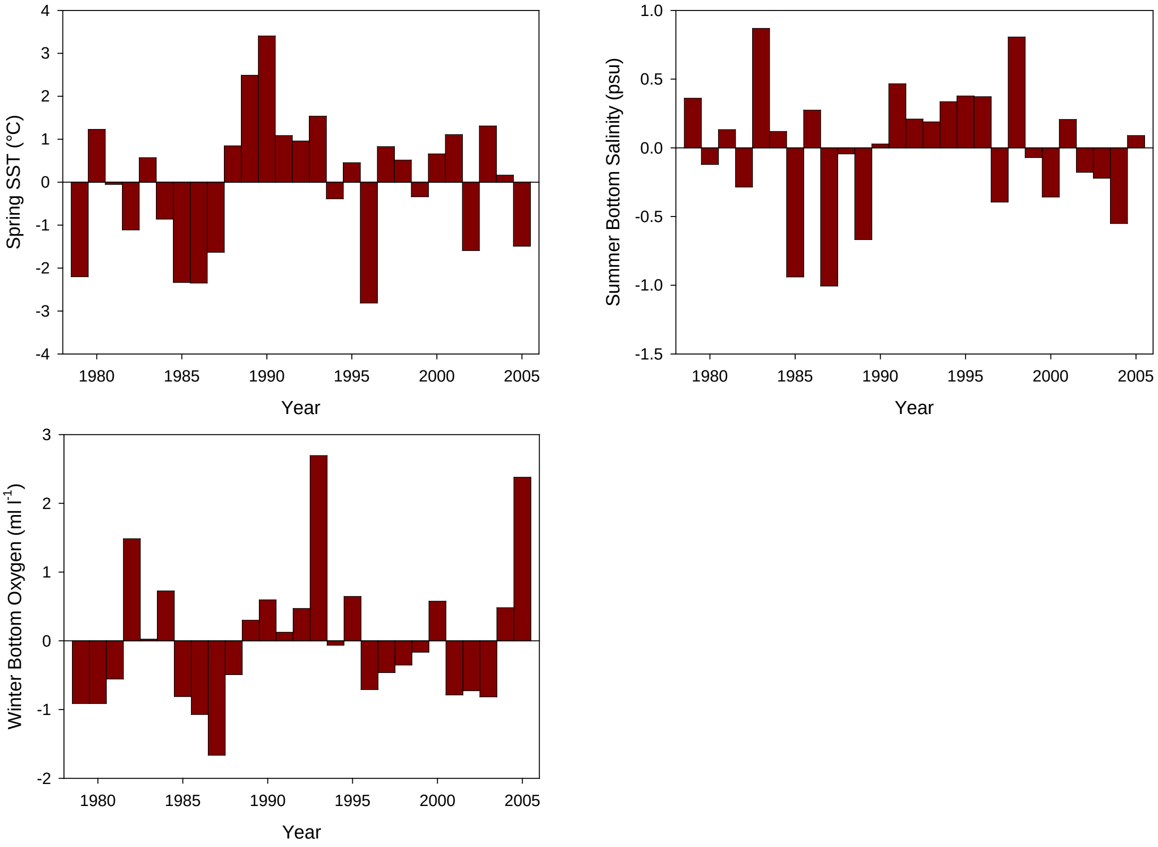


Figure 4.1.1. Long-term hydrographic changes in the Sound. Anomalies of the overall mean for (from left to right): sea surface temperature (SST) in spring (2.6°C); bottom salinity in summer (32.4 psu); and bottom dissolved oxygen concentration in winter (4.7 ml l^{-1}).

4.1.1.2 Nutrients

The Sound faced severe eutrophication in the early 1980s but the implementation of efficient wastewater treatment resulted in a marked reduction of nutrients originating from river run-off (The Sound Water Cooperation, 2004). A decrease in nutrient concentration, particularly pronounced for phosphorus, was also observed at the monitoring stations (Figure 4.1.2). The reduced inflow of nutrient-rich bottom water from the North Sea may also have contributed to the decrease in winter phosphorus and nitrogen levels.

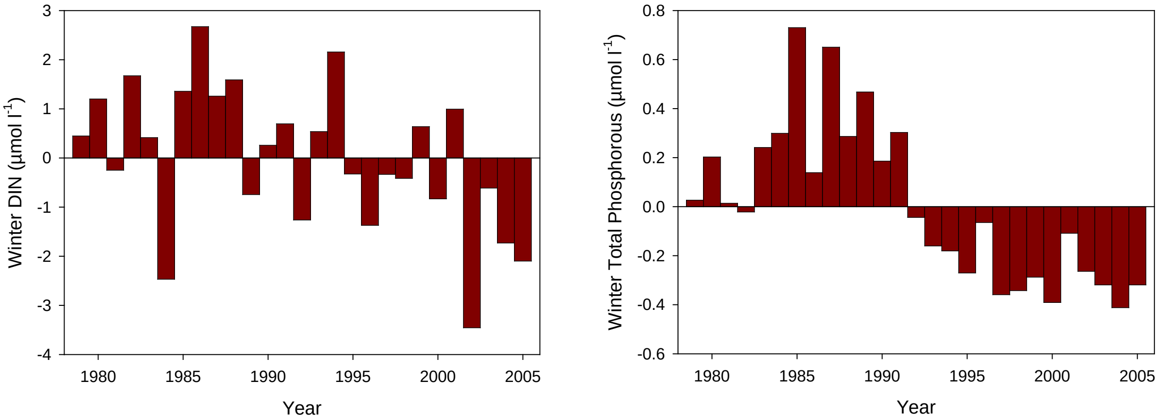


Figure 4.1.2. Long-term changes in nutrient concentrations in the Sound in winter. Anomalies of the overall mean for: (left) DIN (dissolved inorganic nitrogen; 7.05 µmol l^{-1}); and (right) total phosphorus (1.33 µmol l^{-1}).

4.1.1.3 Phytoplankton

Spring and summer phytoplankton biomass displayed a decreasing trend over time (Figure 4.1.3). Although the biomass of smaller cryptophytes decreased dramatically in the late 1980s, diatom biomass decreased only slightly (Figure 4.1.3). Wasmund and Uhlig (2003) related the decreasing trends in Cyanobacteria and chlorophyll *a* in the Belt Sea to increasing temperatures and a decrease in nutrient loadings, particularly phosphorus, which is considered to be a co-limiting nutrient in this area (HELCOM, 2002). Changes in phytoplankton biomass and production may thus be explained by a combination of climate forcing and a reduction in nutrient loads (Figure 4.1.2).

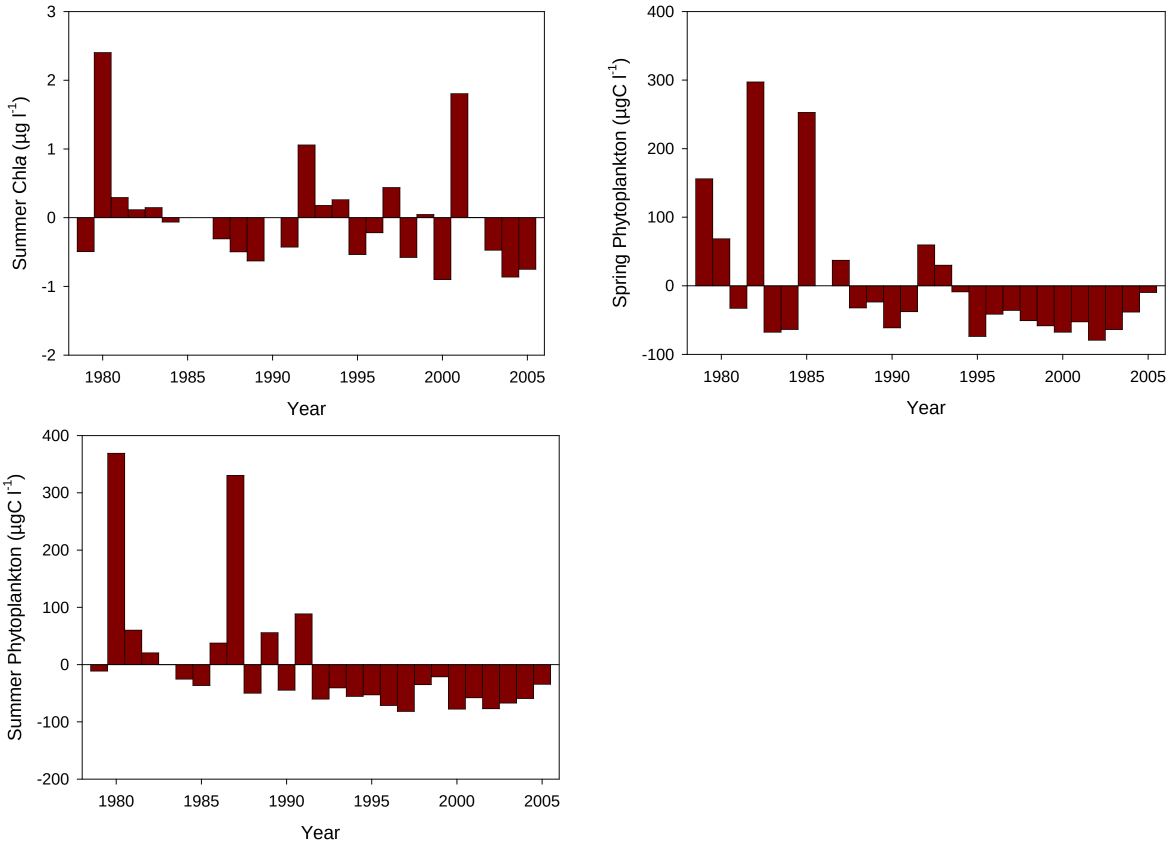


Figure 4.1.3. Long-term changes in phytoplankton biomass in the Sound. Anomalies of the overall mean for (from left to right): chlorophyll *a* content in summer (2.14 µg l^{-1}); and phytoplankton biomass in spring (86.51 µg C l^{-1}) and in summer (107.83 µg C l^{-1}).

4.1.1.4 Zooplankton

Heterotrophic microzooplankton and mesozooplankton biomasses have generally decreased since the early 1980s (Figure 4.1.4). In contrast to the central Baltic Sea, this trend was also observed for the main copepod taxa: *Acartia* spp., *Temora longicornis*, and *Pseudocalanus* spp. However, during the 1990s, there was a high biomass of *Pseudocalanus* spp., which can be related to increasing bottom-water salinities (Lindegren *et al.*, 2010).

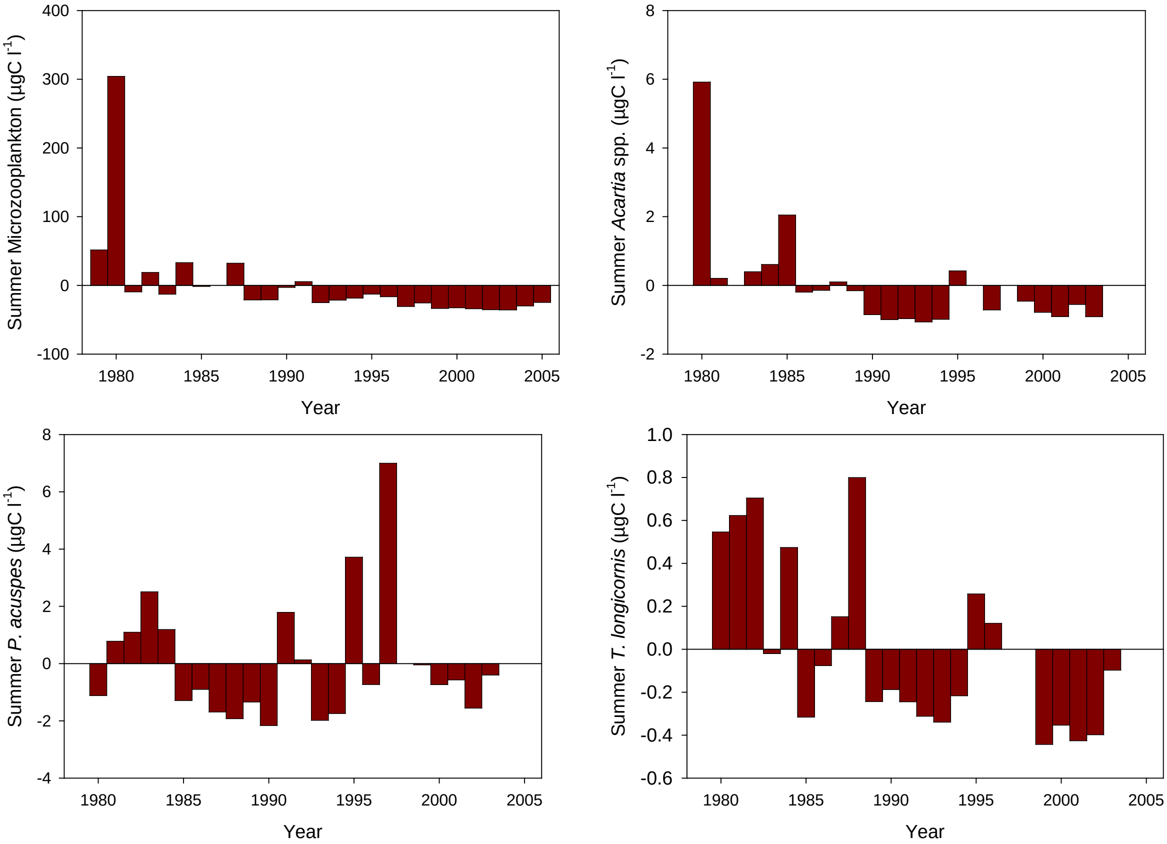


Figure 4.1.4. Long-term changes in zooplankton species composition in the Sound in summer. Anomalies of the overall mean (biomass) for (from left to right): total microzooplankton (36.9 µg C l^{-1}); *Acartia* spp. (1.3 µg C l^{-1}); *Pseudocalanus* spp. (2.4 µg C l^{-1}); and *Temora longicornis* (0.5 µg C l^{-1}).

4.1.1.5 Benthos

A high biomass of molluscs was observed between the late 1980s and early 1990s, but since then it has remained at a low level (Figure 4.1.5, left). In contrast, the biomass values of polychaetes has steadily increased although, in the last three years of the time-series, values were again below average. Henriksen *et al.* (2001) demonstrated a significant positive response of macrobenthos abundance to winter nutrient input and spring primary production in Danish waters. Likewise, Kröncke *et al.* (1998) demonstrated a similar effect on macrozoobenthos in the North Sea. Decreasing nutrient loadings and primary production, combined with a milder climate, may underlie the change in the benthic community, especially the drastic decrease in filter-feeding molluscs. The invasion of the alien species *Marenzelleria neglecta* syn. *viridis* may further explain the increase in polychaetes in the early 1990s (Strömberg and Persson, 2005; Figure 4.1.5, right).

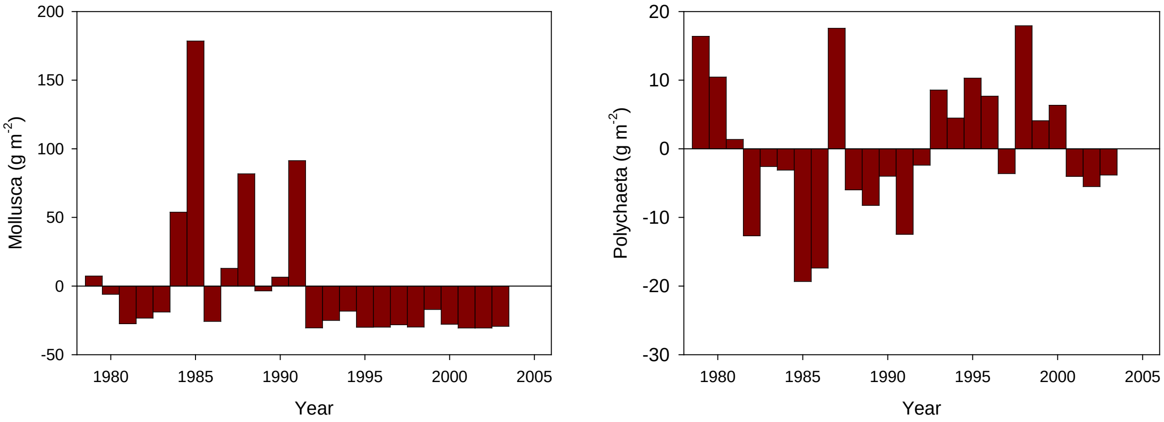


Figure 4.1.5. Long-term changes in the macrozoobenthic community in the Sound. Anomalies of the overall mean for: (left) total molluscan biomass (30.7 g m^{-2}); and total polychaete biomass (23.9 g m^{-2}).

4.1.1.6 Fish and fisheries

Although the eastern Baltic cod stock collapsed as a result of climate-induced recruitment failure and overfishing (Köster *et al.*, 2005), and herring (*Clupea harengus*) stocks have also been decreasing, fish landings in the Sound have displayed a general recovery since the mid-1990s. This increase was most pronounced for flatfish species, such as plaice and flounder, but was also observed for cod and pelagic species such as herring (Figure 4.1.6). Svedäng *et al.* (2002) demonstrated that the stock sizes and structures of several gadoid and flatfish species in the Sound are relatively healthy compared with neighbouring areas. The main reason for these differences is the absence of trawling activities (trawl fishing was banned in 1932 to accommodate shipping (Svedäng *et al.*, 2004).

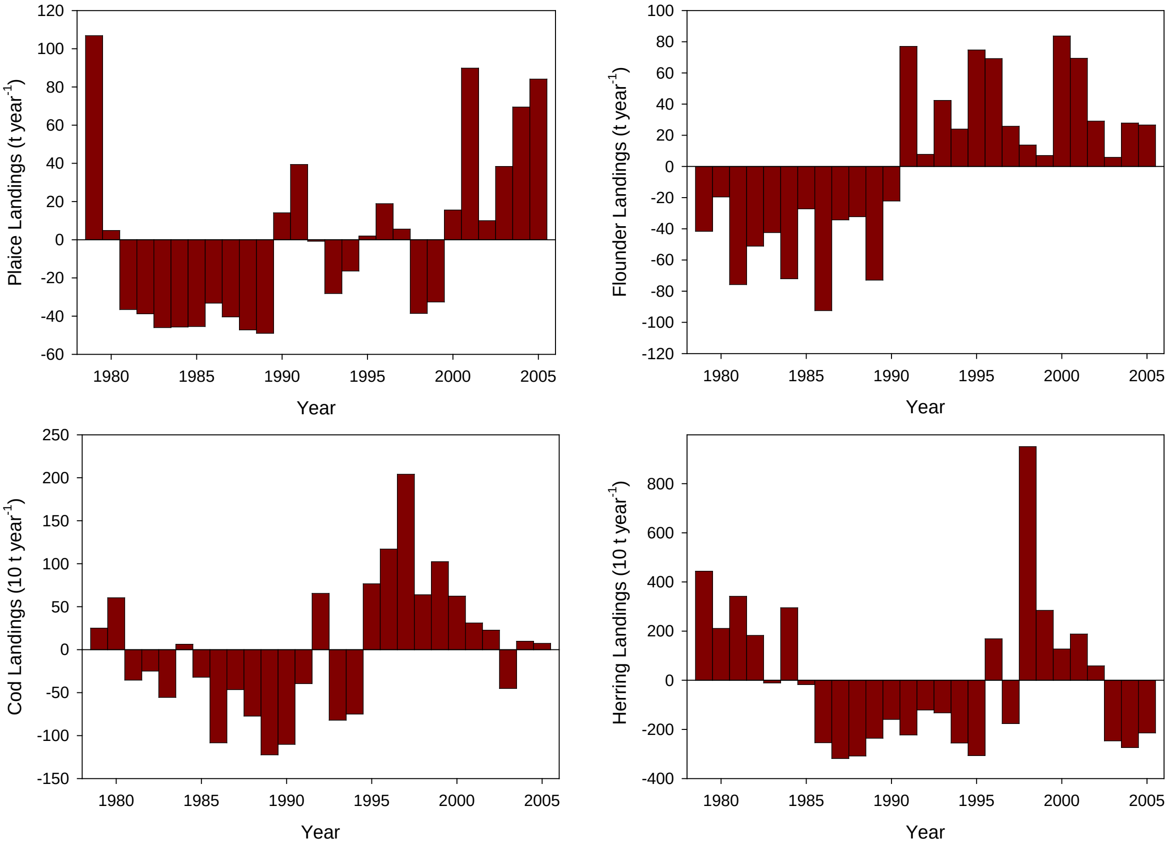


Figure 4.1.6. Long-term changes in yearly landings of the Sound fishery. Anomalies of the overall mean for (from left to right): plaice (62 t year^{-1}), flounder (157 t year^{-1}); cod (1829 t year^{-1}); and herring (3960 t year^{-1}).

4.1.2 Integrated analysis

In total, 50 variables were considered: 12 hydrographic, 4 nutrient, 10 phytoplankton, 12 zooplankton, 4 benthos, and 8 fish species-specific landing datasets. All dataseries were compiled to one value year^{-1} and covered the period 1979–2005 (see Section 8, Table 8.1, for details of variables).

An overview of the temporal changes in all time-series compiled for the Sound is presented in Figure 4.1.7. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red), with the highest values in the last 15 years, to variables at the bottom demonstrating the opposite trend (red–green), with the highest values in the period 1979–1987. The first group of variables comprises mainly temperature measurements, biomass of *Bosmina* spp., and landings of several fish species, including flounder, plaice, and cod. Decreasing values were found for summer biomass estimates of several zooplankton groups (microzooplankton taxa, *Acartia* spp., *Temora* spp., etc.), as well as for Cryptophyceae and Cyanobacteria. Variables with less-clear trends are found at the centre of the plot, some of which demonstrate relatively high values at the beginning of the time-series but also comparatively high estimates in the period from 1990 to early 2000. This includes landings of silver eel (*Anguilla anguilla*) and herring, and many biomass estimates of phytoplankton groups.

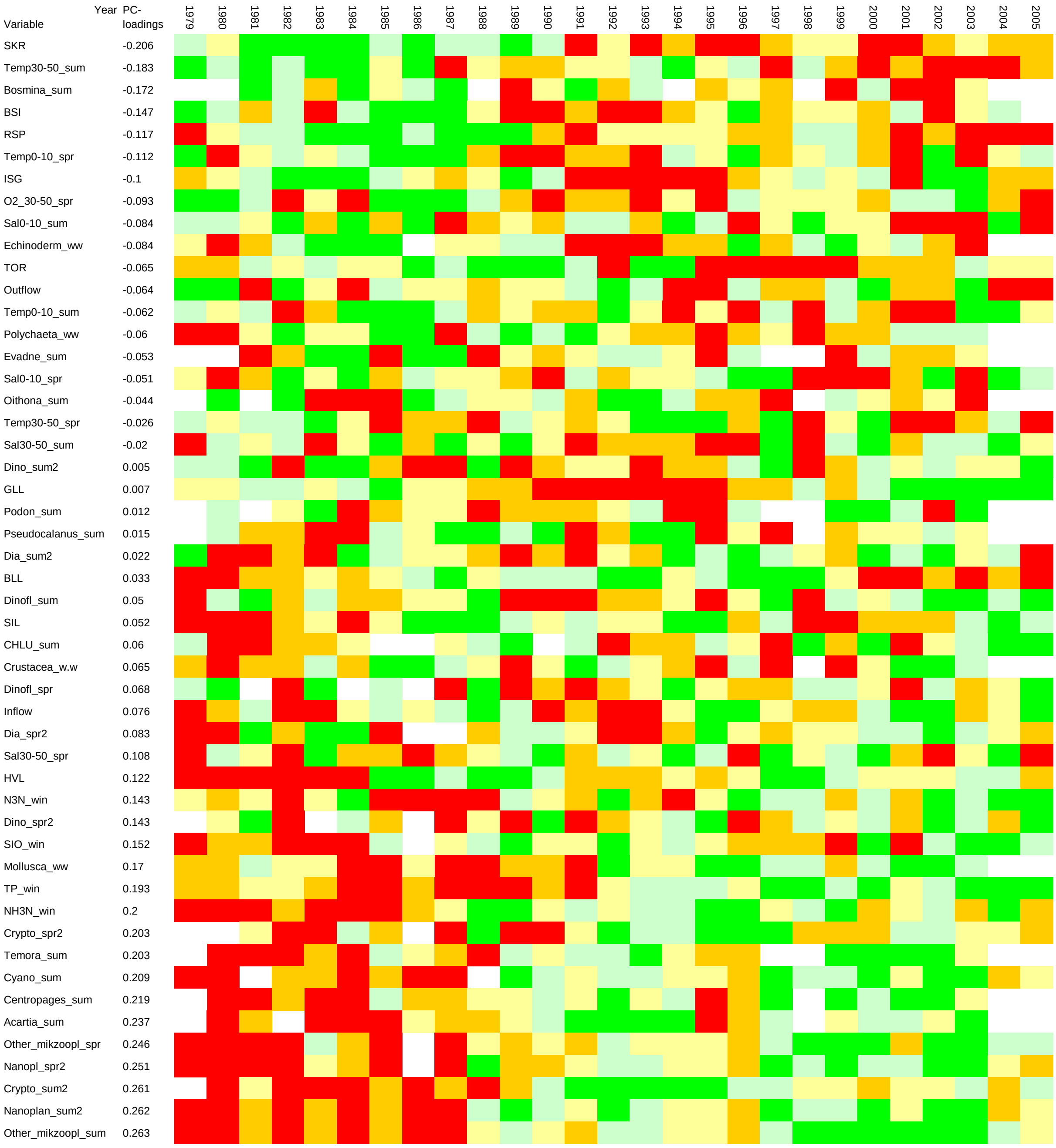


Figure 4.1.7. Traffic-light plot of the temporal development of the Sound time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values) and sorted into numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.1).

The ordination of the full dataset by a standardized PCA resulted in 23.2% and 11.2% of the explained variance on PC1 and PC2, respectively. Scores along PC1 demonstrated a clear temporal trend: from positive values in the early years, a sudden decrease between 1987 and 1988, to negative values thereafter (Figure 4.1.8). Similarly, PC2 scores decreased until 1987, but have moderately increased since then, with only minor fluctuations in the last 10 years of the time-series. The sudden ecosystem shift in 1987–1988 (which can be identified in Figure 4.1.8) was confirmed by both types of discontinuity analyses. STARS located the highest regime shift index (RSI), of 2.16, on PC1 in 1988, indicating that a new regime started in this year. Significant RSI values, although less pronounced, were also identified for PC2 scores, with 1.04 in 1985 and 0.87 in 1995. In addition to the 1987–1988 shift, chronological clustering indicates two more recent shifts, in 1994–1995 and 2000–2001, although these were comparatively small. Generally, the system was more variable at the beginning of the investigated period and started to stabilize after the major shift in 1987–1988. Successive years with hardly any changes in most variables explain why the relatively small interannual differences observed after 1988 were identified as significant shifts.

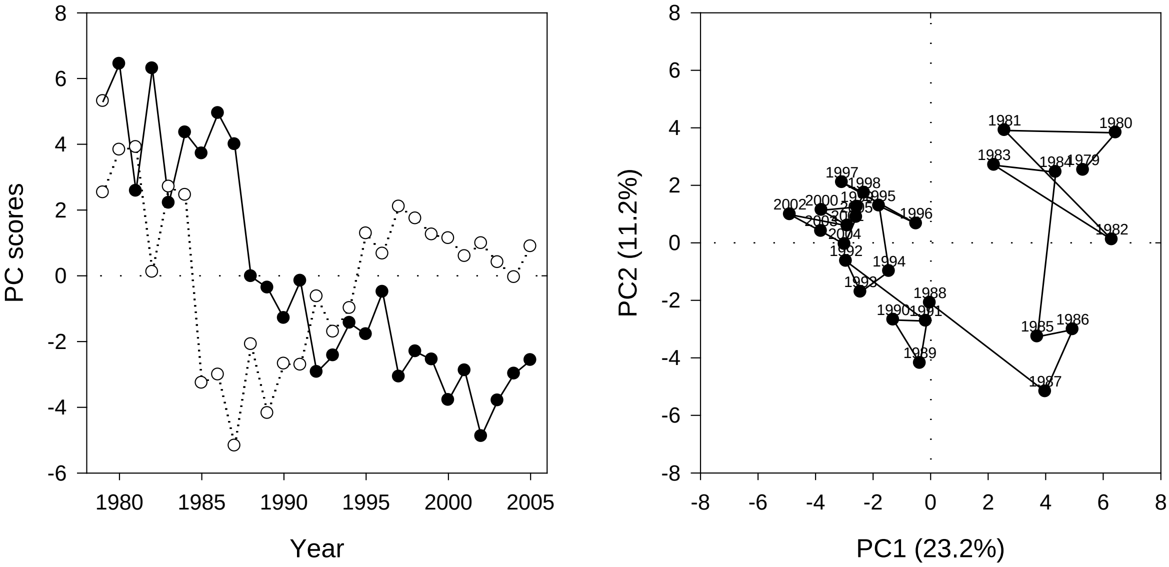


Figure 4.1.8. Results of the standardized principal component analysis (PCA) for the Sound, using all of the assembled 50 variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

The relative changes in the variables over time in relation to the observed ecosystem shifts can be derived from the factor loadings on the two PCs (Figure 4.1.9). PC1 mainly reflects temperature values, biomass of *Bosmina* spp., and landings of flounder and plaice (high negative loadings on PC1, indicating an increasing trend over time). Positively correlated with PC1, and therefore decreasing over the investigated period, were estimates of nano- and microzooplankton biomass. Strongly positively correlated with PC2, and thus displaying a rather unimodal trend, were the landings of cod, whiting (*Merlangius merlangus*), and herring (indicating a fluctuation in estimates from high to low to high). The stocks were thus recovering after the strong shift in the late 1980s, in contrast to stock sizes in the North Sea and Baltic Sea, which remained at historically low levels. Negative correlations with PC2 were found for estimates of dinoflagellate and diatom biomass, indicating maximum values in the late 1980s to early 1990s and slightly below-average biomass in recent years. The shift from smaller, nitrogen-fixing phytoplankton species to larger diatoms and dinoflagellates in the intermediate period may be explained by a combination of climate and nutrient forcing (i.e. decreasing dissolved inorganic phosphorus (DIP) loadings).

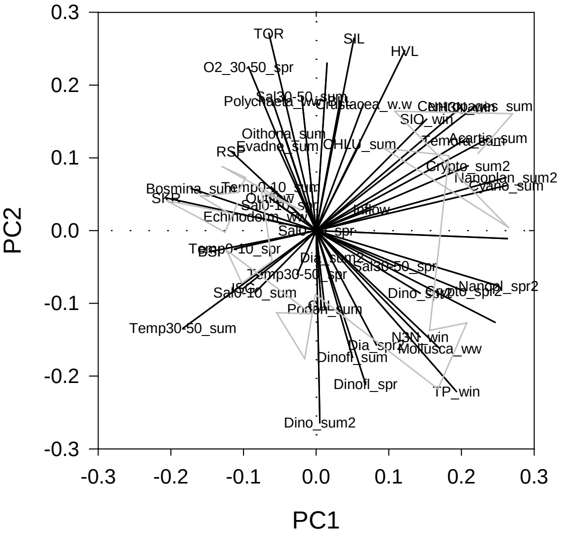


Figure 4.1.9. Results of the standardized principal component analysis (PCA) for the Sound, using all of the assembled 50 variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.1.8 is shown in light grey.)

4.2 Central Baltic Sea

The central Baltic Sea comprises three deep basins: the Bornholm Basin, Gdańsk Deep, and Gotland Basin (ICES Subdivisions 25, 26, 27, and 28), with a maximum water depth in the western Gotland Deep of 459 m. A characteristic of the deep basins is a permanent halocline separating low-salinity surface water from high-salinity deep waters. Because of this stratification, deep-water salinity and DO conditions can only be renewed by lateral advection (i.e. major Baltic inflows of North Sea waters; see Section 3). The frequency of these events therefore strongly regulates the abiotic conditions for the local fauna, which is generally of low diversity, with only a few species dominating the upper trophic levels. Hence, the fish community is dominated by cod, herring, and spratZooplankton is dominated by *Pseudocalanus acuspes*, *Temora longicornis,* and *Acartia* spp.

4.2.1 Trend analysis

4.2.1.1 Hydrography

Episodic inflow events strongly influence the hydrographic situation in the deep basins. This is partly reflected by the depth of the 11-psu isocline. In the Gotland Basin, the depth of the isocline increased from ca. 100 m in the mid-1970s to 200 m in the early 1990s (Figure 3.1). The sporadic but strong inflow events in 1993 and 2003 led to an increase in salinity and were reflected by a sudden increase in depth of the 11-psu isocline and the related deep-water DO conditions.

Time-series of water temperature and salinity from the Bornholm and Gotland basins in spring clearly reflect the change in atmospheric forcing (Figure 4.2.1). Average temperatures were higher after the late 1980s, with a peak in 1990, whereas surface salinity decreased significantly after the mid-1980s. Like the depth of the 11-psu isocline, deep-water salinity depends strongly on the occurrence of inflow events and is reflected in the stagnation period until the early 1990s and the effect of the recent inflows in 1993 and 2003.

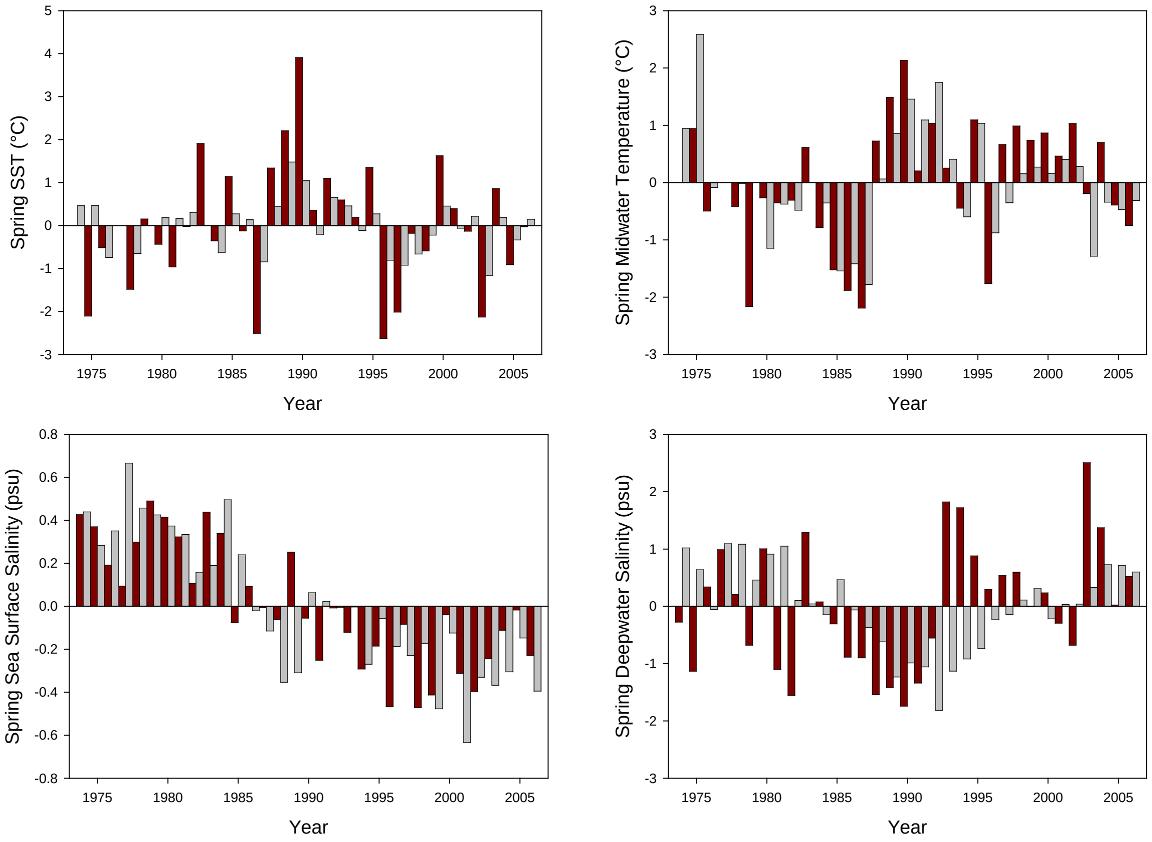


Figure 4.2.1. Long-term hydrographic changes in the Bornholm Basin (BB, red) and Gotland Basin (GB, grey). Anomalies of the overall mean for (from left to right): sea surface temperature (SST) in spring (BB = 5.7°C, GB = 0.6°C); midwater temperature (40–60 m) in spring (BB = 3.6°C, GB = 3.0°C); sea surface salinity in spring (BB = 7.5, GB = 7.2); and deep-water salinity in spring (BB: 70–90 m = 15.4, GB: 80–100 m = 9.7).

4.2.1.2 Nutrients

Surface winter dissolved inorganic nitrogen and phosphorus (DIN and DIP) values display a stepwise increase from the beginning of the time-series until 1990 and a decreasing trend thereafter (Figure 4.2.2). Summer deep-water DIN and DIP time-series are related to the inflow of North Sea water and thus demonstrate increasing values during the stagnation period from the mid-1970s and sharp decreases after the inflows in 1993 and 2003. Time-series of the Bornholm and Gotland basins show similar overall trends, although they differ in the magnitude of their average values and temporal variability. Generally, the Gotland Basin time-series demonstrates higher nutrient concentrations and an opposing trend for deep-water DIP when compared with Bornholm Basin measurements following the major inflow event in 1993.

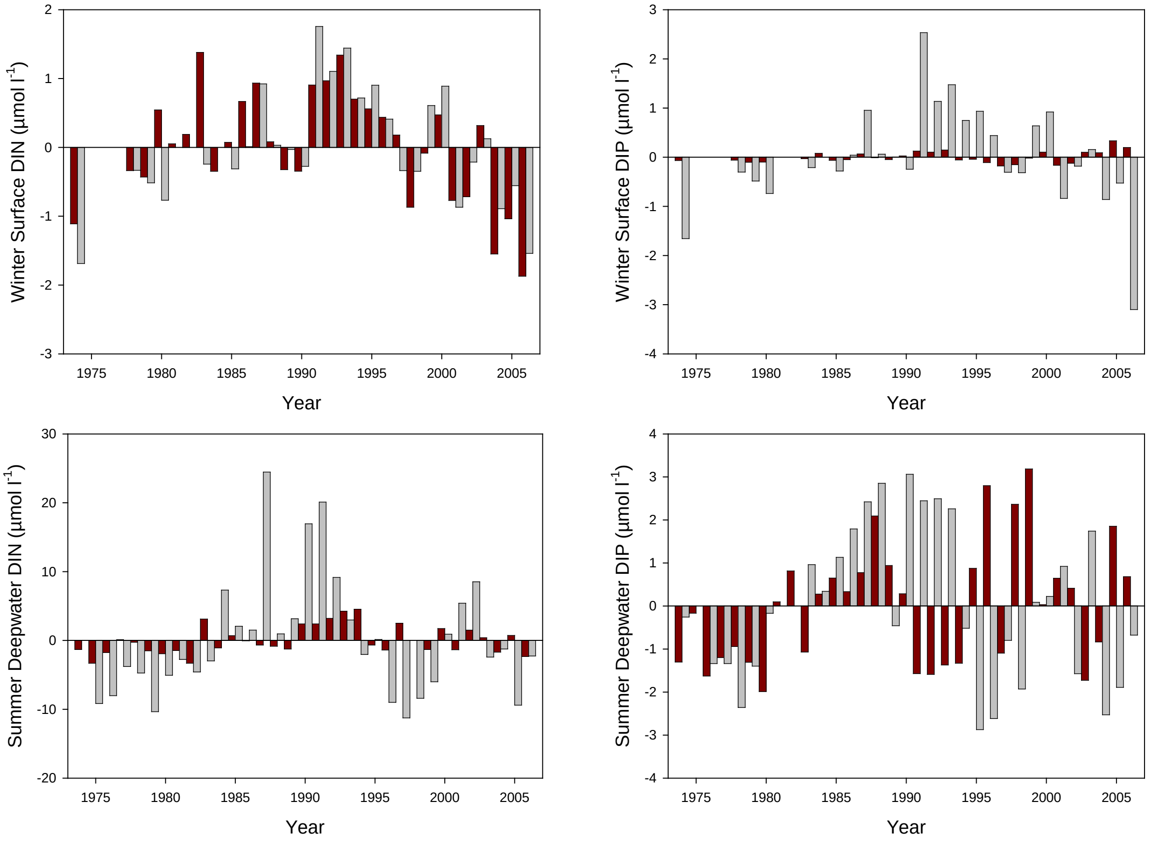


Figure 4.2.2. Long-term changes in nutrient concentrations in the Bornholm Basin (BB, red) and Gotland Basin (GB, grey). Anomalies of the overall mean for: (top) DIN (dissolved inorganic nitrogen; BB = 3.8 µmol l^{-1}, GB = 3.8 µmol l^{-1}) and DIP in winter (dissolved inorganic phosphorus; BB = 0.5 µmol l^{-1}, GB = 3.7 µmol l^{-1}); and (bottom) DIN (BB = 8.4 µmol l^{-1}, GB = 11.7 µmol l^{-1}) and DIP in summer (BB = 2.7 µmol l^{-1}, GB = 4.6 µmol l^{-1}). Winter values are from the surface; summer values are from 70 to 90 m (BB) and 200 to 220 m (GB), respectively.

4.2.1.3 Phytoplankton

The development of the phytoplankton biomass in the central Baltic Sea can be demonstrated using chlorophyll *a* and total biomass estimates based on abundance values obtained from net sampling (Figure 4.2.3). Variability of the phytoplankton time-series is very high, and temporal trends are difficult to detect. In both the eastern Gotland Basin and the Bornholm Basin, the phytoplankton spring bloom was more pronounced during the 1990s. This was caused mainly by a general increase in dinoflagellates (Figure 4.2.4), which was possibly the result of enhanced water-column stability caused by higher winter and spring water temperatures (Wasmund *et al.*, 1998; Alheit *et al.*, 2005). In contrast, diatom time-series demonstrate a slight decrease in biomass, although this was not detectable in the Bornholm Basin in spring. Summer phytoplankton biomass in the Bornholm Basin has decreased slightly in recent years, whereas it remained at a constant level in the eastern Gotland Basin. Apart from climatic effects, there is some evidence that the high summer levels of chlorophyll *a* since the early 1990s could be partly the result of the sprat predation-induced decrease in total zooplankton biomass (Casini *et al.*, 2008).

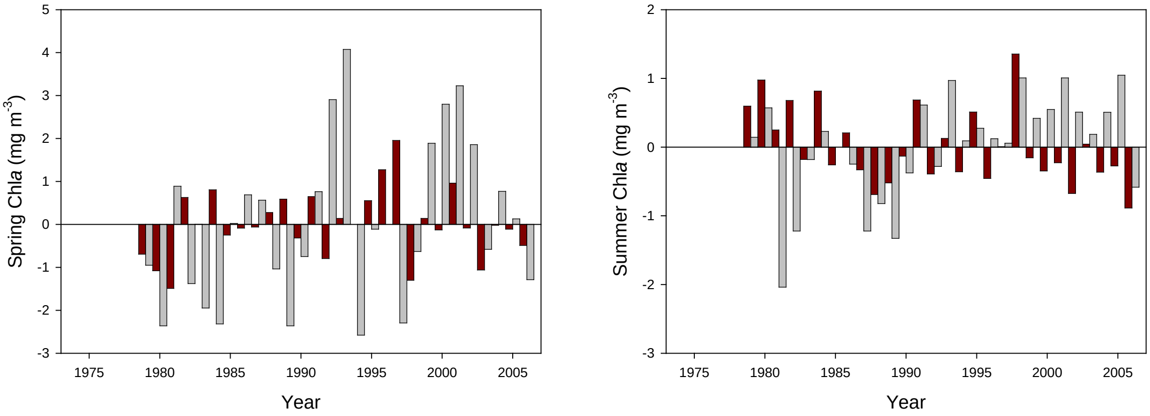


Figure 4.2.3. Long-term changes in phytoplankton biomass in the Bornholm Basin (BB, red) and Gotland Basins (GB, grey). Anomalies of the overall mean for chlorophyll *a*: (left) in spring (BB = 2.5 mg m^{-3}, GB = 3.7 mg m^{-3}); and (right) in summer (BB = 2.1 mg m^{-3}, GB = 2.2 mg m^{-3}).

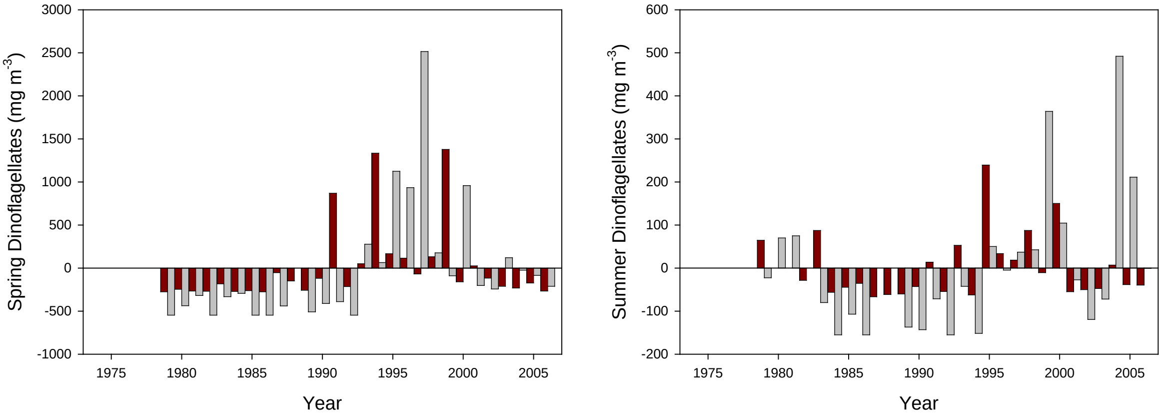


Figure 4.2.4. Long-term changes in dinoflagellate biomass in the Bornholm Basin (BB, red) and Gotland Basin (GB, grey). Anomalies of the overall mean for spring (left; BB = 275.9 mg m^{-3}, GB = 546.8 mg m^{-3}) and summer (right; BB = 66.6 mg m^{-3}, GB = 155.1 mg m^{-3}).

4.2.1.4 Zooplankton

The dominant zooplankton species in the central Baltic Sea are the copepods *Acartia* spp., *Temora longicornis*, and *Pseudocalanus acuspes* (Figure 4.2.5). In spring, a clear shift in dominance occurred, from *P. acuspes* until the end of the 1980s to *Acartia* spp. and *T. longicornis* thereafter. This shift was attributed to decreasing salinities, high sprat-predation pressure (specifically on *P. acuspes*), and increased temperature (favouring *Acartia* spp. and *T. longicornis*; Möllmann and Köster, 2002; Möllmann *et al.*, 2003). During summer, this shift was still visible, despite a higher variability. In summer, a general decrease in total zooplankton biomass was observed, possibly linked to increased predation pressure by sprat (Casini *et al.*, 2008, 2009).

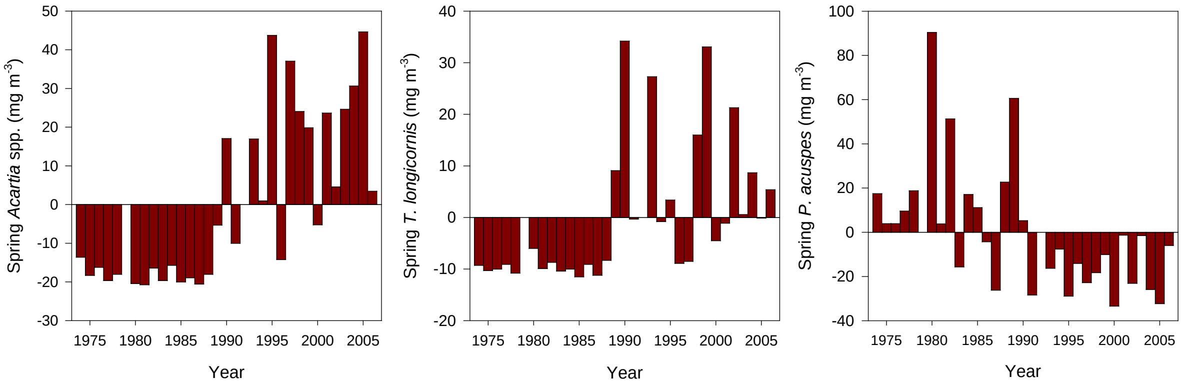


Figure 4.2.5. Long-term changes in zooplankton species composition in the central Baltic Sea in spring. Anomalies of the overall mean for biomass (from left to right): *Acartia* spp. (23.3 mg m^{-3}); *Temora longicornis* (12.1 mg m^{-3}); and *Pseudocalanus acuspes* (41.3 mg m^{-3}).

4.2.1.5 Fish and fisheries

The commercial fish community changed from cod- to sprat-dominated during recent decades (Figure 4.2.6). The cod stock collapsed because of climate-induced recruitment failure and continued high fishing pressure (Köster *et al.*, 2005). Meanwhile, the sprat stock increased to record levels during the 1990s as a result of climate-induced recruitment success and lower predation pressure by cod (Köster *et al.*, 2003; MacKenzie and Köster, 2004). Herring biomass decreased similar to cod. Reasons for this are potentially reduced growth, but also the high fishing pressure and lower recruitment success (ICES, 2008; Figure 4.2.7).

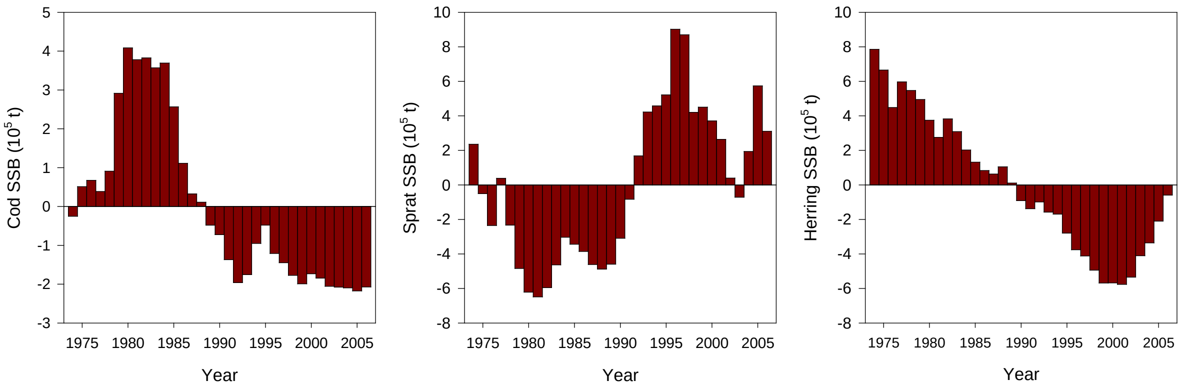


Figure 4.2.6. Long-term changes in fish spawning-stock biomass (SSB) in the central Baltic Sea. Anomalies of the overall mean for (from left to right): cod (2.88 × 10^5 t); sprat (8.65 × 10^5 t); and herring (9.66 × 10^5 t).

Sprat exhibited clear density-dependent responses in individual weight (ICES, 2008), whereas for cod, this relationship broke down in the 1990s. Individual herring weight declined, with stock size stabilizing at low levels after the mid-1990s, partly because of the varying proportion of local populations with variable growth patterns (ICES, 2008). However, a marked herring growth reduction since the late 1980s was observed, probably as a result of competition with the increased sprat stock (Casini *et al.*, 2006; Möllmann *et al.*, 2005). For both pelagic fish species, but especially for herring, the decrease in the population size of the copepod *P. acuspes*, their main food source in spring, was an important factor in reducing individual growth (Möllmann *et al.*, 2003, 2005; Rönkkönen *et al.*, 2004).

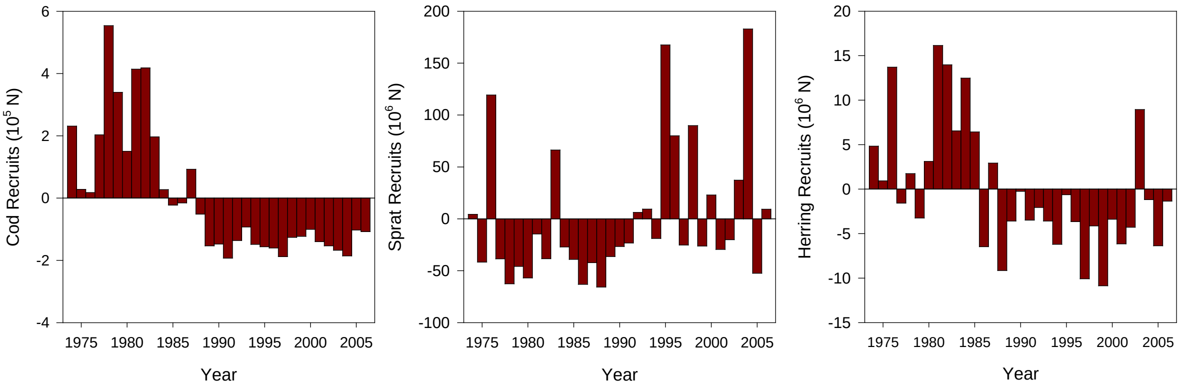


Figure 4.2.7. Long-term changes in fish recruitment in the central Baltic Sea. Anomalies of the overall mean for the number (N) of recruits of (from left to right): cod at age 2 (2.75 × 10^5); sprat at age 1 (79.08 × 10^6); and herring at age 1 (19.26 × 10^6).

4.2.2 Integrated analysis

In total, 59 variables were considered: 17 physical, 8 nutrient, 16 phytoplankton, 6 zooplankton, and 12 fish and fishery-related datasets. All dataseries were compiled to one estimate year^{-1} and covered the period 1974–2007 (see Section 8, Table 8.2, for details of variables).

An overview of the temporal changes of all central Baltic Sea time-series is presented in Figure 4.2.8. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red), with the highest values in the recent 15 years, to variables at the bottom demonstrating the opposite trend (red–green), with the highest values in the late 1970s to early 1980s. The first group of variables comprises, for example, sprat, *Acartia* spp., *T. longicornis*, dinoflagellates, and temperature measures. Decreasing values were found, for example, for cod and herring SSB and recruitment, *P. acuspes* biomass, salinity measures, and the magnitude of the maximum ice extent. Variables with less clear temporal trends are found in the centre of the plot, some of which demonstrate relatively low values in the 1970s/1980s, high values between 1988 and 1993, and, again, low values thereafter. This group consists mainly of indicator time-series related to nutrients and phytoplankton variables. In some cases, lack of data for the 1970s may have affected the sorting procedure.

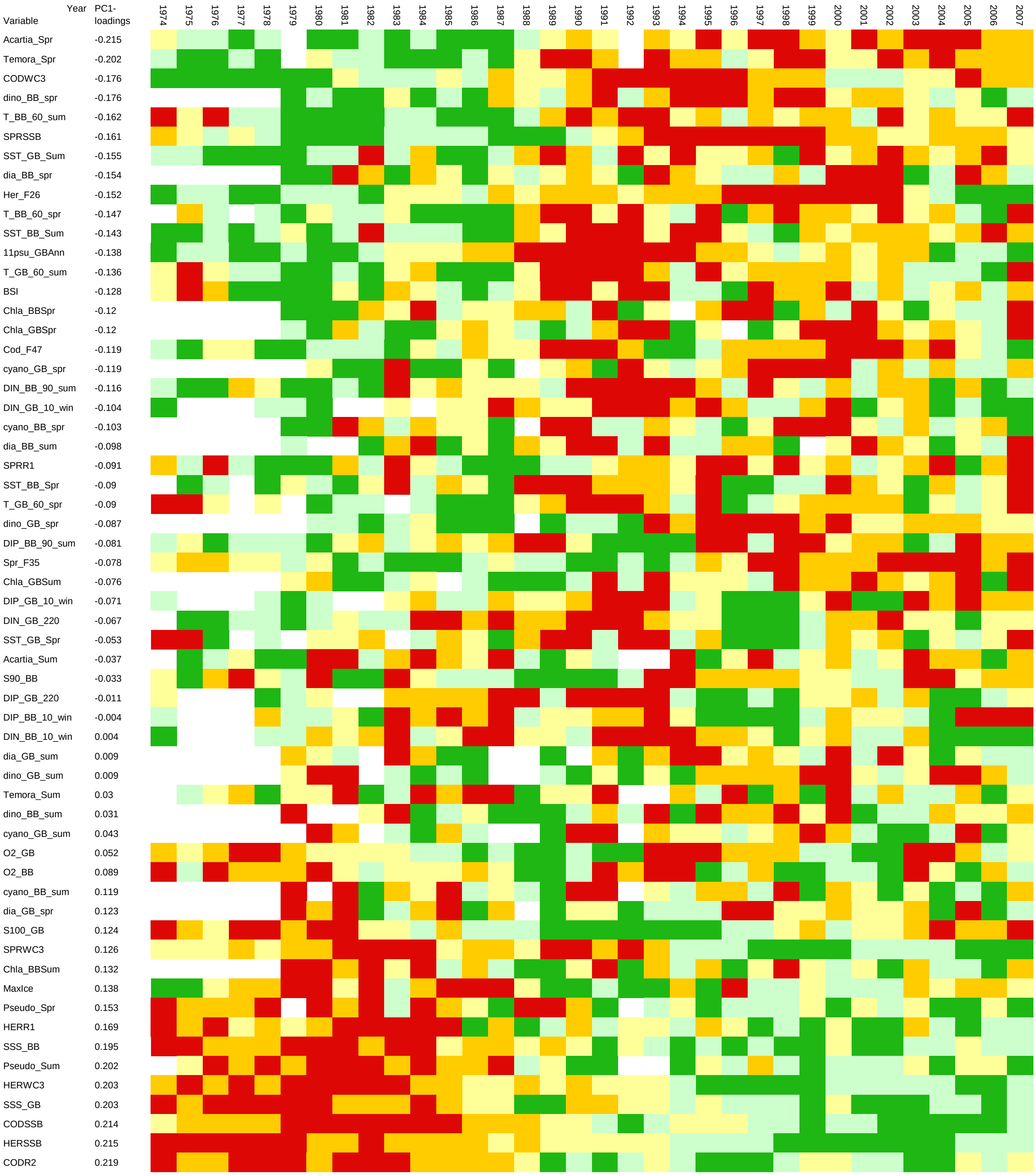


Figure 4.2.8. Traffic-light plot of the temporal development of the central Bothnian Sea time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.2).

The ordination of yearly measures by a standardized PCA resulted in 27.0% and 14.1% of the explained variance on PC1 and PC2, respectively (Figure 4.2.9). Year scores of PC1 display a rapid change from positive to negative values in the early 1990s. The development of PC2 is characterized by a steady decrease until the early 1990s and a sharp increase thereafter. On the first factorial plane (PC1 vs. PC2) changes in ecosystem states most probably occurred in 1987/1988. This was confirmed by STARS, as well as by the results of chronological clustering. Both methods also identified a smaller shift in the early to mid-1980s, possibly caused by the sudden drop in herring and cod SSB and recruitment time-series. This preceded the main shift, which was detectable in the majority of all variables. After the 1993 inflow event, a small shift was observed using STARS on PC2 scores. Since then, the ecosystem state of the central Baltic Sea has remained fairly stable, and variable fluctuations have been comparatively small.

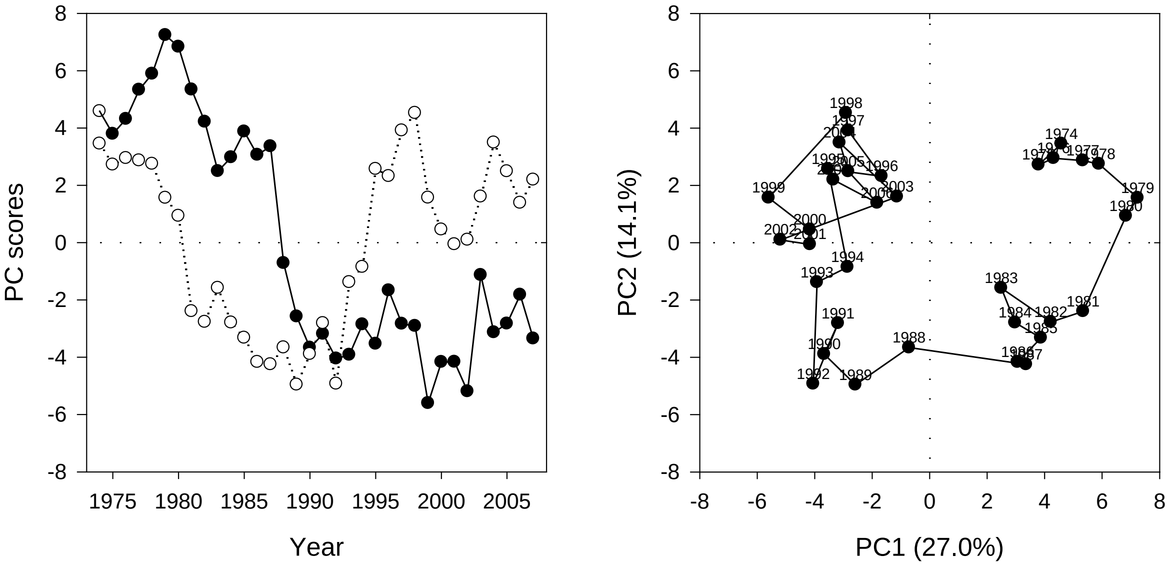


Figure 4.2.9. Results of the standardized principal component analysis (PCA) for the central Baltic Sea using all of the assembled 59 variables: (left) PC scores vs. time (black circles= PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

The relative changes in the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the two PCs (Figure 4.2.10). PC1 mainly reflects temperature (high negative loadings on PC1, indicating an increasing trend over time) and salinity (high positive loadings on PC1, indicating a decreasing trend over time). Highest negative PC1 loadings of biotic time-series were found for species known to have benefited from the recent warming, such as sprat (Köster *et al.*, 2003), *Acartia* spp., and *T. longicornis* (Möllmann *et al.*, 2003), as well as Bornholm Basin dinoflagellates (Wasmund *et al.*, 1998). In contrast, species that suffered from the decrease in salinity, such as cod (Köster *et al.*, 2005), *P. acuspes* (Möllmann *et al.*, 2003), and herring (Möllmann *et al.*, 2005), are negatively correlated with the previous group. Another factor that obviously contributed to the decline in the cod and herring stocks was high fishing pressure (represented as the fishing mortality coefficient (F)). F values for both species have highly negative loadings on PC1, whereas the biomass development of both stocks correlates negatively with fishing pressure and load positively on PC1. PC2 mainly reflects changes that occurred in deep water (i.e. during the long stagnation period until 1993), which decreased deep-water salinity and DO saturation (high positive loadings on PC2). In contrast, deep-water nutrients increased in this period (high negative loadings on PC2). After the reversal of conditions following the 1993 inflow, the same deep-water trends were observed until the recent inflow in 2003.

Generally, the pronounced change in the late 1980s seems to be driven by an increase in temperature resulting from the change in atmospheric forcing reflected by increasing values of the BSI time-series. It affected all ecosystem components and pushed the system into a new state. The smaller shift in 1993–1994 was mainly the result of deep-water-related processes, changes in nutrient loadings (decrease in 1993), and increases in salinity and DO concentrations following the 1993 inflow event. It is thus more a shift in abiotic conditions rather than a change in the whole ecosystem.

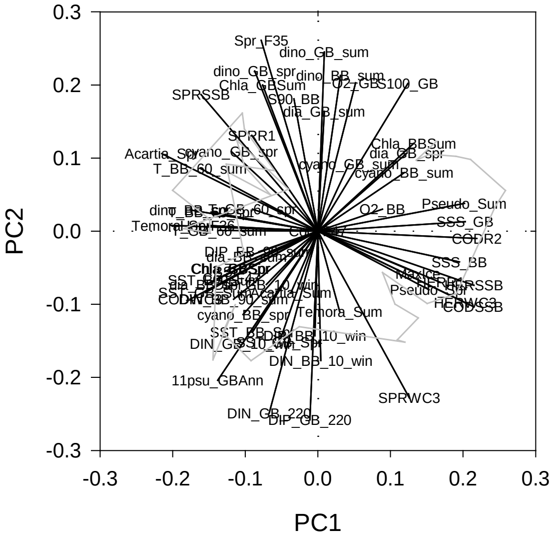


Figure 4.2.10. Results of the standardized principal component analysis (PCA) for the Baltic Sea, using all of the assembled 59 variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.2.9 in shown in light grey).

4.3 Gulf of Riga

The Gulf of Riga is a shallow sub-ecosystem of the Baltic Sea, with restricted water exchange with the surface water of the Baltic proper. It is highly influenced by river run-off, with 18–56 km^3 of freshwater discharging annually into the 424 km^3 of the Gulf. Consequently, it is considered one of the most eutrophic regions of the Baltic Sea (Wassmann and Andrushaitis, 1993; Wasmund *et al.*, 2001). Owing to the shallow sills separating the Gulf of Riga from the Baltic proper, which prevent the inflow of high-salinity water from below the halocline in the Baltic proper, the hydrographical and biological characteristics of the Gulf differ distinctly from those of the western and central Baltic Sea.

4.3.1 Trend analysis

4.3.1.1 Hydrography

The Gulf of Riga lacks a permanent halocline, and the water column is completely mixed during autumn and winter. Freshwater input by precipitation and river run-off, coupled with water exchange with the surface layer of the Baltic proper, determine the salinity in the Gulf. Surface salinity is only ca. 1.5 psu lower than in the adjacent eastern Gotland Sea. However, since the beginning of the time-series, salinity in the upper 50 m decreased gradually until 2002, after which it started to increase again (Figure 4.3.1).

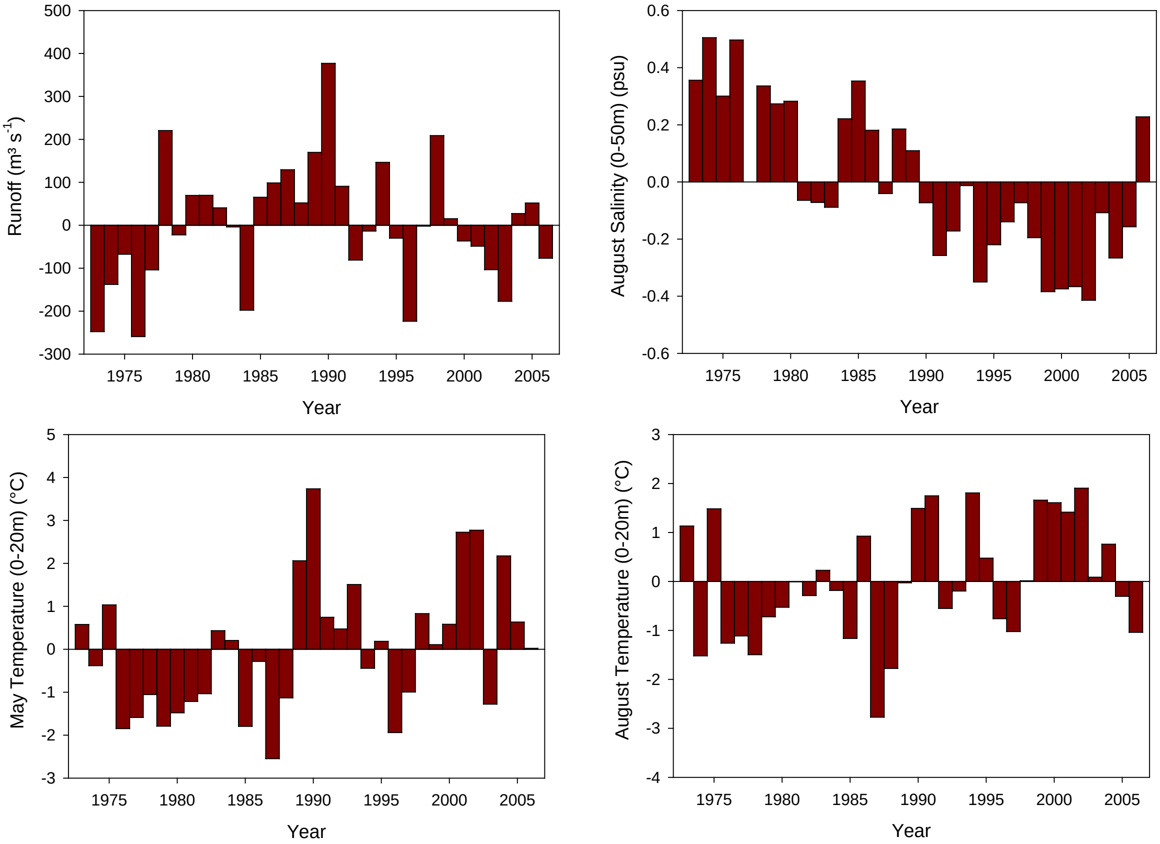


Figure 4.3.1. Long-term hydrographic changes in the Gulf of Riga. Anomalies of the overall mean for (from left to right): run-off ($613\ m^3\ s^{-1}$); salinity in August (5.6 psu); sea surface temperature (SST; 0–20 m) in spring (4.4 °C); and SST in summer (16.2 °C).

From April to September/October, a seasonal thermocline separates the upper 20 m of the water column from the bottom waters. The onset of thermal stratification in spring and the temperature of the surface water layer are determined by spring air temperatures and by conditions during the preceding winter, and the onset is especially delayed following icy winters. Time-series of spring and summer SSTs demonstrate an overall increase from the mid-1970s (Figure 4.3.1).

4.3.1.2 Nutrients

Run-off from the Daugava River (Figure 4.3.1), the largest river draining into the Gulf of Riga, provides a proxy for the nutrient load in the Gulf, especially with respect to nitrogen inputs (Yurkovskis, 2004). River run-off peaked around 1990 and declined thereafter. The decreases in freshwater input and, correspondingly, nutrient loads are reflected in the decrease in winter DIN concentrations in the Gulf. Winter DIP concentrations remained at a high level because phosphorus has a longer residence time in the system and is continually replenished by internal sources in the bottom sediments (Figure 4.3.2).

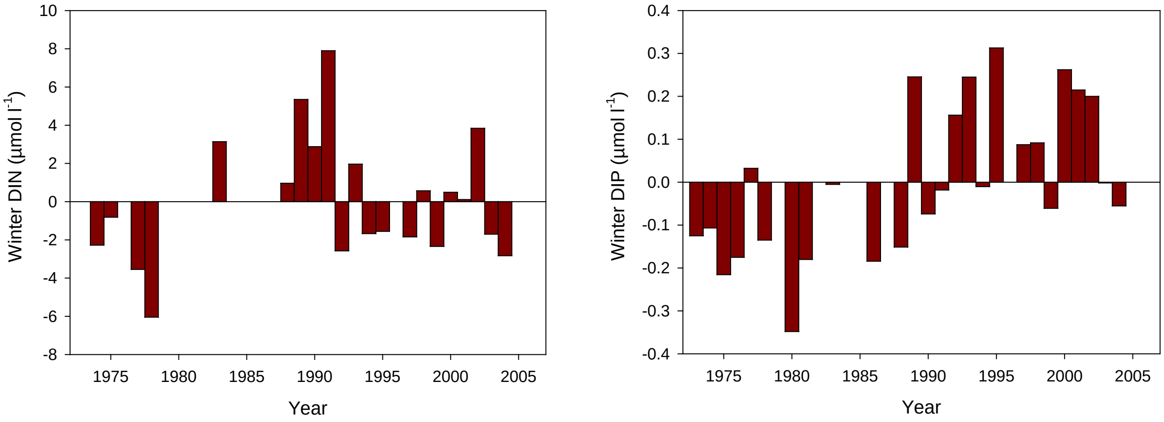


Figure 4.3.2. Long-term changes in nutrient concentrations in the Gulf of Riga in winter. Anomalies of the overall mean for: (left) DIN (dissolved inorganic nitrogen; 11.4 µmol l^{-1}); and (right) DIP (dissolved inorganic phosphorus; 0.8 µmol l^{-1}).

4.3.1.3 Phytoplankton

Phytoplankton development in the Gulf of Riga follows the pattern seen in temperate ecosystems. A pronounced spring bloom, comprised of diatoms and dinoflagellates, occurs after the onset of thermal stratification in April/May and is followed by a short, low-biomass phase in June and a stable summer community in July–August/September. Depending on the onset and dynamics of autumn storms, a diatom-dominated autumn bloom can develop in September/October.

Assessment of the phytoplankton spring-bloom dynamics (Figure 4.3.3), based on available monitoring survey data, is difficult because of the large temporal and spatial variability of the bloom. Long-term trends are more obvious during the relatively stable summer period (Figure 4.3.3). Thus, since the early 1980s, summer chlorophyll *a* values have increased, whereas water transparency has steadily decreased.

The proportion of Cyanobacteria in the summer phytoplankton biomass fluctuated between 25% and 50% in the past ten years (for which detailed species composition data are available). Non-toxic *Aphanizomenon* dominated the Cyanobacteria community (Latvian Institute of Aquatic Ecology, 2008).

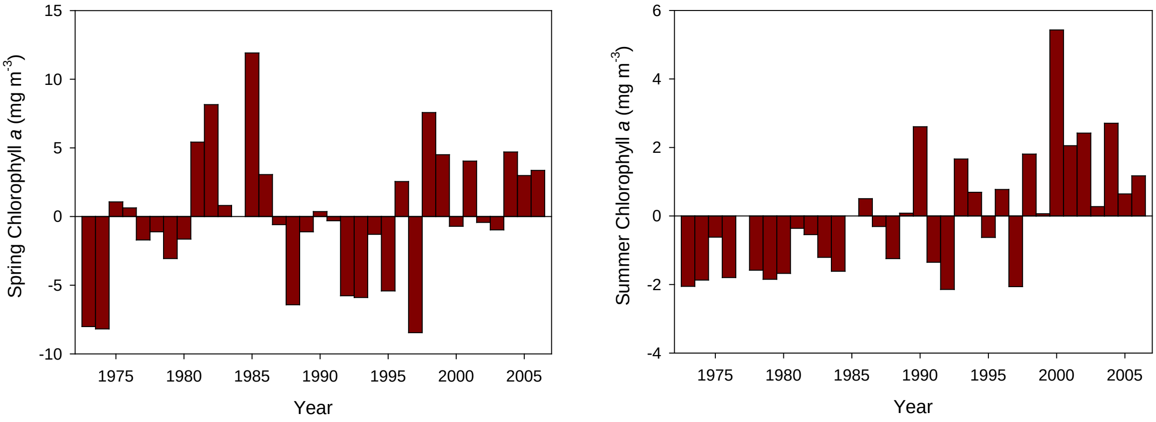


Figure 4.3.3. Long-term changes in phytoplankton biomass in the Gulf of Riga. Anomalies of the overall mean for chlorophyll *a*: (left) in spring (14.3 mg m^{-3}); and (right) in summer (3.5 mg m^{-3}).

4.3.1.4 Zooplankton

Characteristic of the long-term trends in the Gulf of Riga zooplankton community is the increasing biomass of the dominant copepods, *Acartia* spp. and *Eurytemora affinis*, in spring (Figure 4.3.4), which is most probably caused by higher spring temperatures. In contrast, the long-term biomass of these copepod taxa decreased in summer (Figure 4.3.5), possibly as a result of predation pressure from an enlarged herring stock (see below).

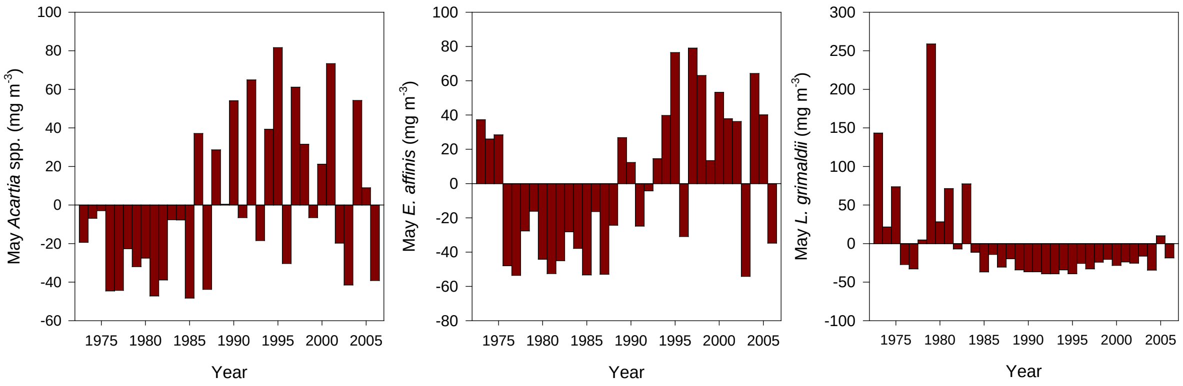


Figure 4.3.4. Long-term changes in zooplankton species composition in the Gulf of Riga in spring. Anomalies of the overall mean for (from left to right): *Acartia* spp. (57.8 mg m^{-3}); *Eurytemora affinis* (60.8 mg m^{-3}); and *Limnocalanus grimaldii* (143.3 mg m^{-3}).

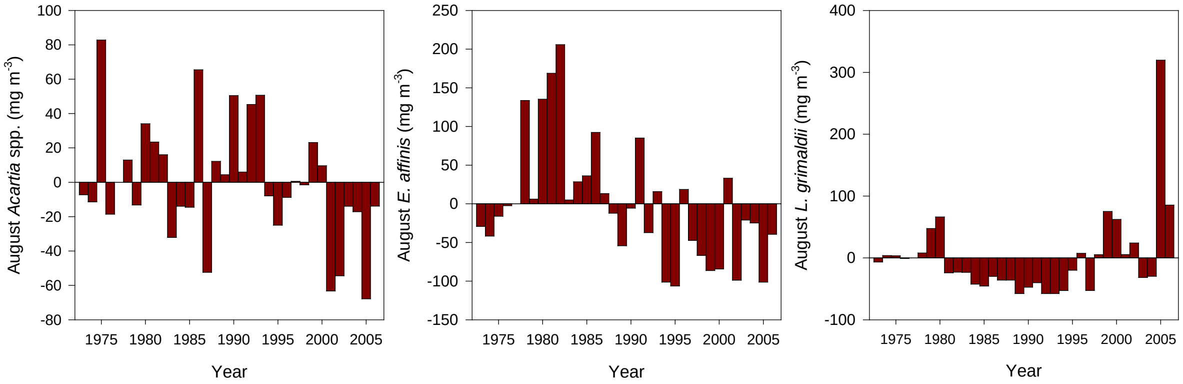


Figure 4.3.5. Long-term changes in zooplankton species composition in the Gulf of Riga in summer. Anomalies of the overall mean for biomass (from left to right): *Acartia* spp. (81.2 mg m^{-3}); *Eurytemora affinis* (157.7 mg m^{-3}); and *Limnocalanus grimaldii* (57.7 mg m^{-3}).

The biomass of the largest zooplankton species in the Gulf of Riga, the glacial relict *Limnocalanus grimaldii*, has been at a low level since the mid-1980s, whereas the summer biomass of this species increased after the early 1990s, reaching values higher than those at the beginning of the time-series. The introduced predatory cladoceran *Cercopagis pengoi* has been a significant component of the zooplankton community in the Gulf since the mid-1990s. Its biomass reached a record high in summer 2007.

4.3.1.5 Fish and fisheries

Herring is the dominant commercial fish species in the Gulf of Riga and the main planktivorous predator. The Gulf of Riga herring forms a separate population, with low growth rates and only very limited migration into the Baltic proper (ICES, 2006b). The herring stock tripled between the mid-1980s and mid-1990s, and since then has remained at a high level (Figure 4.3.6). Recruitment (i.e. number of individuals at age 1) demonstrated some degree of correlation with the development of the spawning stock, but with more pronounced interannual variations. Consequently, SSB was found to be a crucial factor driving herring recruitment in the Gulf (Cardinale *et al.*, 2009). The year-class strength of Gulf of Riga herring is also negatively correlated with cold winters. Therefore, the improved recruitment success observed throughout the time-series might be caused by milder winters and higher spring temperatures (Cardinale *et al.*, 2009). Condition, indicated by herring weight at age 3, dropped in parallel with the stock increase. This could be related to density-dependent processes in combination with changes in the composition of available food.

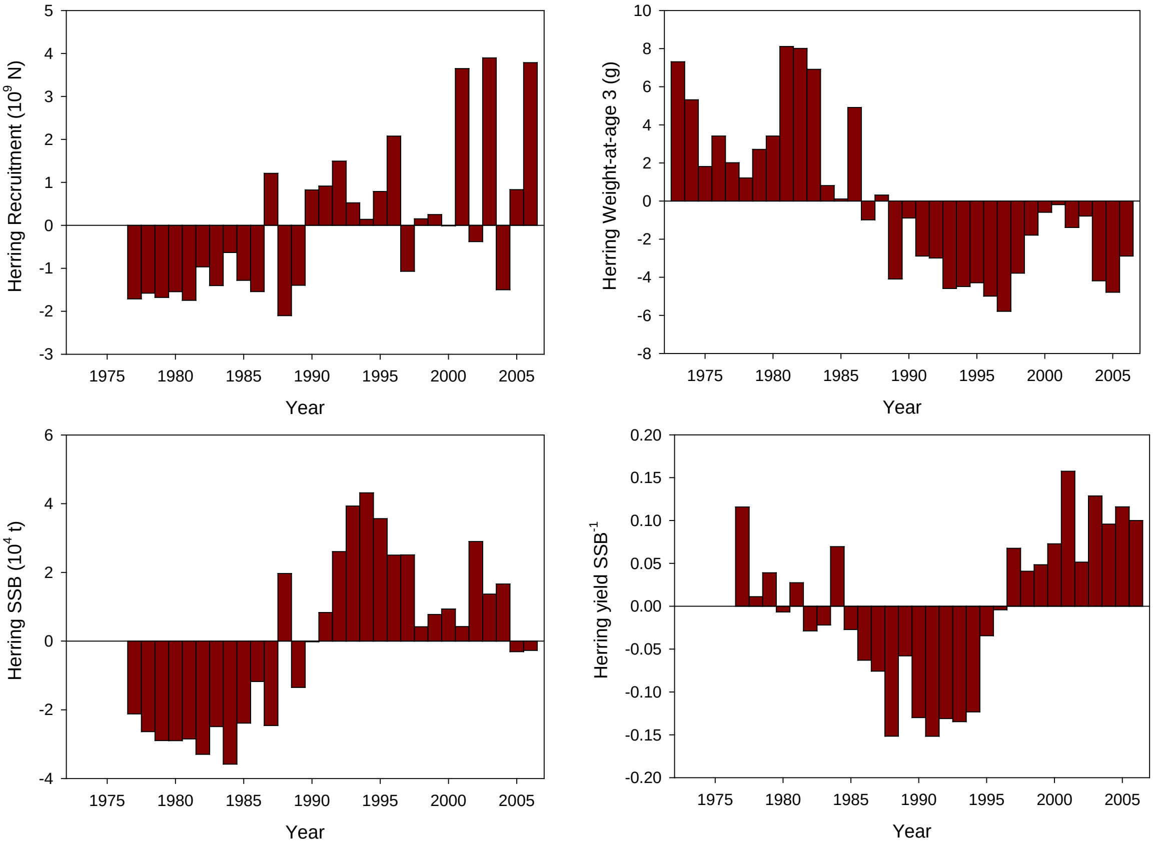


Figure 4.3.6. Long-term changes in herring stocks in the Gulf of Riga. Anomalies of the overall mean for (from left to right): the number (N) of recruits at age 1 (2.654 × 10^9); weight at age 3 (21 g); SSB (spawning-stock biomass; 7.57 × 10^4 t); and yield/SSB (0.33).

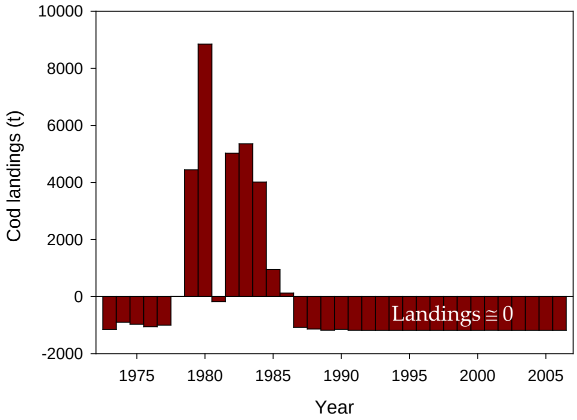


Figure 4.3.7. Long-term changes in cod landings in the Gulf of Riga. Anomalies of the overall mean landings (1184 t).

Cod was only present in the Gulf of Riga at the beginning of the 1980s, when the Baltic cod stock reached its highest level in recent years, and virtually disappeared thereafter (Figure 4.3.7). Its role as main fish predator may have changed the foodweb structure and the fish community. Sprat is permanently encountered in the Gulf of Riga, but its abundance was comparatively low and fluctuated depending on the stock abundance in the central Baltic.

4.3.2 Integrated analysis

In total, 24 variables were considered: 4 physical, 2 nutrient, 4 phytoplankton, 7 zooplankton, and 7 fish- and fishery-related datasets. All dataseries were compiled to one value year^{-1} and covered the period 1973–2007 (see Section 8, Table 8.3, for details of variables).

An overview of the temporal changes of all Gulf of Riga time-series is presented in Figure 4.3.8. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red), with above-median values since the late 1980s, to variables at the bottom demonstrating the opposite trend (red–green), with the highest values at the beginning of the time-series. The first group of variables comprises, for example, herring SSB and recruitment success, biomass estimates of the copepod taxa *Acartia* spp. and *Eurytemora affinis*, and temperature measures or metrics of the invasive species *Cercopagis pengoi*. Variables with a decreasing trend include cod landings, Secchi depths (measured in spring and summer and representing water transparency), and summer salinity in deeper water layers. The colours in the traffic-light plot indicate a sudden decrease or increase in variable values between 1987 and 1989. Only a few variables (eelpout abundance, chlorophyll *a*, and river run-off) failed to demonstrate a clear trend, but fluctuated throughout the investigated period.

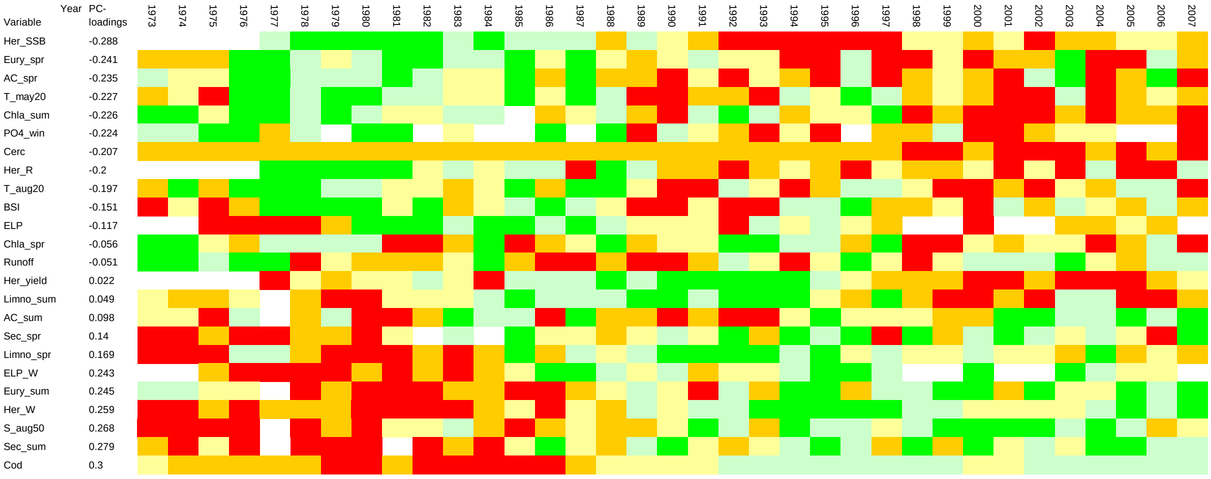


Figure 4.3.8. Traffic-light plot of the temporal development of the Gulf of Riga time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.3).

The ordination of yearly measures by a standardized PCA of all 24 variables resulted in 36.0% and 13.8% of the explained variance on PC1 and PC2, respectively (Figure 4.3.9). Year scores of PC1 dropped abruptly from positive to negative values following 1988 and remained negative thereafter. PC2 scores demonstrated a unimodal development, with the lowest values in the early 1990s, but similar scores at the beginning and end of the period. On the first factorial plane (PC1 vs. PC2), the shift in the late 1980s is well identified, although the ecosystem following this change seemed to be less stable than in the 1970s to mid-1980s.

The sequential regime shift analysis (STARS, using PC1 scores) and chronological clustering (using all variables) identified the most pronounced shifts, in 1986–1987 and 1988–1989, respectively. This small discrepancy is caused by the different methodological approaches. Although the PC scores used for STARS summarize the overall variability of the data, chronological clustering uses each single variable to identify the shift. Variables with an increasing trend were more numerous, and there was an identifiable change in 1988–1989 (Figure 4.3.8). STARS also identified a break in the mid-1990s, whereas chronological clustering determined it to be slightly later, in 1997–1998.

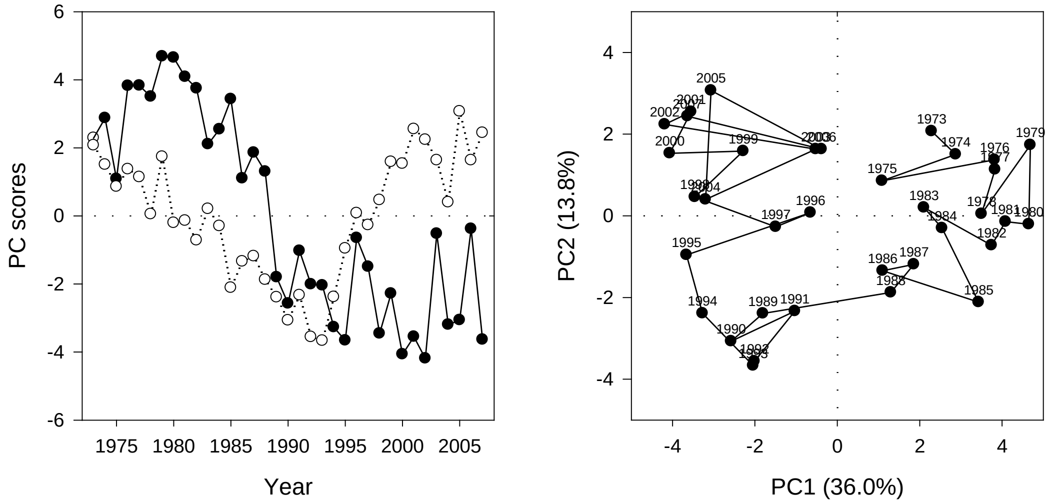


Figure 4.3.9 Results of the standardized principal component analysis (PCA) for the Gulf of Riga using all of the 24 assembled variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

Independently of the methods used to identify abrupt changes, the investigated period can be divided into three different states. The first and last periods were mainly related to variables correlated with PC1, whereas the intermediate period was characterized by extreme values of variables correlated with PC2 (Figure 4.3.10). The period from the 1970s to late 1980s was characterized by cold but fairly saline conditions, with low spring zooplankton biomass, low herring stock size, and the presence of cod in the Gulf. After the strong shift in the late 1980s, contrasting conditions were found, with the addition of decreasing freshwater input and high winter phosphate concentrations. Furthermore, an intermediate period from the late 1980s to the mid-1990s was identified, when changes occurred mainly along the PC2 axis. This period was characterized by comparatively high river run-off and low fishing pressure on herring, as well as high biomass estimates of *Acartia* spp. and a contrastingly low biomass of *Limnocalanus grimaldii* (both measured in summer). These variables shifted back to their pristine conditions thereafter.

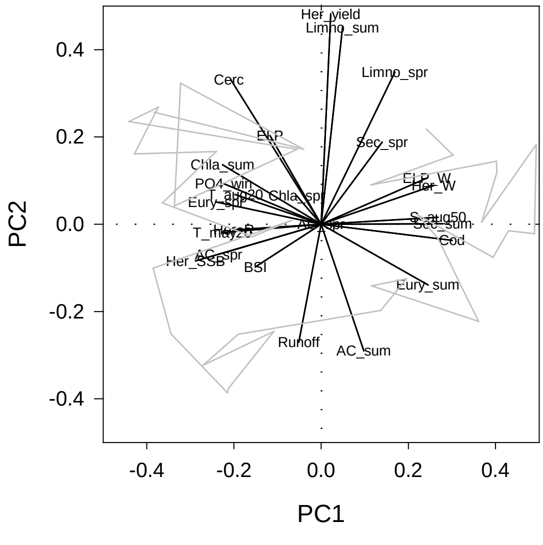


Figure 4.3.10 Results of the standardized principal component analysis (PCA), using all of the 24 assembled variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.3.9 is shown in light grey).

The PCA results indicate that climatic and eutrophication-related signals are important drivers for the ecosystem dynamics in the Gulf of Riga. Furthermore, the dynamics of the herring stock seem to have a significant influence on the structure of the system. All of these factors are strongly correlated with PC1. Winter DIP dynamics are further decoupled from the freshwater input, which is consistent with the long residence time of phosphorus in the Gulf (Savchuk, 2002) leading to prolonged internal loading from bottom sediments. Productivity, as reflected by summer chlorophyll *a* levels, is linked to the phosphorus pool as the ultimately limiting nutrient, whereas the spring zooplankton dynamics are most probably related to the warming of the Gulf. Summer zooplankton trends are opposite to those in spring, suggesting top–down control by the increasing herring stock.

4.4 Gulf of Finland

The Gulf of Finland is the easternmost Baltic system and its hydrographic situation strongly depends on the conditions found in the central Baltic Sea. As no sill separates the two areas, deep, stagnated water can enter the Gulf, with short-term consequences on salinity and DO conditions. Oxygen deficiency is also the result of a long-term increase in the load of internal nutrients, especially phosphate.

The basic flow pattern in the Gulf of Finland is one of inflowing water along the south coast of the Gulf, which then traverses the eastern end and flows out along the north coast. The Neva River, which is the largest river in the Baltic Sea drainage area, runs into the Gulf. Hence, the Gulf obtains significant nutrient loads not only from its adjacent coast but also from the more-distant drainage area.

During winter, the Gulf of Finland is usually ice-covered at the coast, and at least to the longitude of Suursaari Island, can be completely covered with ice. The extent of ice cover has profound effects on the seasonal dynamics of the system. When the surface is covered with ice, strong winds cannot mix the water column. This may lead to anoxic conditions in near-bottom layers, a decrease in the biomass of benthic organisms, and an increase in nutrients through internal processes. However, the river run-off spreads far under the ice, thus attenuating the situation. In years, when the central Gulf is ice-free, gale-force winds can entirely mix the water column and thus oxygenate the near-bottom layers. Nevertheless, during spring and early summer, stratification can build up rapidly, again resulting in deep-water stagnation.

4.4.1 Trend analysis

The trend analysis covers, at a minimum, the period of the HELCOM Monitoring Programme (i.e. from 1979 to the present). The monitoring is performed by the Finnish Environment Institute's Marine Centre (formerly the Finnish Institute of Marine Research (FIMR)) and the Estonian Marine Institute (EMI).

4.4.1.1 Hydrography

Similar to other areas, the SST of the Gulf of Finland has increased, whereas surface and bottom salinities have generally decreased (Figure 4.4.1). Only recently summer bottom salinities again reached above-average values, apparently as a result of deep-water intrusion from the central Baltic Sea. During the long stagnation period until 1993, the halocline in the Gulf of Finland disappeared because no saline water was transported into the Gulf. This resulted in the full convection of the water column and, hence, oxygenation of near-bottom layers. Consequently, benthic communities flourished during the late 1980s and early 1990s. This situation ended with the 1993 inflow event (Laine *et al.*, 2007). Recent hydrographic trends are towards higher temperatures, lower surface salinities, and increased periods of deep-water anoxia.

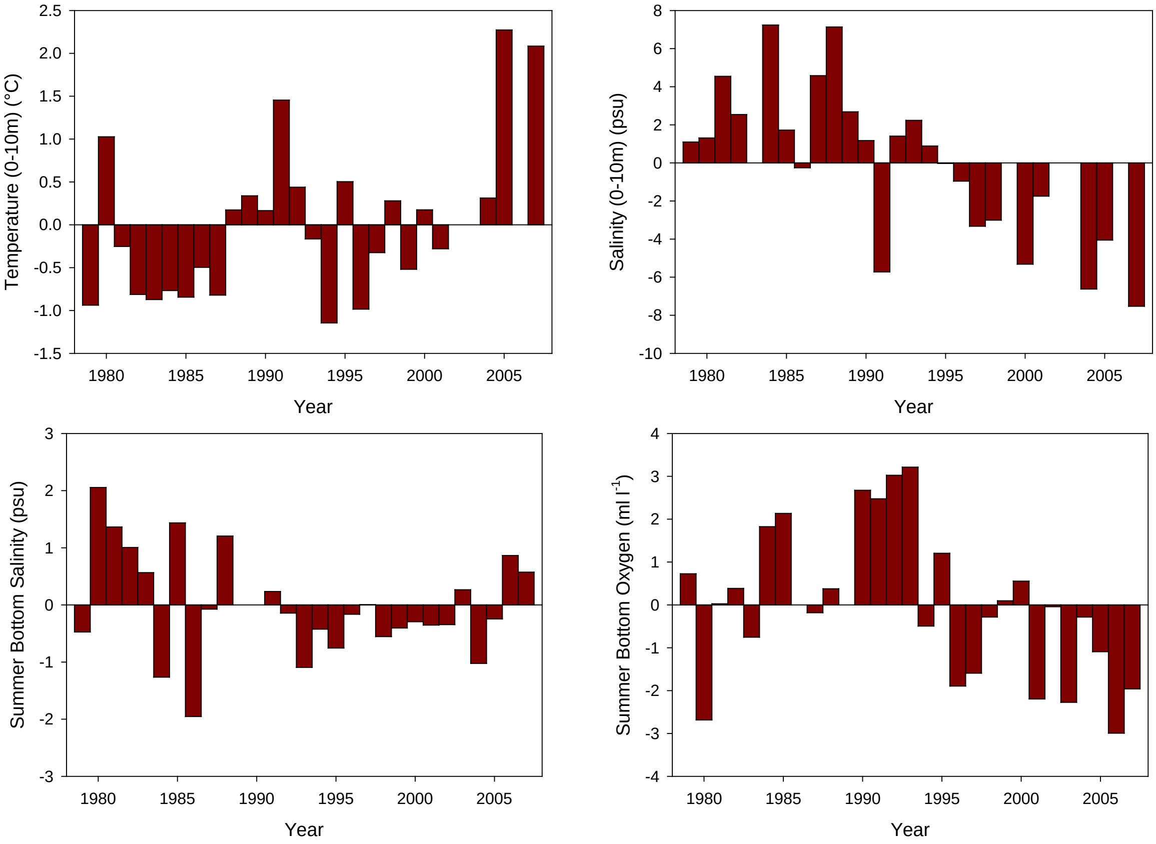


Figure 4.4.1. Long-term hydrographic changes in the Gulf of Finland. Anomalies of the overall mean for (from left to right): sea surface temperature in winter (0.6 °C); sea surface salinity in winter (12.6 psu); bottom-water (>30 m) salinity in summer (6.4 psu); and bottom-water (>30 m) dissolved oxygen content in summer (3.0 ml l^{-1}).

4.4.1.2 Nutrients

A marked increase in DIP in winter and summer since the mid-1990s was observed and attributed to high nutrient input as well as internal loading (Figure 4.4.2.). The latter was caused by prolonged anoxic conditions in near-bottom waters following inflow events and the establishment of a permanent halocline, which facilitate phosphorus release from sediments. High concentrations of phosphorus in summer mean a phosphorus surplus after the spring bloom, which in turn can amplify blue-green algal blooms. A slight decrease in DIN was observed after the early 1990s, followed by a steady increase in more recent years. The winter values given here are for the DIN concentrations after mixing, and represent the concentrations available for the phytoplankton spring bloom, which is generally nitrogen-restricted.

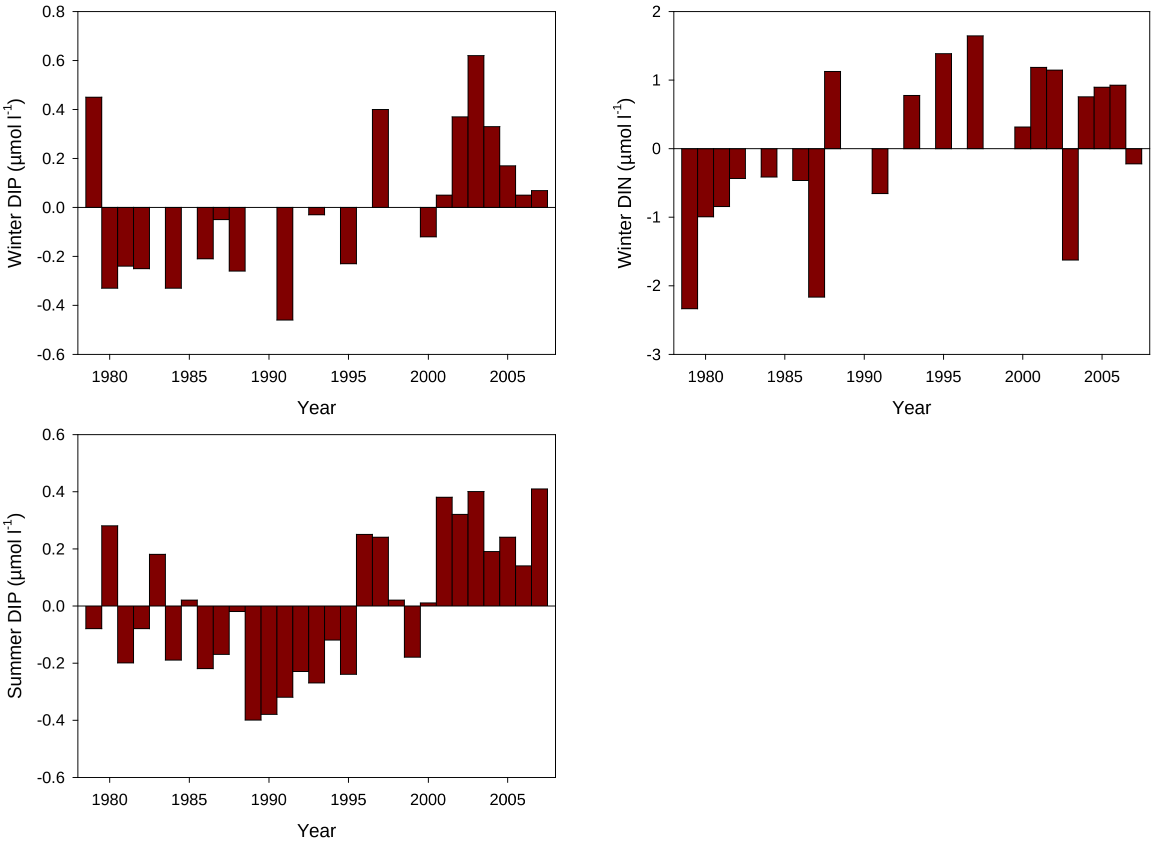


Figure 4.4.2. Long-term changes in nutrient concentrations in the Gulf of Finland. Anomalies of the overall mean for: (top) DIP (dissolved inorganic phosphorus; 1.0 µmol l^{-1}) and DIN (dissolved inorganic nitrogen; 6.6 µmol l^{-1}) in winter; and (bottom) DIP in summer (0.7 µmol l^{-1}).

Spatially, the concentrations of both nutrients increased towards the eastern parts of the Gulf. This can be explained by the effect of the River Neva, which discharges into the easternmost end of the Gulf, and the River Kymijoki, which discharges into the Gulf at approximately 27°E.

4.4.1.3 Phytoplankton and zooplankton

Chlorophyll *a* concentration, representing phytoplankton biomass, increased nearly monotonically in the Gulf of Finland (Figure 4.4.3). The seasonal distribution of chlorophyll *a* is strongly dependent on spring blooms, with another peak in late summer to early autumn. Significant contributors to this latter peak are Cyanobacteria, which, by this time of the year, represent 40–80% of the total phytoplankton biomass.

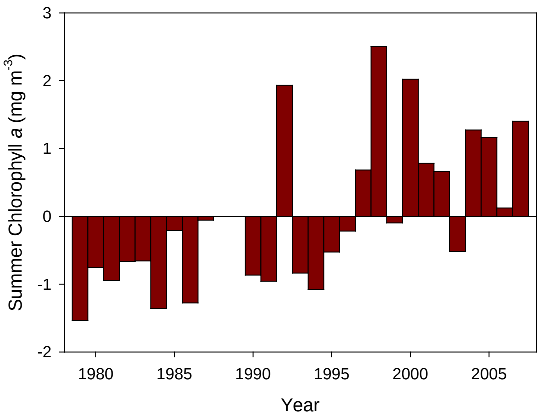


Figure 4.4.3. Long-term changes in phytoplankton biomass in the Gulf of Finland. Anomalies of the overall mean for chlorophyll *a* in summer (2.9 mg m^{-3}).

Total zooplankton biomass did not demonstrate any clear time-trends. However, on the species level, the trends found in the Gulf of Finland were similar to those in the central Baltic Sea. In terms of biomass, *Pseudocalanus acuspes* displayed a significant decreasing trend, whereas other copepod species, such as *Temora longicornis* and *Eurytemora* spp. were slightly increasing (Figure 4.4.4). This was especially evident in summer 2007, when *T. longicornis* and *Eurytemora* spp. abundance was highest in relation to the entire observation period. It should be noted that only one sampling campaign was performed each summer, so observations may be biased by short-term events.

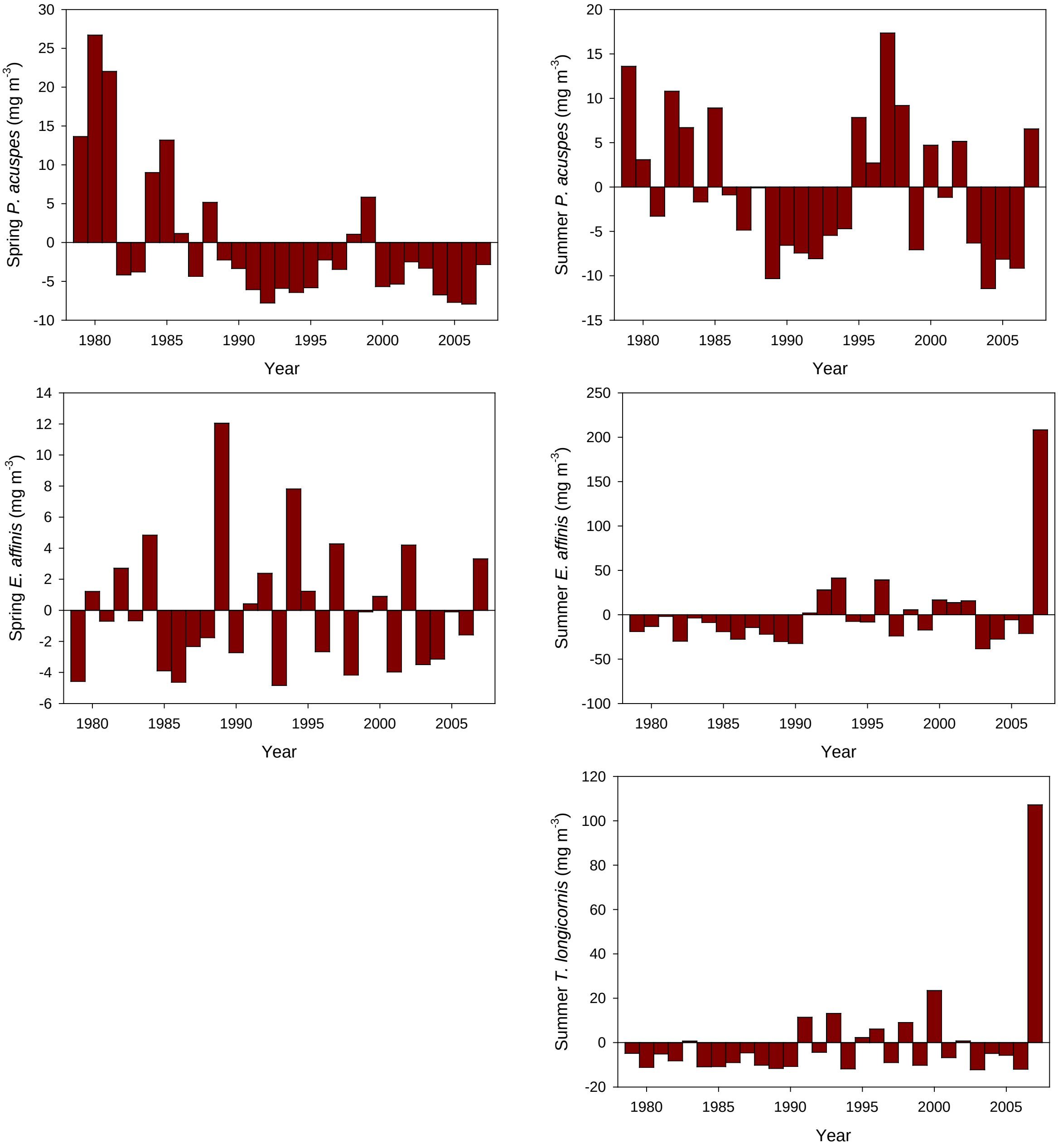


Figure 4.4.4. Long-term changes in zooplankton species composition in the Gulf of Finland. Anomalies of the overall mean for estimated biomass of (from right to left): *Pseudocalanus* spp. in spring and in summer (8.64 and 13.73 mg m^{-3}); *Eurytemora affinis* in spring and in summer (5.38 and 38.90 mg m^{-3}); and *Temora longicornis* in summer (13.02 mg m^{-3}).

4.4.1.4 Fish and fisheries

No separate fish stock assessments are performed for the Gulf of Finland. However, by using catch statistics from Estonian and Finnish sources, a general picture of fish stock sizes can be developed (Figure 4.4.5).

Landings of sprat, herring, and salmon (*Salmo salar*) have fluctuated strongly in the past 30 years. Sprat catches were comparatively low until the mid-1990s, when a strong increase was recorded, with the highest landings in the year 2000. In contrast, herring catches decreased after the late 1980s and have remained on a historically low level in recent years. Salmon and trout (*Salmo trutta*) landings peaked in the early 1990s, but decreased again, with a low level of landings, similar to those at the beginning of the time-series. The general downward trend in fish stocks other than sprat was attributed to a decrease in salinity and the more frequent occurrence of anoxic conditions.

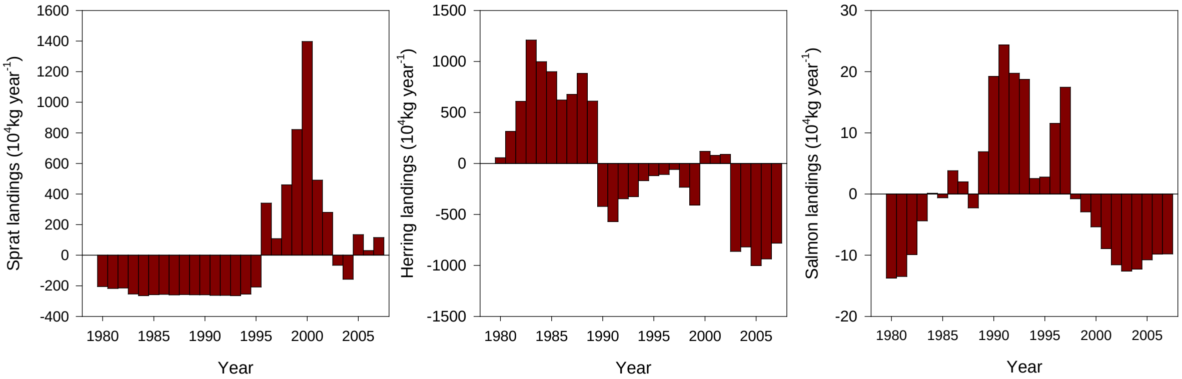


Figure 4.4.5. Long-term changes in landings of fish in the Gulf of Finland. Anomalies of the overall mean for (from left to right): herring (1078 × 10^4 kg year^{-1}); sprat (267.8 × 10^4 kg year^{-1}); and salmon (16.48 × 10^4 kg year^{-1}).

4.4.2 Integrated analysis

In total, 30 variables were considered: 8 physical, 4 nutrient, 1 phytoplankton, 10 zooplankton, and 7 fish- and fishery-related datasets. All dataseries were compiled to one value year^{-1} and covered the period 1979–2008 (see Section 8, Table 8.4, for details of variables).

An overview of the temporal changes of all Gulf of Finland time-series is presented in Figure 4.4.6. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red) and variables at the bottom demonstrating the opposite trend (red–green), with the highest values in the first 10–15 years of the time-series. The first group comprises sprat catches, phosphate loadings in winter and summer, chlorophyll *a* concentrations, and upper layer temperatures in winter. Decreasing trends were found for herring biomass and catches, upper-layer salinities (winter), and weight at age 3 of sprat (probably the result of density-dependent processes). In contrast to the other investigated systems, many variables demonstrated no significant trend, which means that high and low values were found throughout the investigated period. This includes various estimates of zooplankton biomass and measurements of summer temperature and salinity.

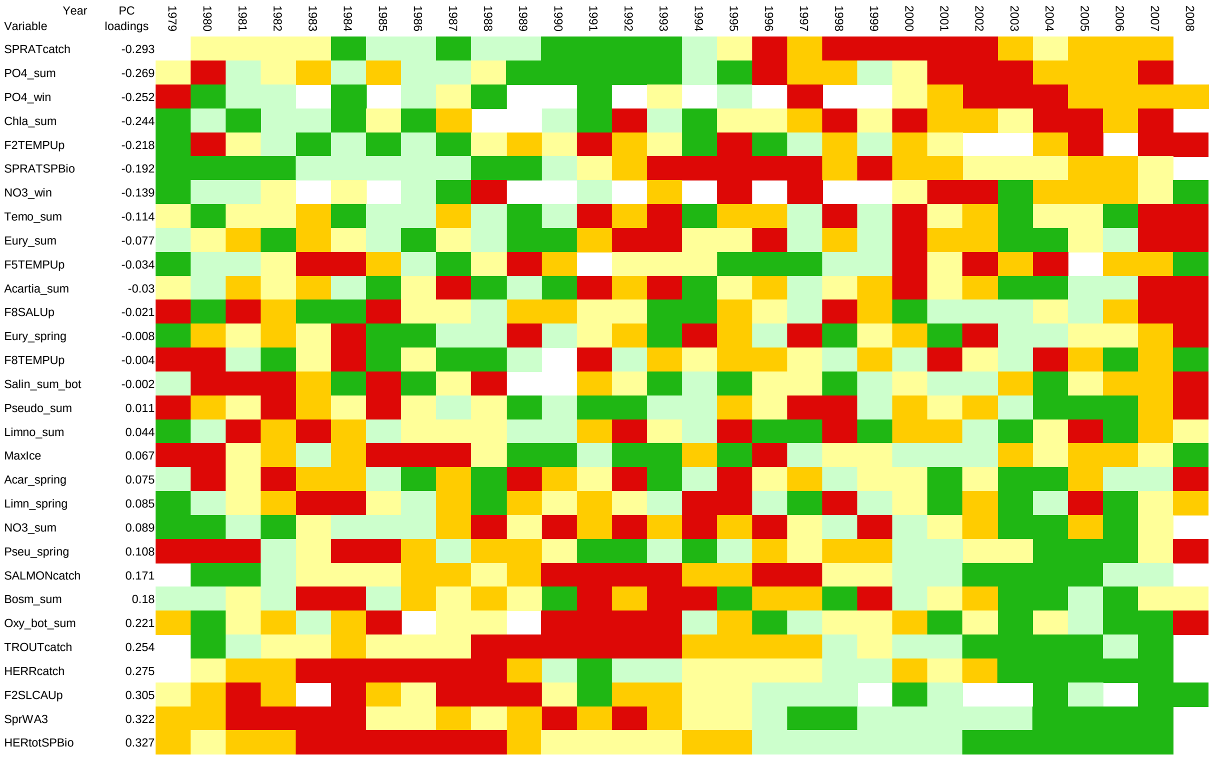


Figure 4.4.6. Traffic-light plot of the temporal development of the Gulf of Finland time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.4).

The ordination of yearly measures by a standardized PCA resulted in 26.7% and 17.3% of the explained variance on PC1 and PC2, respectively (Figure 4.4.7). Year scores of PC1 displayed a rapid change from positive to negative values between 1994 and 1998. PC2 scores are rather variable, with no clearly detectable trend. On the first factorial plane (PC1 vs. PC2) a change in the mid-1990s along PC1 and the high variability along the PC2 axis, especially after 2000, is visible (Figure 4.4.7). Chronological clustering identified three overall shifts in the dataseries, which divides the time-series into four distinct periods: 1979–1988, 1989–1995, 1996–2002, and 2003–2008. STARS detected one shift on the first axis (1994–1995) and two breakpoints on the second axis (1990–1991 and 2006–2007). However, RSI values were comparatively small, ranging between 0.14 and 0.24. This illustrates that the Gulf of Finland is a highly variable system, and changes can occur relatively frequently, but without reaching a new ecosystem state.

According to the variable loadings (Figure 4.4.8), salinity and temperature, measured in February in the upper layers, are negatively correlated and both are strongly associated with PC1. Conditions in the Gulf depend on saltwater inflows from the central Baltic Sea, but responses are diametrically opposite. Inflow events strengthen the vertical stratification, which can lead to anoxic conditions in near-bottom layers that adversely affect benthic organisms. This is consistent with the observed decrease in DO concentrations following the strong inflow event in 1993. During stagnation periods, like that of 1984–1993, stratification dissolved and deep-water layers became well oxygenated, which induced thriving benthic communities (Laine *et al.*, 2007), with positive effects for the entire Gulf of Finland foodweb. Increasing temperatures may have been beneficial for the sprat stock, whereas the herring stock is currently at a low level. Zooplankton organisms were all correlated with PC2, and thus demonstrated high interannual fluctuations. *Pseudocalanus acuspes*, as a true marine species, was negatively correlated with the other zooplankton taxa and positively correlated with salinity. Furthermore, phosphate loadings from the drainage basin, as well as internal loading, were clearly increasing over time. The effects on the ecosystem, however, remained ambiguous.

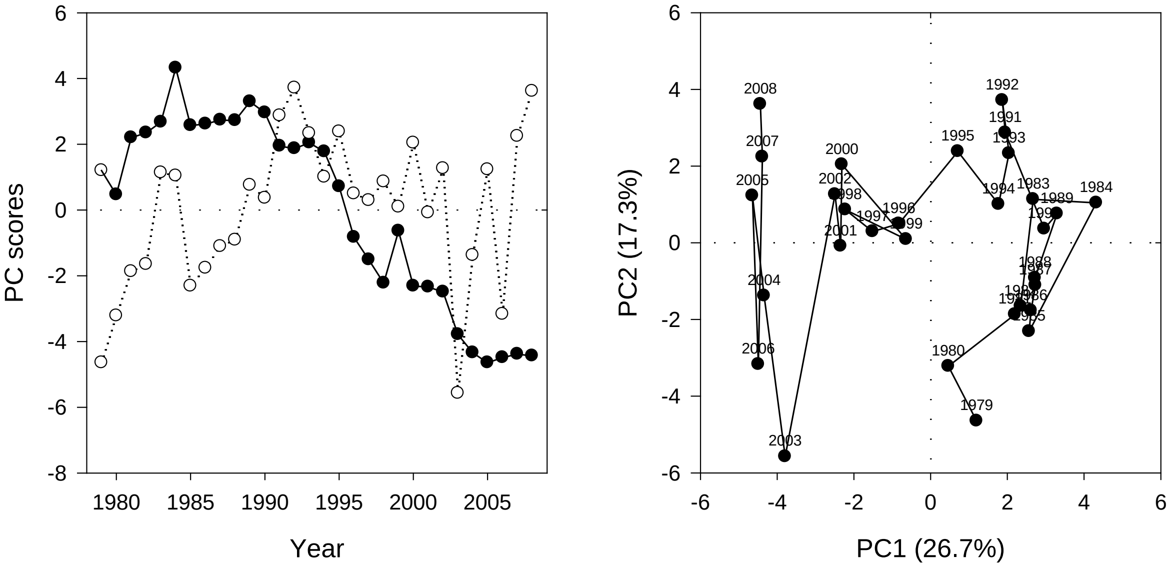


Figure 4.4.7 Results of the standardized principal component analysis (PCA) for the Gulf of Finland using all of the 30 assembled variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

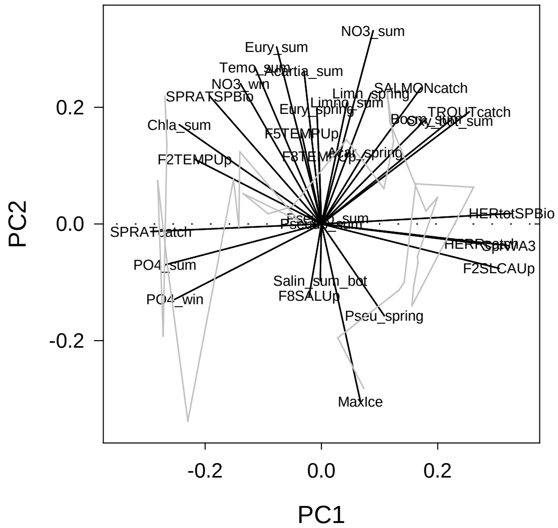


Figure 4.4.8 Results of the standardized principal component analysis (PCA) for the Gulf of Finland, using all of the assembled 30 variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.4.7 is shown in light grey).

4.5 Bothnian Sea

The Bothnian Sea has a surface area of ca. 70 000 km² and is separated by shallow sills in the south and north (the northern and the southern Quarks). The sills limit water exchange with surrounding areas, and thereby maintain the characteristic hydrographical properties and biotic communities of the Bothnian Sea area. Salinity increases with depth, from ca. 3–5 psu in the surface waters to 7 psu in the bottom waters, but there is no permanent halocline. The water below the thermocline is often well mixed (Voipio, 1981), and DO deficiencies are not commonly observed in offshore bottom areas (HELCOM, 2009). The salinity of the Bothnian Sea is strongly affected by the outflow of freshwater from rivers, but regular inflows of saline water from the south allow the persistence of marine species. Examples of marine species in the Bothnian Sea include the zooplankton species *Pseudocalanus acuspes* and *Temora longicornis,* and fish species such as herring. The phytoplankton community is nitrogen-limited generally, but increasingly phosphorus-limited further north (Granéli *et al.,* 1990; Andersson *et al.,* 1996).

4.5.1 Trend analysis

4.5.1.1 Hydrography

Summer SSTs have generally increased over the last 30 years, although year-to-year variability was high. In contrast, a decreasing trend in winter SSTs was observed, with the lowest temperatures measured in 2002. Pronounced decreasing trends were also found for bottom salinities and pH. The first may be the result of fewer inflow events into the Bothnian Sea, coinciding with increasing river run-off or precipitation. Lower pH values may be important because they can affect productivity by altering the carbon–carbonate balance (Riebesell *et al.,* 2000, 2007; Figure 4.5.1).

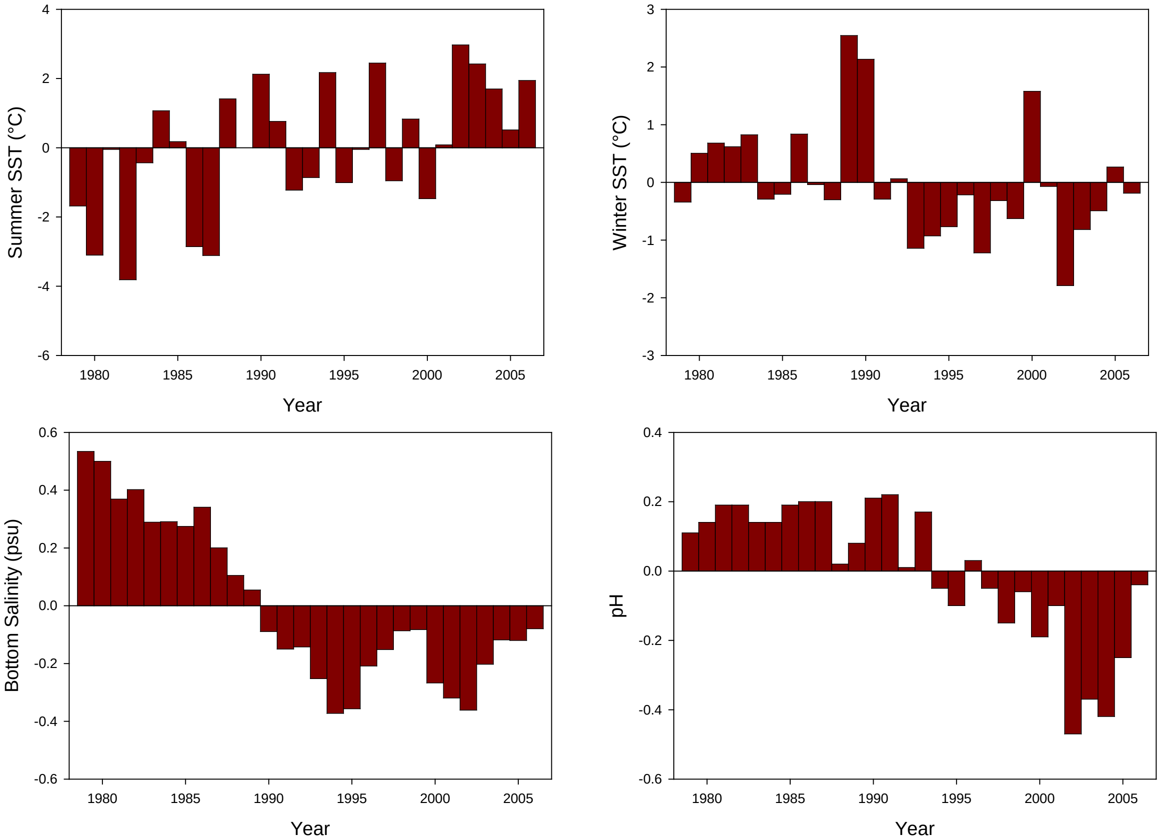


Figure 4.5.1. Long-term hydrographic changes in the Bothnian Sea. Anomalies of the overall mean for (from left to right): sea surface temperature (SST) in summer (4.0 °C); SST in winter (14.3 °C); bottom salinity in winter (6.0 psu); annual average pH values (8.1).

4.5.1.2 Nutrients

The levels of DIN and DIP in winter have increased since the 1970s (Figure 4.5.2). However, in more recent years (2003–2005), below-average DIN concentrations have been observed. DIN and DIP levels were not correlated with nutrient loads in river run-off in the western drainage basins of the Bothnian Sea, which fluctuated, with no clear trend, over the respective period. Additionally, no change was observed in the total loading of silicate, which can be used as an indicator of total run-off volume from these western rivers. It is unknown how this loading from the western drainage basins (Sweden) correlates with total loading into the Bothnian Sea because data from the eastern drainage basins are lacking. Moreover, the nutrient status of the Bothnian Sea also depends on the inflow of water from the central Baltic Sea basin.

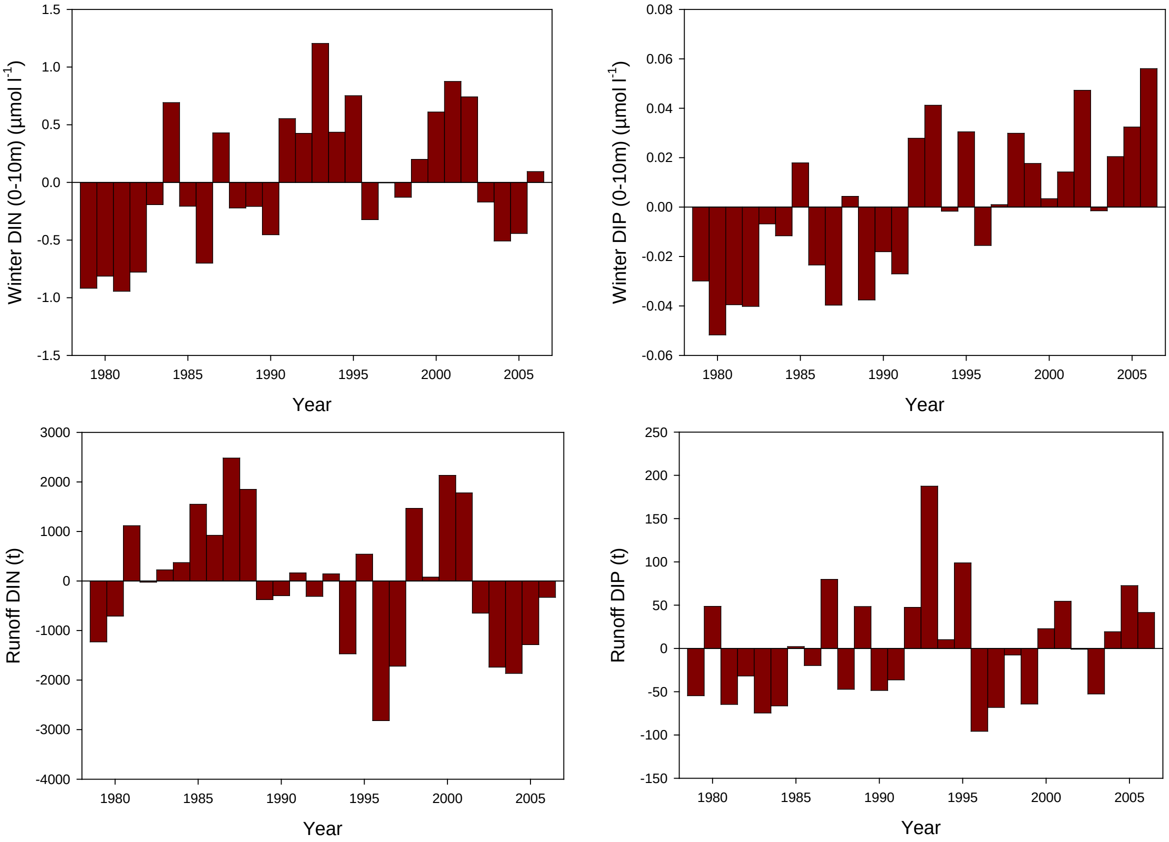


Figure 4.5.2. Long-term changes in nutrient concentrations in the Bothnian Sea. Anomalies of the overall mean for: (top) surface DIN (dissolved inorganic nitrogen; 2.88 µmol l^{-1}) and DIP (dissolved inorganic phosphorus; 0.18 µmol l^{-1}) in winter; and (bottom) total annual nutrient loads from run-off water from the western drainage basins, indicated by total DIN (7499 t) and DIP (216 t).

4.5.1.3 Phytoplankton

No clear trends were observed in the summer biomass of diatoms, dinoflagellates, and Cyanobacteria (Figure 4.5.3). However, the concentration of chlorophyll *a*, which is an indicator of the standing stock of phytoplankton biomass, was relatively low at the beginning of the time-series, since when it has almost doubled, with pronounced fluctuations around the overall mean. The increasing trend is in accordance with the increase in nutrient concentrations observed in the Bothnian Sea.

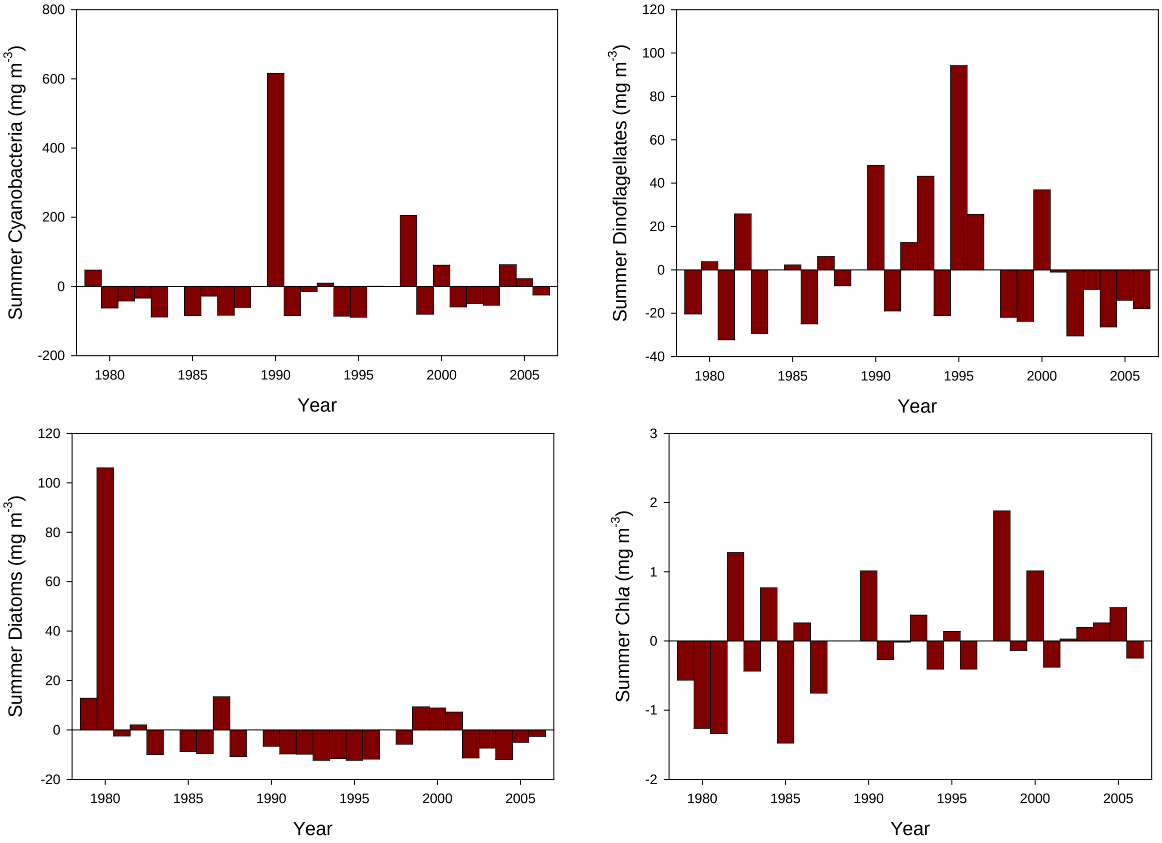


Figure 4.5.3. Long-term changes in phytoplankton biomass in the Bothnian Sea in summer. Anomalies of the overall mean for (from left to right): Cyanobacteria (98.0 mg m^{-3}); dinoflagellates (44.4 mg m^{-3}); and diatoms (13.3 mg m^{-3}); plus chlorophyll *a* content (2.23 mg m^{-3}).

4.5.1.4 Zooplankton

The brackish-water cladoceran *Bosmina* demonstrated extremely high biomass in 2001, 2002, and 2006. It is uncertain whether or not this tendency towards higher biomass will persist in subsequent years. The other cladoceran species, *Podon* spp. and *Evadne* spp., generally occurred at lower biomass levels and did not demonstrate any trend in recent years (Figure 4.5.4).

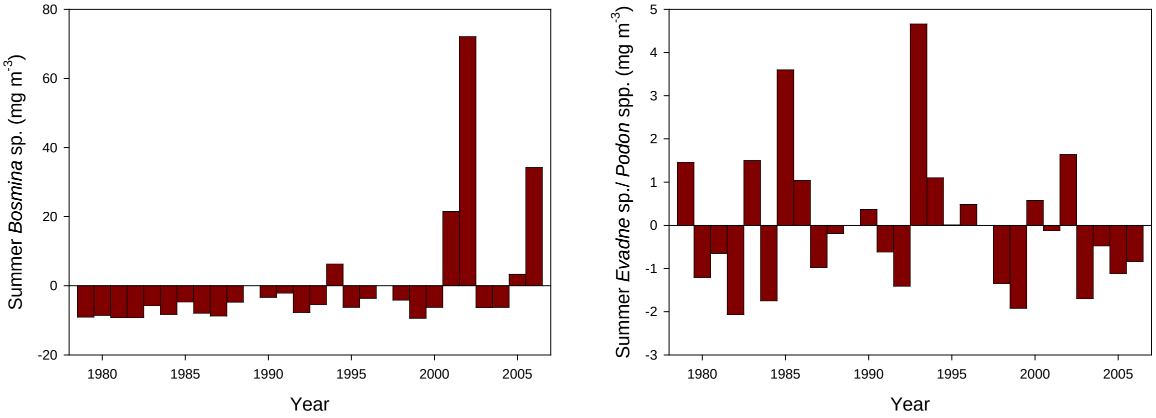


Figure 4.5.4. Long-term changes in the cladoceran community of the Bothnian Sea in summer. Anomalies of the overall mean for biomass for: (left) *Bosmina* spp. (9.42 mg m^{-3}); and (right) *Evadne* spp. and *Podon* spp. (combined; 2.36 mg m^{-3}).

The copepod community is a mixture of marine, brackish, and generally euryhaline species (Figure 4.5.5). In parallel with the lower salinities measured in near-bottom layers, the biomass of the marine copepod *Pseudocalanus acuspes* decreased markedly and has remained at a low level since 1988. Likewise, the biomass of the euryhaline copepod *Acartia* spp. decreased, with its lowest biomass in 1999. The brackish-water species *Limnocalanus* spp. demonstrates the opposite trend, with a largely above-average biomass since 1993. The temporal development of *Eurytemora* spp. biomass remains ambiguous.

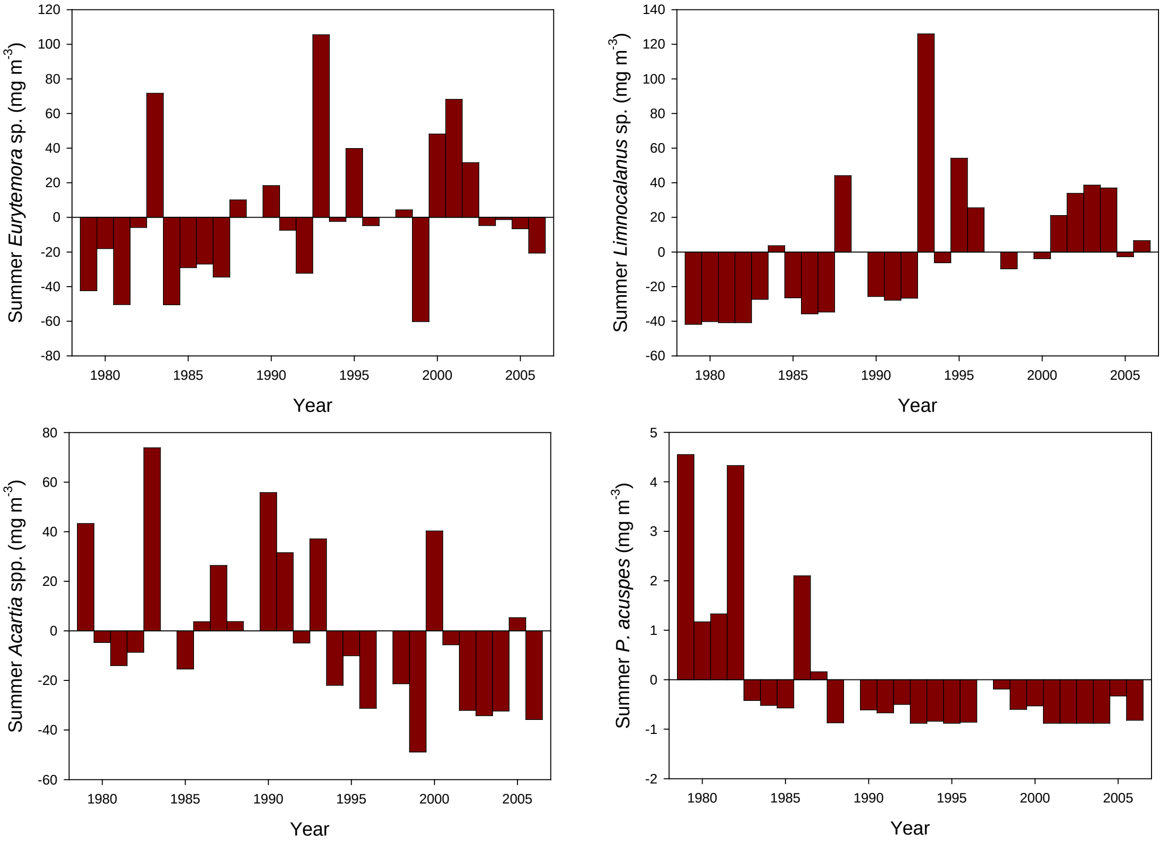


Figure 4.5.5. Long-term changes in the biomass of the copepod community of the Bothnian Sea in summer. Anomalies of the overall mean for (from left to right): *Eurytemora* spp. (69.76 mg m^{-3}); *Limnocalanus* spp. (43.41 mg m^{-3}); *Acartia* spp. (50.48 mg m^{-3}); and *Pseudocalanus acuspes* (0.88 mg m^{-3}).

4.5.1.5 Zoobenthos

Zoobenthos biomass data were studied in one coastal area (Figure 4.5.6) and in offshore areas (Figure 4.5.7). In the coastal area, the bivalve *Macoma baltica*, the dominant benthic organism, and the isopod *Saduria entomon* generally increased, although, in *S. entomon*, this was partly driven by the all-time high biomass measured in 2004. Biomass of the amphipod *Monoporeia affinis* decreased strongly after 1989, but, demonstrated above-average biomass again in the last two years of the time-series. In the offshore area, the zoobenthic community is species-poor and is strongly dominated by *Monoporeia* and *Saduria*. *Monoporeia* increased until the mid-1990s, after which it declined again, whereas *Saduria*, although undergoing cycles, demonstrated an overall decreasing trend throughout the investigated period.

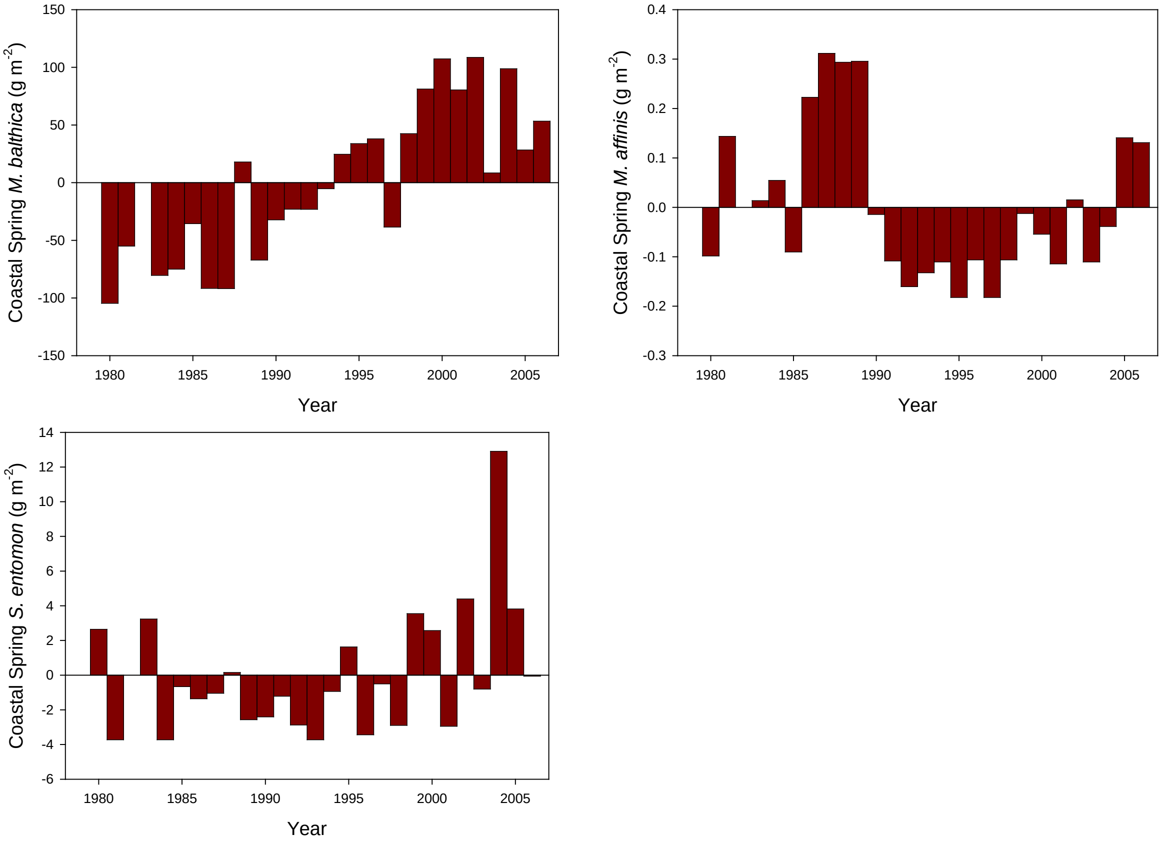


Figure 4.5.6. Long-term changes in the biomass of the benthos community on the coast of the southern Bothnian Sea in spring. Anomalies of the overall means for (from left to right): *Macoma balthica* (151.03 g m^{-2}); *Monoporeia affinis* (0.18 g m^{-2}); and *Saduria entomon* (3.73 g m^{-2}).

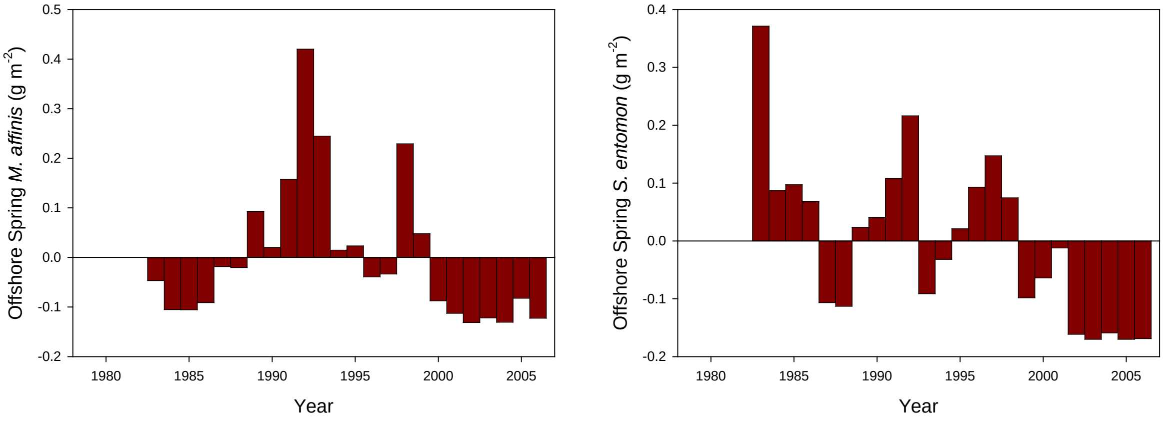


Figure 4.5.7. Long-term changes in the biomass of the offshore benthos community of the Bothnian Sea in spring. Anomalies of the overall mean for: (left) *Monoporeia affinis* (0.13 g m^{-2}), and (right) *Saduria entomon* (0.17 g m^{-2}).

4.5.1.6 Fish and fisheries

Data on selected coastal freshwater fish demonstrated that catch per unit effort (cpue) of perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) almost doubled from the mid-1970s to the mid-1990s (Figure 4.5.8). Thereafter, cpue decreased again. However, the cpue of perch was at an all-time high in 2006.

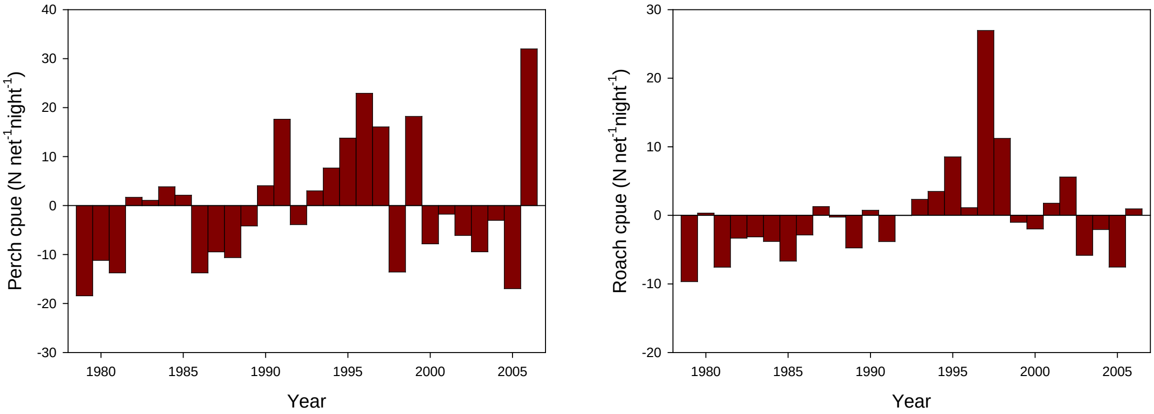


Figure 4.5.8. Long-term changes in catch per unit effort (cpue) (in numbers, N) of freshwater fish off the southwest coast of the Bothnian Sea. Anomalies of the overall mean for: (left) perch (25.8 net^{-1} night^{-1}); and (right) roach (10.4 net^{-1} night^{-1}).

Data on herring biomass and recruitment, obtained from WGBFAS (ICES, 2007b), demonstrated an even more drastic increase at the end of the 1980s (Figure 4.5.9). For example, mean recruitment of herring in the period 1990–2006 was almost twice as high as in 1973–1989, with extraordinarily high recruitment in 2003. However, these estimates are not independent from data on fishing effort. In parallel with the increase in herring biomass, weight-at-age decreased by 25–45%, as observed for herring populations throughout the Baltic Sea (ICES, 2008).

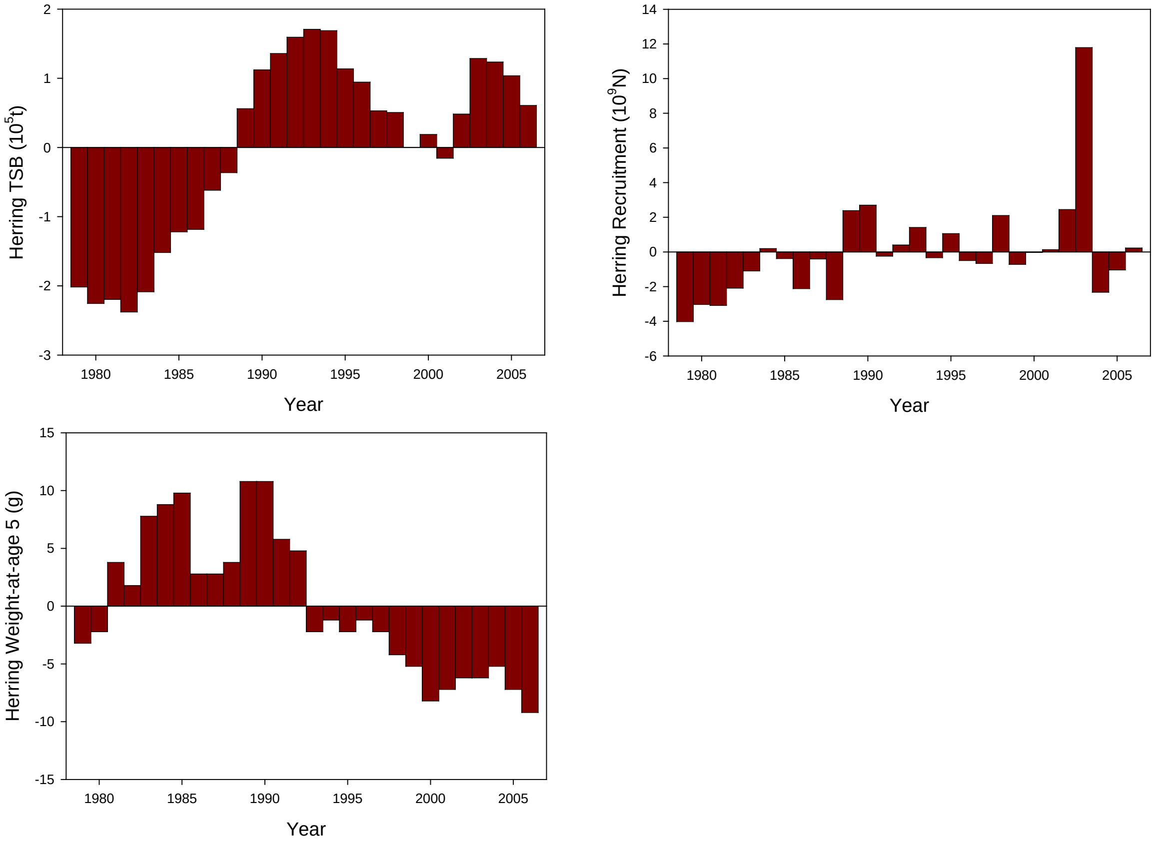


Figure 4.5.9. Long-term changes in the herring stock of the Bothnian Sea. Anomalies of the overall mean for (from left to right): total-stock biomass (TSB; 3.665 × 10^5 t), number (N) of recruits at age 1 (4.521 × 10^9), and weight at age 5 (36.2 g).

4.5.1.7 Seals

The number of grey seals (*Halichoerus grypus*) in an area in the southern Bothnian Sea increased markedly since monitoring began in 1989 (Figure 4.5.10). In the last two decades, numbers have more than doubled. The result is in accordance with estimates for the entire population in the Bothnian Sea, which has increased ca. 7.5% annually since 1990 (Karlsson and Helander, 2004).

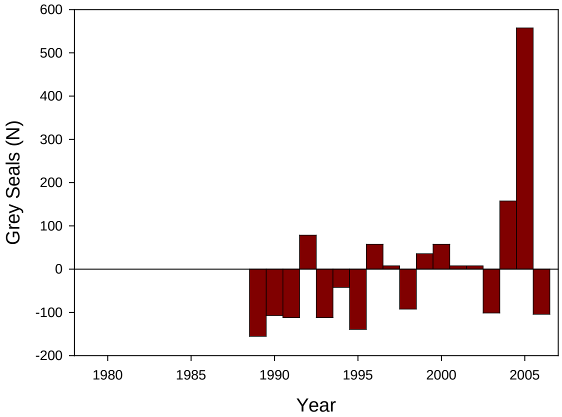


Figure 4.5.10. Long-term changes in the number of grey seals in an area in the southern Bothnian Sea. Anomalies of the overall mean for the total number (N) of individuals (342.4).

4.5.1.8 Fishing effort

Fishing effort data from the Finnish herring fishery in the Bothnian Sea were obtained from the WGBFAS (ICES, 2007b). In these data, hours fished from the pelagic and demersal trawl fishery were multiplied by an annually updated trawl-size coefficient to correct for increased efficiency. Total corrected fishing effort for both trawl fisheries is summed herein. The herring fishery displayed pronounced changes (Figure 4.5.11), with trapnet fishing being replaced by massive trawl fishing; the two fisheries thus demonstrate opposite trends.

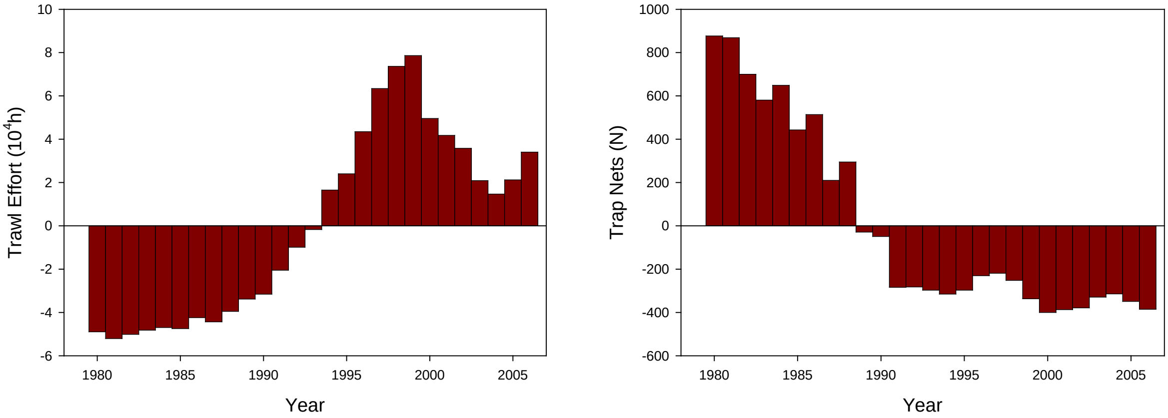


Figure 4.5.11. Long-term changes in fishing effort in the Finnish herring fishery in the Bothnian Sea. Anomalies of the overall mean for: (left) the combined pelagic and demersal trawling effort (56 367 h); and (right) the number (N) of trapnets (582).

4.5.2 Integrated analysis

In total, 35 variables were considered: 6 physical, 5 nutrient, 5 phytoplankton, 6 zooplankton, 5 benthos, 1 top predator (seal), and 7 fish- and fishery-related datasets. All dataseries were compiled to one value year^{-1} and covered the period 1979–2006 (see Section 8, Table 8.5, for details of variables).

An overview of the temporal changes of all Bothnian Sea time-series is presented in Figure 4.5.12. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red), with above-average values since the early 1990s, and variables at the bottom demonstrating opposite trends (red–green). The first group of variables comprises fishing effort (trawling hours), herring total-stock biomass (TSB) and recruitment, phosphate and nitrate loadings, SST, biomass of *Limnocalanus* and *Bosmina*, and abundance of seals. A strong decrease in variable values following 1987 was found for bottom salinities, *Pseudocalanus acuspes* biomass, number of trapnets, and offshore biomass of *Saduria entomon*. A number of variables, including bottom temperature, chlorophyll *a* concentrations, *Evadne* and *Podon* biomass, and perch cpue, demonstrated no clear trends over time.

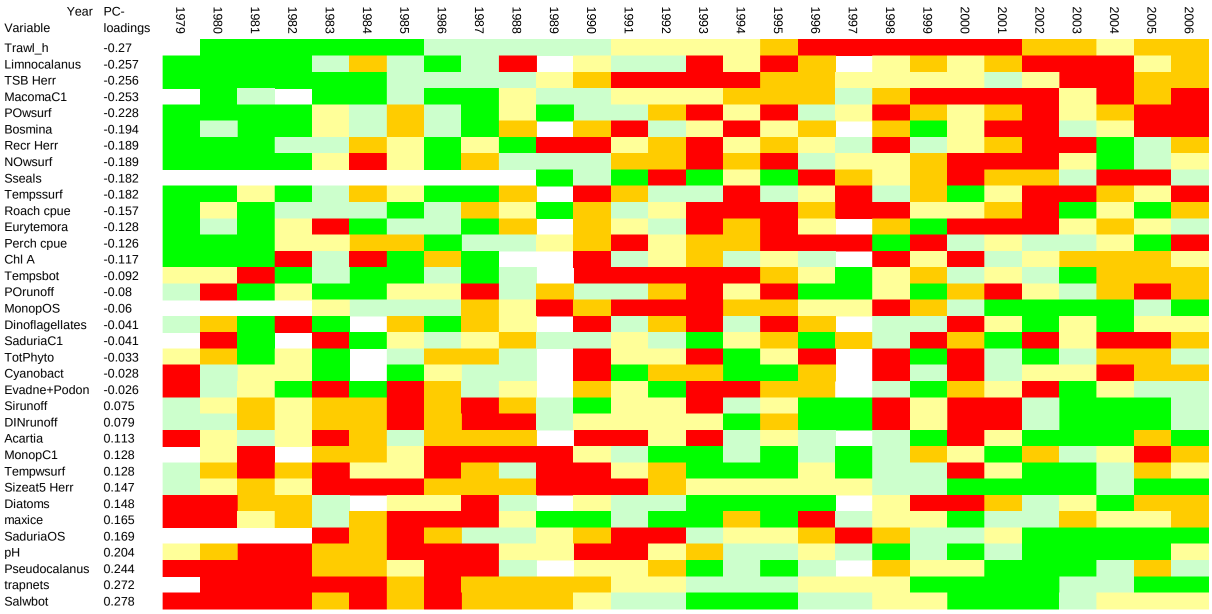


Figure 4.5.12. Traffic-light plot of the temporal development of the Bothnian Sea time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.5).

The ordination of the full dataset by a standardized PCA resulted in 33.8% and 12.2% of the explained variance on PC1 and PC2, respectively (Figure 4.5.13). Year scores of PC1 demonstrated a clear decreasing trend, with the most pronounced changes between 1987 and 1993. Scores dropped to negative values in 1990 and have since remained negative. PC2 scores were increasing in the first half of the investigated period, with the highest values observed in 1993, but decreased thereafter. The first factorial plane (PC1 vs. PC2) also illustrates that the variance in the dataset was highest in the late 1980s to early 1990s. Both types of discontinuity analyses confirmed this. A high RSI value was found on the PC1 axis for the years 1987–1988 (RSI = 2.27) and weaker shifts on the PC2 axis in 1988–1989 and 1998–1999. Chronological clustering also identified a shift in 1988–1989. An additional shift was detected in the early 1980s (1982–1983), when a sudden drop in PC1 scores could be observed; zooplankton taxa, in particular, experienced drastic changes in their overall biomass.

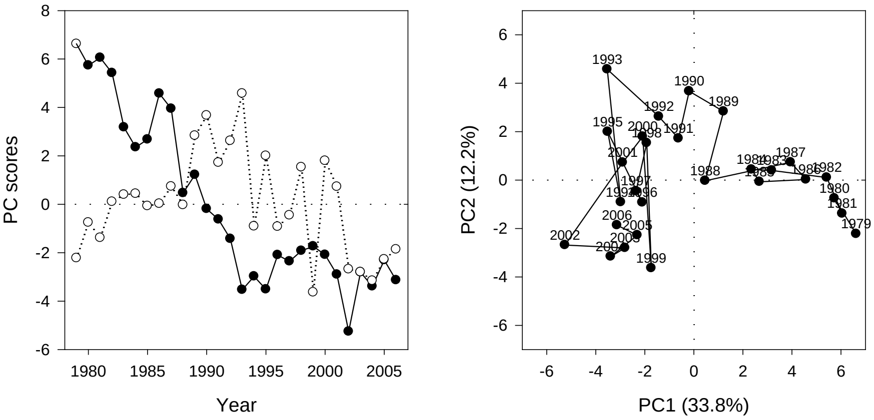


Figure 4.5.13. Results of the standardized principal component analysis (PCA) for the Bothnian Sea using all of the 35 assembled variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

The relative changes in the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the two PCs (Figure 4.5.14). The PC1 primarily reflects salinity, phosphorus concentration, fishing effort, and the zooplankton groups *Bosmina*, *Limnocalanus*, and *Pseudocalanus*. *Pseudocalanus*, salinity, and the number of trapnets are positively correlated; the other variables, including trawling effort, are negatively correlated with the PC1 axis, indicating that their estimates tend to increase over time. In the early 1990s, high scores were found along the PC2 axis, with the highest loadings for *Acartia* spp., the abundance of offshore *Monoporeia*, and various phytoplankton groups. In contrast, the coastal biomass of *Saduria entomon* was negatively correlated with the previous variables, thus demonstrating opposite trends and low biomass estimates in the early 1990s.

Generally, the period as a whole (1989–2006) is characterized by low salinities, higher temperatures, and higher nutrient loads than the two preceding decades. Marine zooplankton taxa were thus replaced by brackish-water species. At the same time, offshore macrozoobenthos and herring growth decreased, whereas the populations of grey seal, herring, and coastal macrozoobenthos increased.

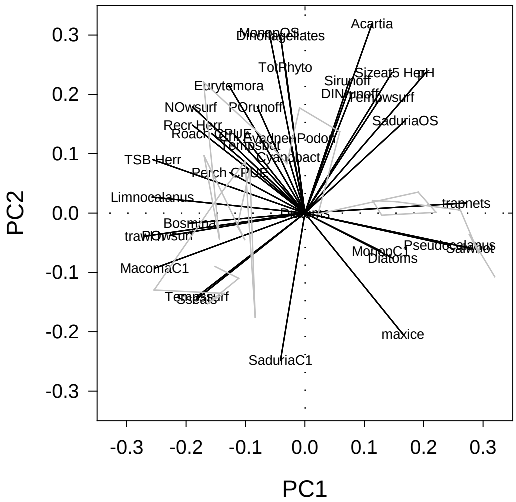


Figure 4.5.14. Results of the standardized principal component analysis (PCA) for the Bothnian Sea, using all of the 35 assembled variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.5.13 is shown in light grey).

4.6 Bothnian Bay

Bothnian Bay is a shallow basin with a surface area of ca. 40 000 km², separated from the Bothnian Sea in the south by a sill. The salinity in the area ranges from ca. 2 psu at the surface in the north to ca. 4 psu in the southern bottom waters. The water below the thermocline is often well mixed (Voipio, 1981). The foodweb in the Bothnian Bay is highly dependent on humic substances from river run-off. Thus, bacteria are a relatively more important component in the foodweb than in the other Baltic basins. Primary productivity is considered to be mainly phosphorus-limited (Granéli *et al.*, 1990; Andersson *et al.*, 1996). The biotic community is dominated by brackish-water and freshwater species. The dominant top predators are the grey seal (*Halichoerus grypus*) and the ringed seal (*Phoca hispida*).

4.6.1 Trend analysis

4.6.1.1 Hydrography

As in the Bothnian Sea, winter SSTs have decreased and were mainly below average after 1991. In contrast, summer SSTs demonstrate a weak increasing trend, although this needs to be confirmed by future measurements(Figure 4.6.1, upper panels). The salinity of bottom waters, and similarly pH, decreased significantly over time, and values were exceptionally low in recent years (Figure 4.6.1, lower panels). Among other things, the low pH may affect the nutritional value of plankton (Riebesell *et al.*, 2007) and, thereby, the foodweb structure of the system.

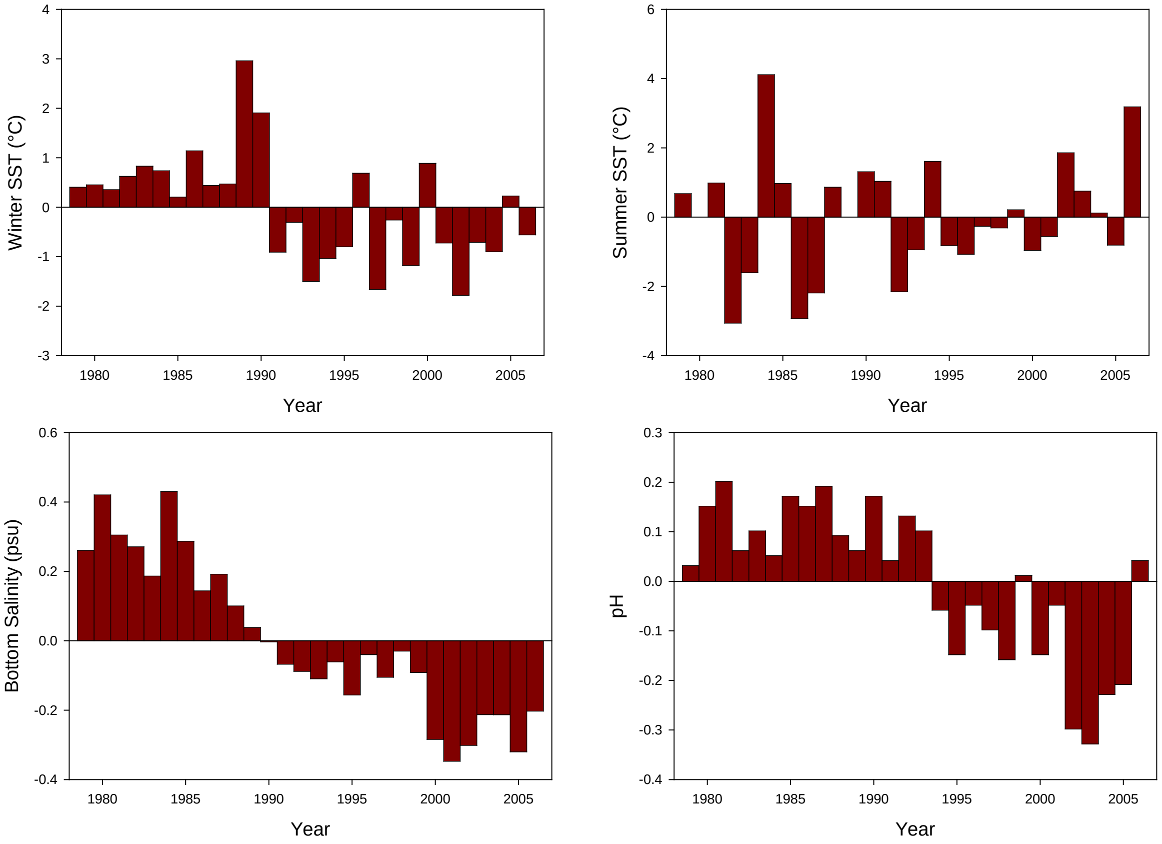


Figure 4.6.1. Long-term hydrographic changes in the Bothnian Bay. Anomalies of the overall mean for (from left to right): sea surface temperature (SST) in winter (3.25 °C); SST in summer (13.28 °C); bottom-water (>30 m) salinity (3.61 psu); and water pH (7.84).

4.6.1.2 Nutrients

The surface concentration of DIN (measured in winter) increased, especially at the beginning of the time-series, and has remained at a high level over the last 20 years. There was no clear trend in the concentration of DIP (Figure 4.6.2, upper panels). This is in contrast to the total annual loading of phosphorus from river run-off from the western drainage basins (Sweden), which more than doubled in the investigated period. The level of DIN or silicate loading (an indicator of total run-off volume) from these rivers fluctuated but, on average, remained fairly constant (Figure 4.6.2, lower panels).

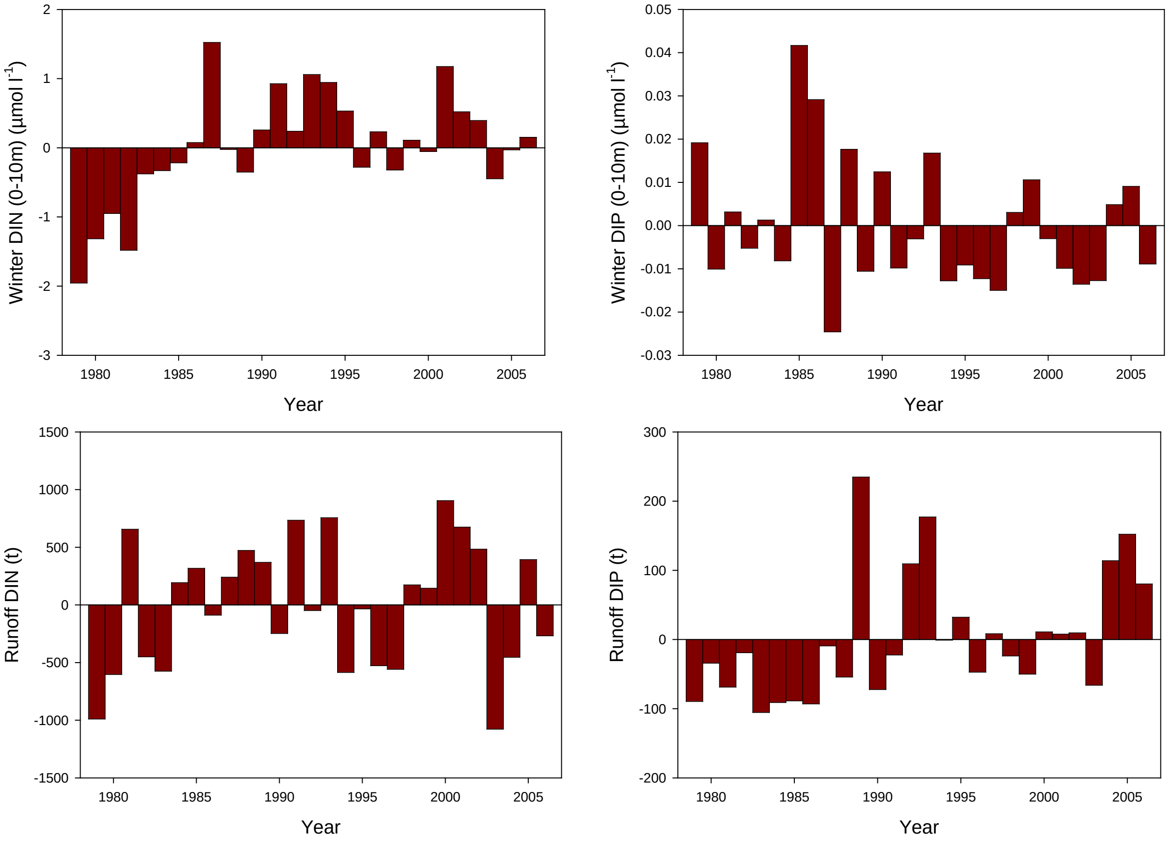


Figure 4.6.2. Long-term changes in nutrient concentrations in the Bothnian Bay. Anomalies of the overall mean for: (top) surface DIN (dissolved inorganic nitrogen; 6.53 µmol l^{-1}) and DIP (dissolved inorganic phosphorus; 0.06 µmol l^{-1}) in winter; and (bottom) total annual nutrient loads from run-off water from the western drainage basins, indicated by total DIN (3602 t) and DIP (215 t).

4.6.1.3 Phytoplankton

Total phytoplankton biomass has decreased by almost two-thirds since the early 1980s. However, there were no significant trends in either chlorophyll *a* or individual phytoplankton group biomass (i.e. diatoms (Diatomophyceae), dinoflagellates (Dinophyceae), and Cyanobacteria (Nostocophyceae); Figure 4.6.3).

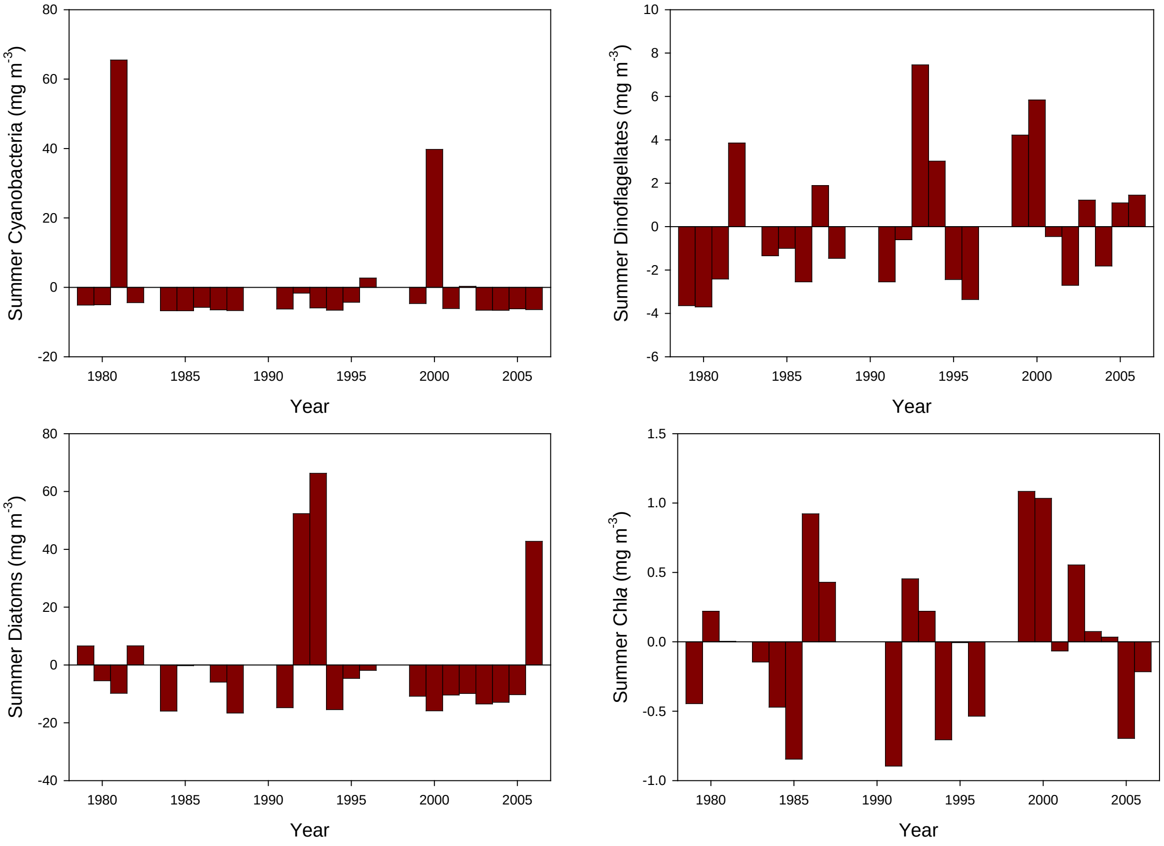


Figure 4.6.3. Long-term changes in phytoplankton biomass in Bothnian Bay surface waters. Anomalies of the overall mean for (from left to right): Cyanobacteria (6.75 mg m^{-3}); dinoflagellates (3.70 mg m^{-3}); diatoms (17.19 mg m^{-3}); and chlorophyll *a* content (1.95 mg m^{-3}).

4.6.1.4 Zooplankton

Zooplankton biomass of various taxonomic groups (the copepods *Eurytemora* and *Limnocalanus*, and the cladocerans *Bosmina* and *Evadne* and *Podon,*the latter two are pooled) did not demonstrate any temporal trends. However, a peak biomass for most zooplankton taxa was recorded in 1992–1993 (Figure 4.6.4).

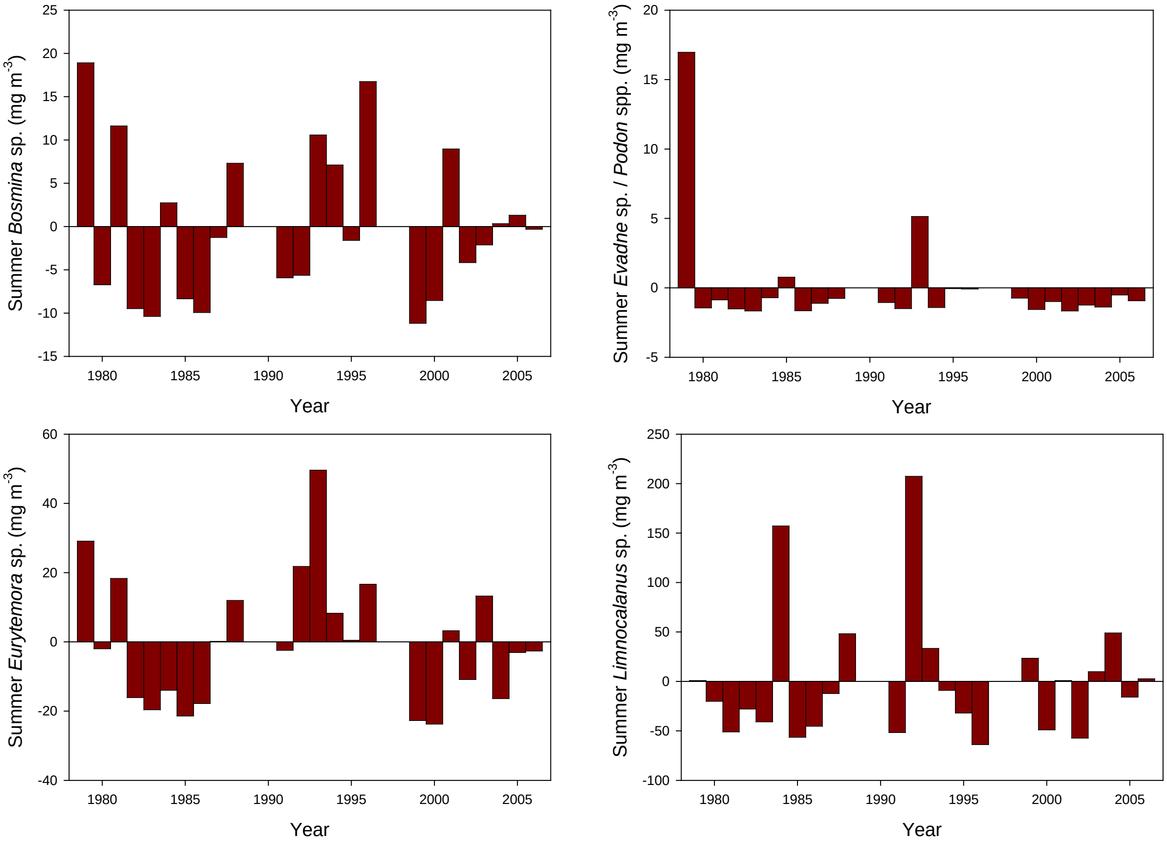


Figure 4.6.4. Long-term changes in zooplankton biomass in the Bothnian Bay in summer. Anomalies of the overall mean for (from left to right): *Bosmina* spp. (11.62 mg m^{-3}); *Evadne* spp. and *Podon* spp. (combined; 1.67 mg m^{-3}); *Eurytemora* spp. (30.81 mg m^{-3}); and *Limnocalanus* spp. (100.96 mg m^{-3}).

4.6.1.5 Fish and fisheries

Data on herring biomass and weight at age 5, as obtained from WGBFAS (ICES, 2007b), demonstrated a drastic decrease at the end of the 1980s, and both variables have remained at below-average values since 1993. As in other basins, herring mean weight has decreased substantially, with mean weight at age 5 being 25% higher during 1980–1989 than during 1990–2006. A weak tendency towards a long-term decrease in the number of recruits was also observed, and extremely high recruitment success was only found at the beginning of the time-series and not in more recent years. However, these estimates are not independent of fishing effort data, and variability is generally high (Figure 4.6.5).

The biomass of the other important pelagic fish species, vendace (*Coregonus albula*), increased substantially at the year 2000, because of a combination of reduced fishing effort and some consecutive years of good recruitment (Figure 4.6.5, bottom right). However, this time-series did not start until 1991 and was not included in the integrated analysis.

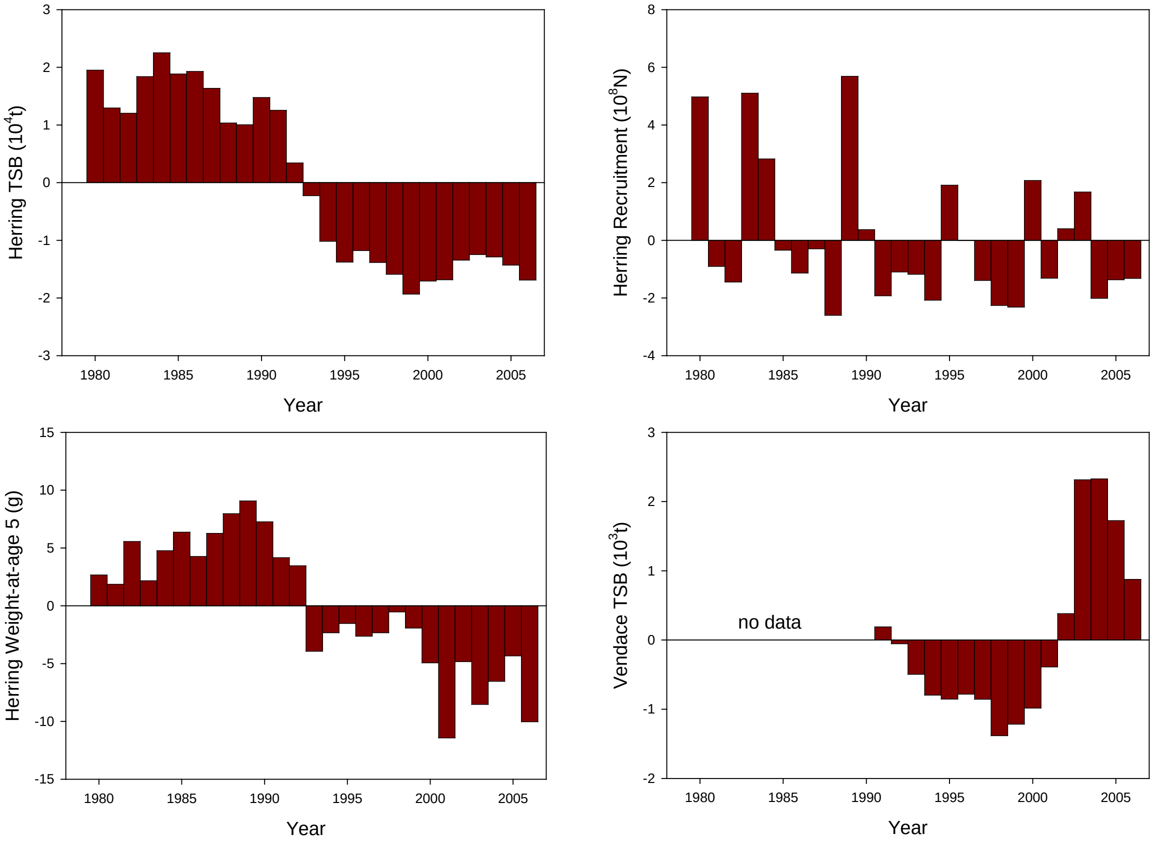


Figure 4.6.5. Long-term changes in the fish stocks of the Bothnian Bay. Anomalies of the overall mean for (from left to right): herring total-stock biomass (TSB; 3.267 × 10^4 t); herring number (N) of recruits at age 1 (3.625 × 10^8); herring weight at age 5 (37.3 g); and vendace TSB (2.031 × 10^3 t).

4.6.1.6 Seals

The number of grey seals in the Bothnian Bay has increased almost exponentially since monitoring began in 1989. According to counts in the area of Sydvästbrotten, in the southern Bothnian Bay, the number has more than doubled during the last two decades (Figure 4.6.6).

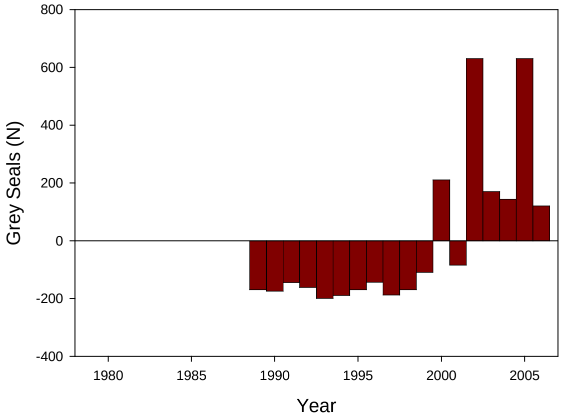


Figure 4.6.6. Long-term changes in the number of grey seals in an area in southern Bothnian Bay. Anomalies of the overall mean for the total number (N) of individuals (269.6).

4.6.1.7 Fishing effort

Fishing effort data from the Finnish herring fishery were obtained from WGBFAS (ICES, 2007b) and processed in the same way as the Bothnian Sea effort data. Both trawling (pelagic and demersal) effort and the number of trapnets decreased almost tenfold in the period between 1979 and 2006 (trawling hours corrected for efficiency increases), and both fisheries have remained at a relatively low level in recent years (Figure 4.6.7).

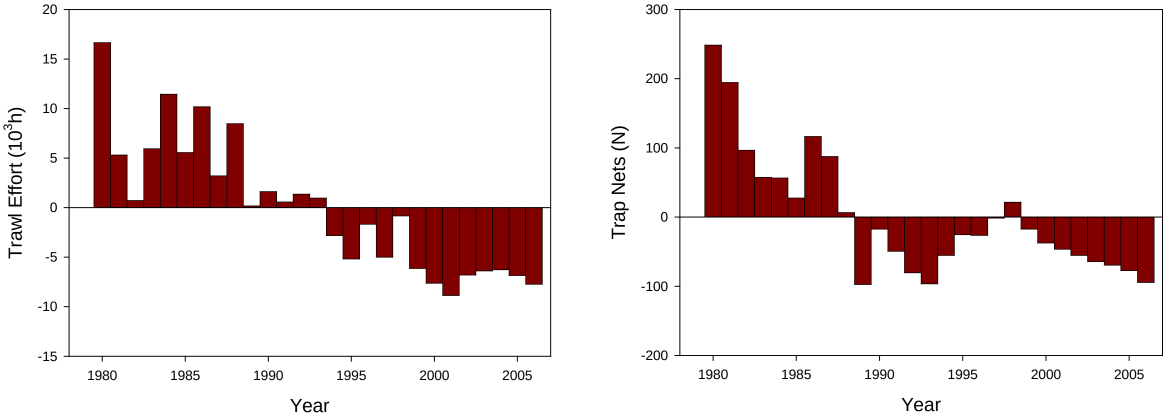
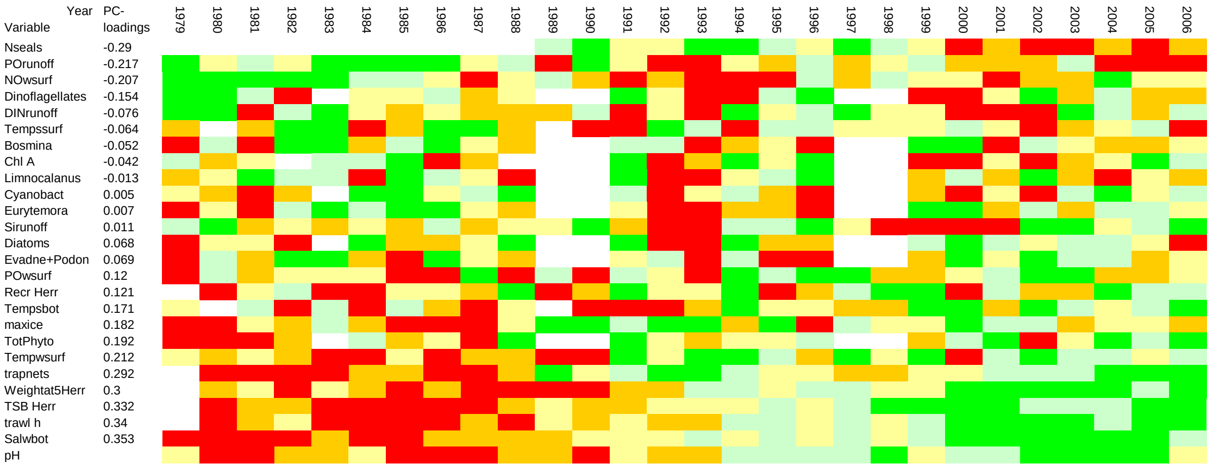


Figure 4.6.7. Long-term changes in fishing effort in the Finnish herring fishery in the Bothnian Bay. Anomalies of the overall mean for: (left) combined pelagic and demersal trawling effort (10.91 × 10^3 h); and (right) the number (N) of trapnets (175.5).

4.6.2 Integrated analysis

In total, 26 variables were considered: 6 physical, 5 nutrient, 5 phytoplankton, 4 zooplankton, 1 top predator (seal), and 5 fish- and fishery-related datasets. All dataseries were compiled to one value year^{-1} and covered the period 1979–2006 (see Section 8, Table 8.6, for details of variables).

An overview of the temporal changes of all Bothnian Bay time-series is presented in Figure 4.6.8. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal an increasing trend over time (green–red), and variables at the bottom demonstrating opposite trends (red–green), with a strong decline following 1990. The first group of variables comprises the number of seals, phosphate and nitrate run-off, dinoflagellates, and SST. In contrast, pH, salinity, fishing effort (trawling hours), and herring TSB, belonging to the second group of variables, decreased. For some variables, there was no clear trend, but short-term fluctuations were found (e.g. in the biomass of diatoms and the cladocerans *Podon* spp. and *Evadne* spp. [combined]). The results presented in the integrated analysis of the Bothnian Bay should be regarded as preliminary because some relevant functional groups could not be included in the analysis, owing to a lack of data. These included macrozoobenthic species and large piscivorous fish. Furthermore, plankton data are missing for the years 1989–1990, which is within the period when major ecosystem shifts were identified in other Baltic Sea areas.



Variable	PC-loadings
Nseals	-0.29
POrunoff	-0.217
NOwsurf	-0.207
Dinoflagellates	-0.154
DINrunoff	-0.076
Tempssurf	-0.064
Bosmina	-0.052
Chl A	-0.042
Limnocalanus	-0.013
Cyanobact	0.005
Eurytemora	0.007
Sirunoff	0.011
Diatoms	0.068
Evadne+Podon	0.069
POwsurf	0.12
Recr Herr	0.121
Tempsbot	0.171
maxice	0.182
TotPhyto	0.192
Tempwsurf	0.212
trapnets	0.292
Weightat5Herr	0.3
TSB Herr	0.332
trawl h	0.34
Salwbot	0.353
pH	

Figure 4.6.8. Traffic-light plot of the temporal development of the Bothnian Bay time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.6).

An ordination of the full dataset by a standardized PCA resulted in 27.9% and 11.8% of the explained variance on PC1 and PC2, respectively (Figure 4.6.9). PC1 scores demonstrated a constant decline over time, with the most pronounced change between 1990 and 1991, when PC scores turned negative. Since 2000, PC1 scores have remained relatively constant, indicating a less variable ecosystem state. The trend in PC2 scores was equivocal, and extreme values were found in the first year of the time-series (1979) and in 2000. The two-dimensional time-trajectory (PC1 vs. PC2) illustrates the high interannual variability of the data, as well as the pronounced structural changes over the past decades. Discontinuities in the dataset were identified by chronological clustering between the years 1987/1988 and 1993/1994, encompassing a period with few extreme variable values, in contrast to the time before or after the shifts. Using STARS with scores along the PC1 axis gave a similar picture, with an RSI above 1.8 in 1988/1989, but an additional, slightly weaker change in 1999/2000. Owing to the high fluctuation along the PC2 axis, no sudden changes could be identified.

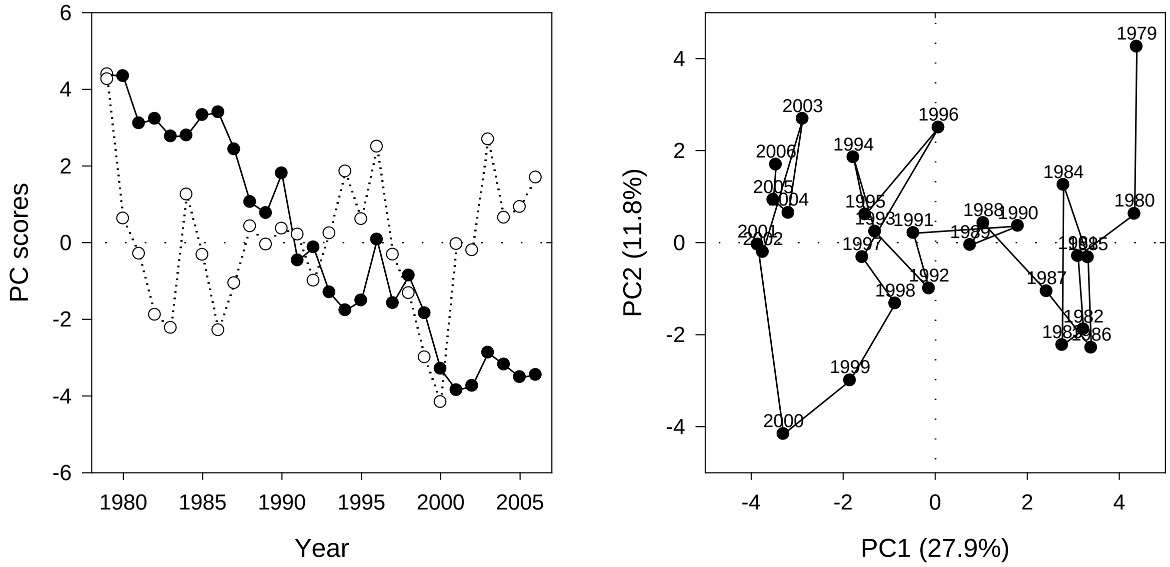


Figure 4.6.9. Results of the standardized principal component analysis (PCA) for the Bothnian Bay using all of the 50 assembled variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

The factor loadings on the two PCs give an overview about the relative changes in the variables over time (Figure 4.6.10). The variables revealing the most pronounced trends over the investigated period (see Figure 4.6.8) are the ones that demonstrate the highest correlation with the PC1 axis. Bottom salinity, fishing effort (trawling hours and number of trapnets), herring total biomass, and weight at age 5 were positively correlated with the PC1 axis, thus demonstrating an overall decline, whereas the number of grey seals and nutrient run-off were negatively correlated with this axis, resulting in increasing temporal trends. Zooplankton variables (i.e. *Eurytemora*, *Bosmina*, and cladocerans) strongly correlated with the PC2 axis, and their relative biomass estimates roughly follow fluctuations in PC2 scores. Phytoplankton biomass estimates were negatively correlated with zooplankton variables, thereby demonstrating opposite temporal trends.

Generally, compared with the two preceding decades, the most recent period is characterized by lower salinity, higher temperature, and increasing eutrophication. Given the data available, how much this affects the biology remains equivocal. The strong increase in the number of grey seals, accompanied by a decrease in herring biomass and a decline in their condition, are the principal biological factors in the system. However, the extent to which their dynamics are linked to environmental and anthropogenic drivers could not be identified.

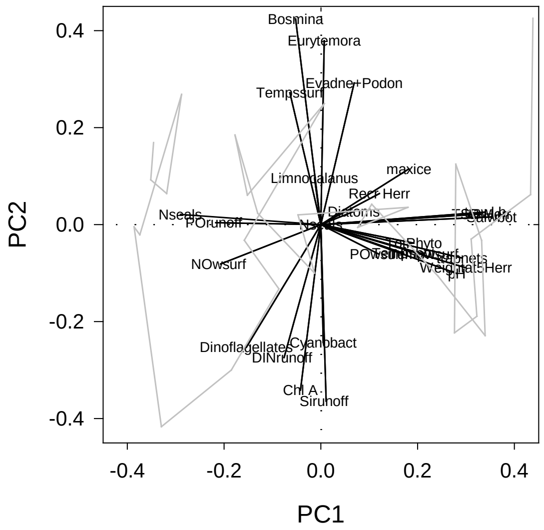


Figure 4.6.10. Results of the standardized principal component analysis (PCA) for the Bothnian Bay using all of the 26 assembled variables, showing the variable loadings on the first factorial plane (for orientation: the time-trajectory from Figure 4.6.9 is shown in light grey).

4.7 Coastal area

The coastal area of Kvädöfjärden (COAST) in the northern Baltic proper is an archipelago generally considered to be of good environmental quality, without major local anthropogenic influences. The surrounding land area is not densely populated, and the level of local fishing pressure is assumed to be low (Andersson *et al.*, 2005). However, water clarity has decreased in recent decades, indicating that the area is affected by large-scale eutrophication. Data for various biological variables are available since the early 1960s, and monitoring was further expanded in 1989. For the current report, the assessment was carried out on a dataset starting in 1971.

Compared with open-sea areas, environmental conditions at the coast are typically more spatially heterogeneous, owing to variations in topography. This affects local properties, such as depth patterns, the level of exposure to wave action, and the level of water and propagule exchange. In addition, terrestrial influences are of greater importance, with closeness to freshwater outflows and the state of anthropogenic land use being the most significant factors.

4.7.1 Trend analysis

4.7.1.1 Hydrography

Similar to the trends observed in the open Baltic Sea, winter and summer temperatures increased during the last three decades in the coastal area (Figure 4.7.1). Since relevant coastal salinity data were only available for a limited period (1993–2005), surface salinities measured in offshore areas in summer were included in the assessment. We assume that offshore salinity can represent coastal conditions because both time-series demonstrated the same trends. However, measurements began to deviate after the year 2000, when surface salinity remained constant in the open sea but continued to decrease in the coastal area (1993–2005).

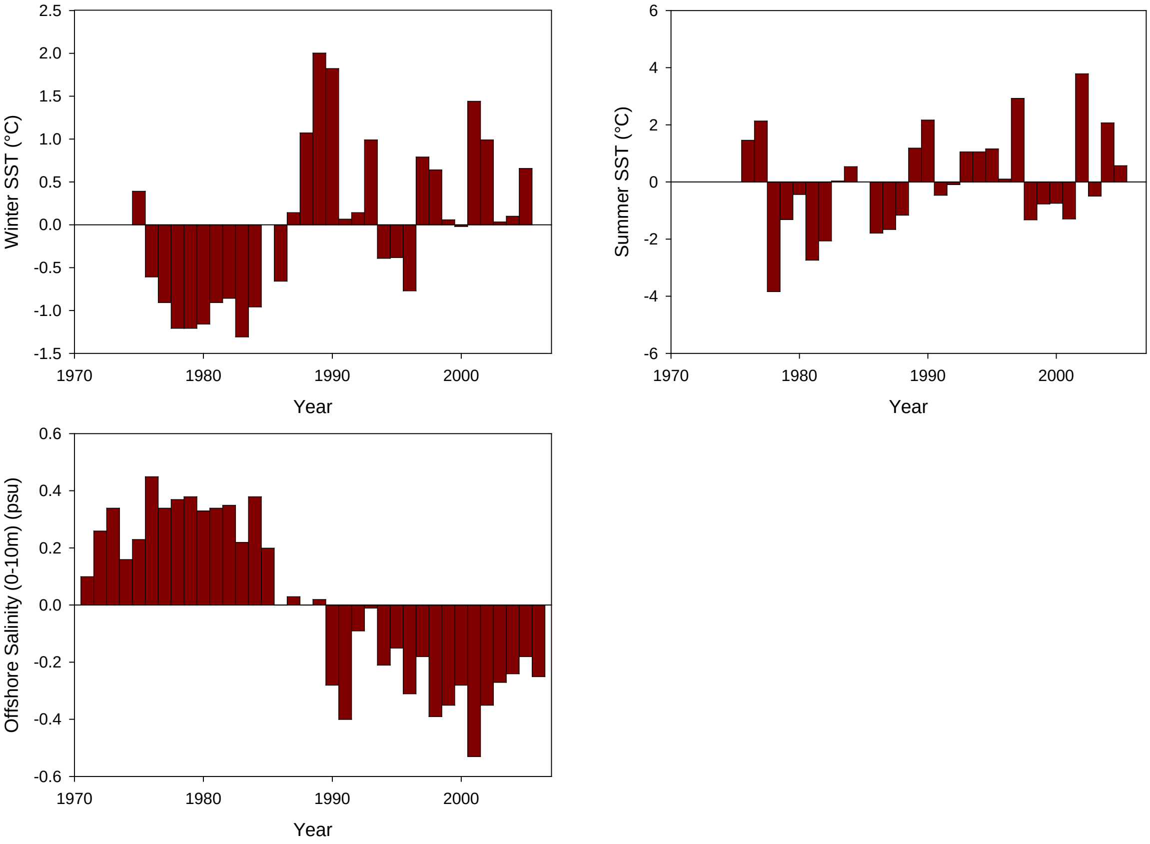


Figure 4.7.1. Long-term hydrographic changes in the Kvädöfjärden area (COAST). Anomalies of the overall mean for: (top) coastal sea surface temperature (SST) in winter (1.0 °C) and in summer (11.4 °C); and (bottom) offshore sea surface salinity (7.0 psu).

4.7.1.2 Nutrients

Nutrient levels in the open-sea surface layer were used to represent the influence of non-point source loading at the coast. Open-sea levels of DIN and DIP both demonstrated a slightly increasing trend during the last three decades (Figure 4.7.2, upper panels). The period with the highest concentrations of DIN occurred in the early 1990s, whereas the highest concentrations of DIP were observed in the most recent years (2003–2006). The levels of nitrogen and phosphate loading from land did not demonstrate any clear trends (Figure 4.7.2, lower panels).

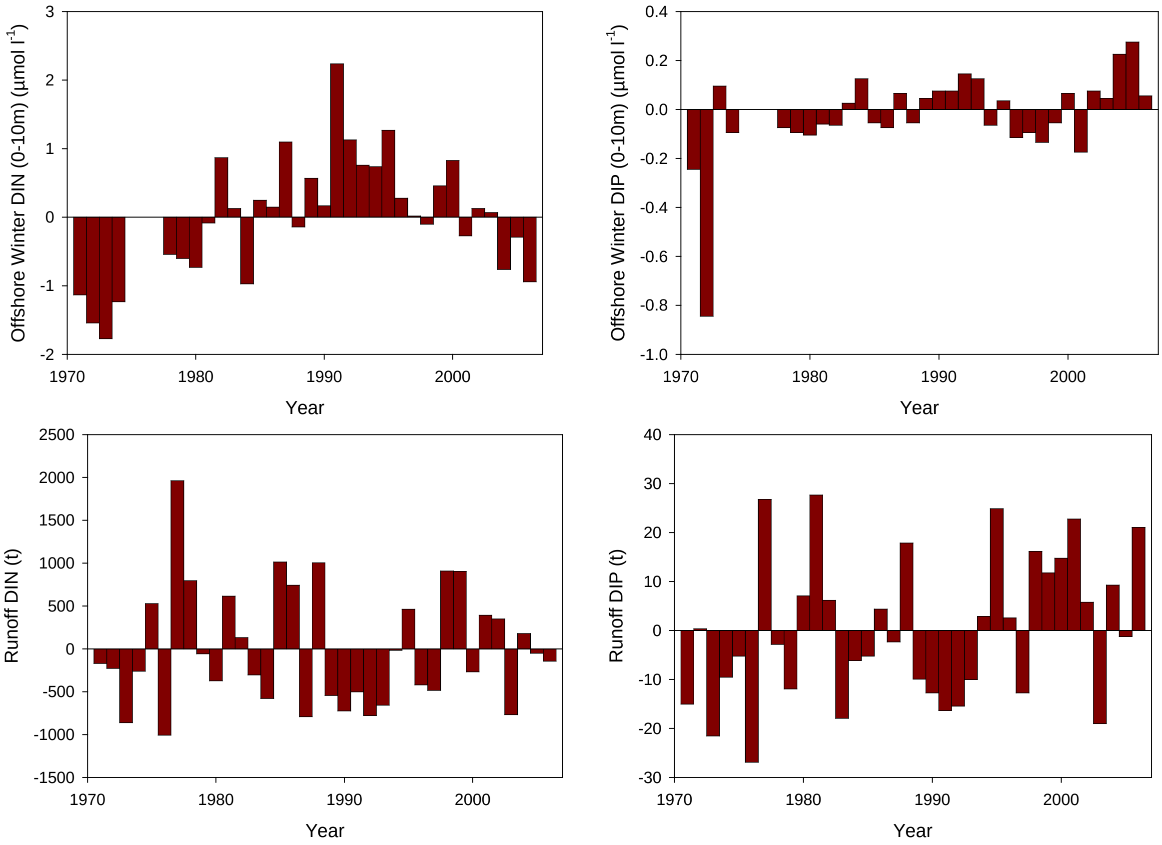


Figure 4.7.2. Long-term changes in nutrient concentrations in the Kvädöfjärden area (COAST). Anomalies of the overall mean for: (top) offshore DIN (dissolved inorganic nitrogen; 3.81 µmol l^{-1}) and DIP (dissolved inorganic phosphorus; 0.56 µmol l^{-1}) in winter; and (bottom) total nutrient loads of run-off water, indicated by total DIN (1228 t) and total DIP (36 t).

4.7.1.3 Phytoplankton and zooplankton

No direct data for phytoplankton and zooplankton were obtainable. However, Secchi depth measurements indicate a strong decrease in water transparency over the investigated period, which may be related to an increase in water turbidity, and in productivity and phytoplankton biomass (Figure 4.7.3).

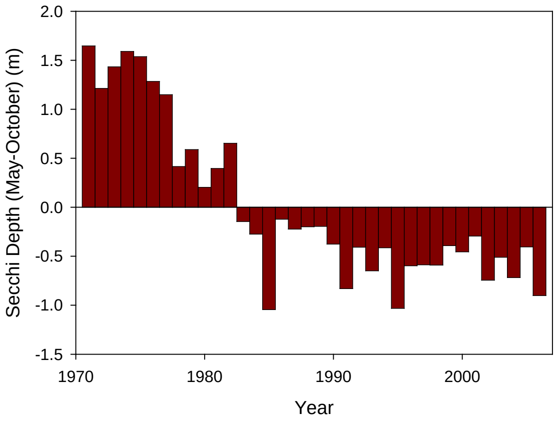


Figure 4.7.3. Long-term changes in Secchi depth measured in the Kvädöfjärden area (COAST). Anomalies of the overall mean from May to October (4.65 m).

4.7.1.4 Macrophytes

The dispersal and depth distribution of the habitat-forming, perennial macroalgae *Fucus vesiculosus* has decreased significantly since 1989, when monitoring began (Figure 4.7.4). Since the end of the 1990s, both variables remained at a low level. Owing to the limitation of the time-series, these data were not included in the present IEAs.

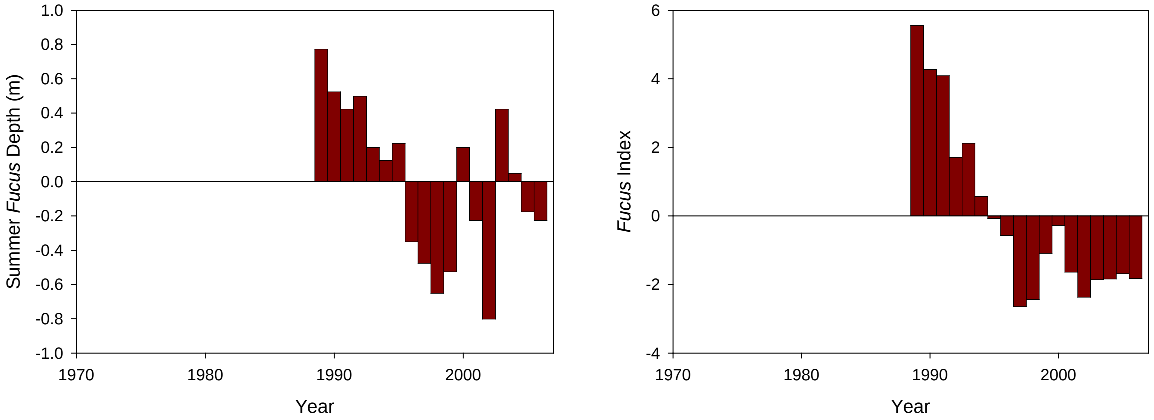


Figure 4.7.4. Long-term changes in the macroalgae patterns in the Kvädöfjärden area (COAST). Anomalies of the overall mean for: (left) the depth distribution of *Fucus vesiculosus* (1.08 m); and (right) the *Fucus* index (5.09) as a percentage of total bottom coverage.

4.7.1.5 Macrozoobenthos

The benthic macrofauna was studied in the Kvädöfjärden area since 1962. Five quantitatively dominant species, of different taxonomic groups and with different ecological functions, were considered in the assessment. The bivalve *Macoma baltica* increased continuously over the investigated period. The amphipod *Monoporeia affinis* (Figure 4.7.5, left panel) and the polychaete *Harmothoe sarsi* demonstrated the highest abundance during the 1980s and, thereafter, have been relatively scarce. The invasive species *Marenzelleria neglecta* syn. *viridis* was observed in the area for the first time in 1998, but now occurs regularly with increasing abundance (Figure 4.7.5, right panel). Abundance of the isopod *Saduria entomon* demonstrated no trend over time.

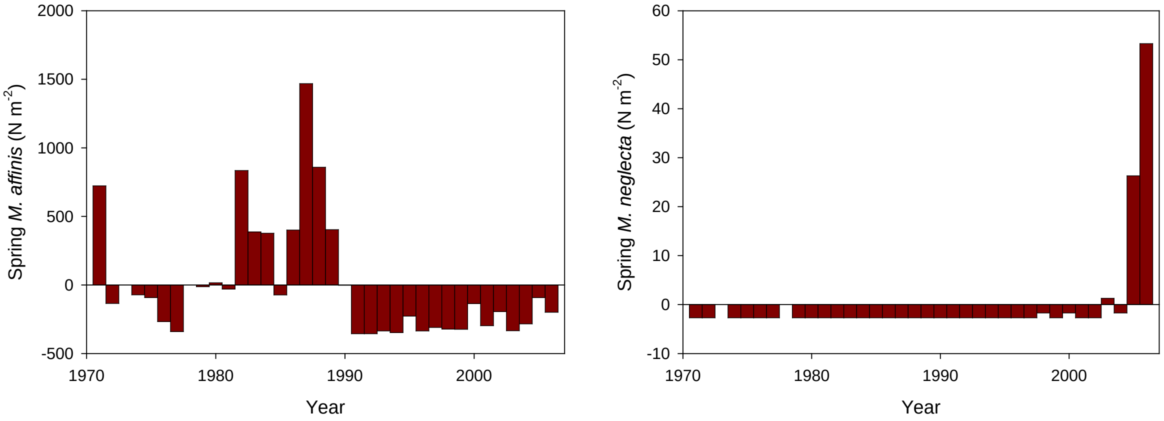


Figure 4.7.5. Long-term changes in the benthic community in the Kvädöfjärden area (COAST) in spring. Anomalies of the overall mean (in numbers, N) for: (left) *Monoporeia affinis* (372.0 m^{-2}); and (right) *Marenzelleria neglecta* (2.7 m^{-2}).

4.7.1.6 Fish and fisheries

Abundance estimates (cpue) for coastal fish species were obtained from monitoring programmes using coastal survey nets. Five species were considered in the assessment, including the dominant species that, in addition, represent different ecological traits. The most dramatic change was in the abundance of cod, which increased rapidly until 1983, but thereafter was very low (Figure 4.7.6, left panel). In contrast, the abundance of the freshwater perch increased continuously, reaching a peak in 2005 (Figure 4.7.6, right panel). The abundance of the other three species (shorthorn sculpin [*Myoxocephalus scorpius*], flounder, and roach) did not demonstrate any significant trends over time.

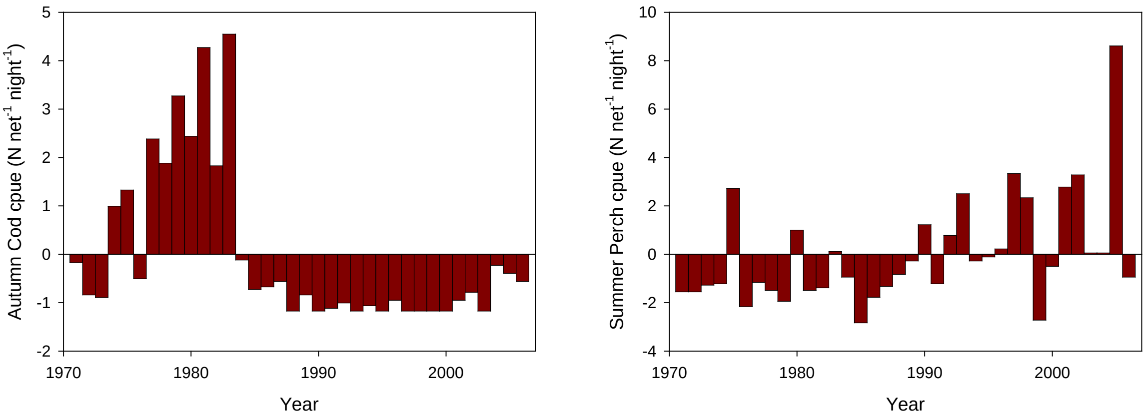


Figure 4.7.6. Long-term changes in catch per unit effort (cpue) in the Kvädöfjärden area (COAST). Anomalies of the overall mean (in numbers, N) for: (left) cod in autumn (1.17 net^{-1} night^{-1}), and (right) perch in summer (3.78 net^{-1}night^{-1}).

4.7.1.7 Seals

Estimates of the total abundance of grey seal are based on annual counts (Figure 4.7.7). The time-series began in 1989, but was extrapolated backwards to 1971 by replacing missing values with the mean value for 1989–1993. This approach was used because the seal populations in the Baltic Sea currently demonstrate nearly exponential increases and it is generally assumed that the lowest abundance occurred around the 1970s (Karlsson and Helander, 2005).

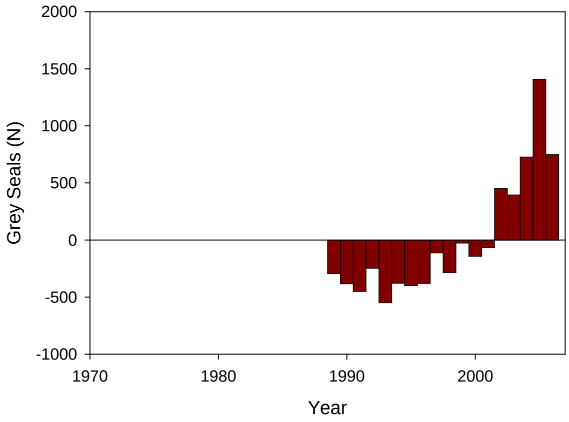


Figure 4.7.7. Long-term changes in the number of grey seals in the Kvädöfjärden area (COAST). Anomalies of the overall mean for the total number (N) of individuals (732).

4.7.2 Integrated analyses

In total, 18 variables were considered: 2 physical, 4 nutrient, 1 phytoplankton, 5 benthos, 1 top predator (seal), and 5 fish- and fishery-related datasets. All dataseries were compiled to one value year^{-1} and covered the period 1971–2008 (see Section 8, Table 8.7, for details of variables).

An overview of the temporal changes of all time-series from the coastal site is presented in Figure 4.7.8. Variables are sorted according to their PC1 loadings on the subsequently performed PCA, generating a pattern with variables at the top that reveal a decreasing trend over time (red–green), and variables at the bottom demonstrating opposite trends (green–red). The first group of variables comprises salinity, summer Secchi depth, cod biomass, and two macrozoobenthic species – the amphipod *Monoporeia affinis* and the polychaete *Harmothoë sarsi*, both of which had recently been relatively scarce. In contrast, abundance of *Macoma baltica* strongly increased over time, and similar trends were found for the number of seals and freshwater perch. *Marenzelleria neglecta* is an invasive species and occurred for the first time in 1998.

The presented analysis includes only a limited number of variables, and not all important ecosystem components could be considered. Additional time-series became available after 1989, but were not included in the integrated analysis of this report.

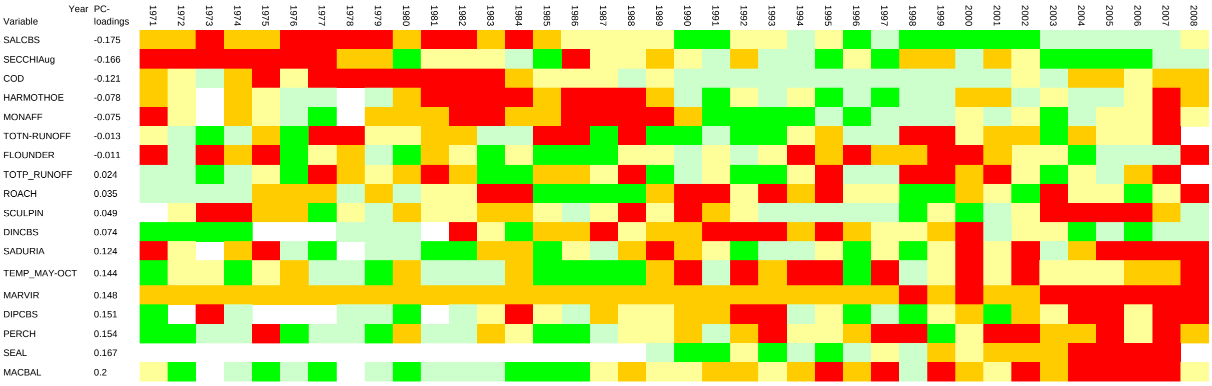


Figure 4.7.8. Traffic-light plot of the temporal development in the Kvädöfjärden area (COAST) time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1). Variable names are explained in Section 8 (Table 8.7).

The ordination of the full dataset from 1971 until 2008 by a standardized PCA resulted in 26.7% and 16.7% of the explained variance on PC1 and PC2, respectively (Figure 4.7.9). PC1 scores demonstrated an increasing trend over time, with a pronounced switch from negative to positive values during the period 1985–1990. Similarly, a very strong year-to-year change in PC2 scores was observed between 1990 and 1991. However, PC2 scores became positive again in 2004 and, recently, were similar to values at the beginning of the investigated period. The first factorial plane illustrates that, from 1971 until approximately 1989, interannual differences were fairly small. The same applies to the years 1991–1999, but before and after this period pronounced changes were captured by the plot. Accordingly, major shifts were identified by chronological clustering between the years 1988 and 1989, 1997 and 1998, and further between 2002 and 2003. Using STARS with scores of the PC1 axis gave a similar picture, with RSIs above 1 in 1987–1988 and 2002–2003. The sudden change in 1991/1992 could only be identified on the second PC.

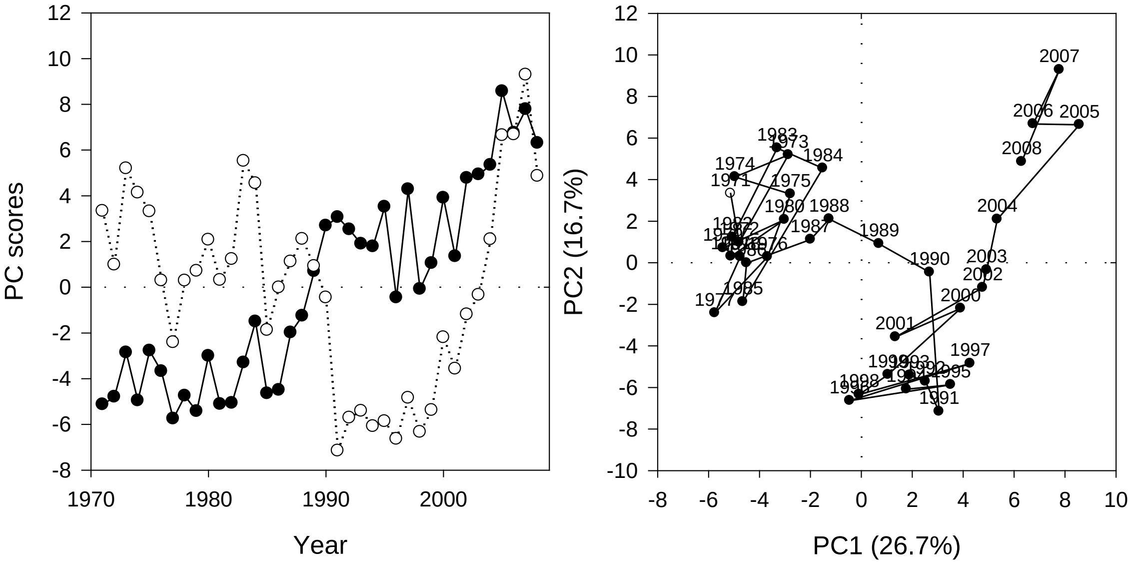


Figure 4.7.9. Results of the standardized principal component analysis (PCA) for the Kvädöfjärden area (COAST) using all of the 18 assembled variables: (left) PC scores vs. time (black circles = PC1, white circles = PC2); and (right) the time-trajectory on the first factorial plane.

The factor loadings on the two PCs indicate the variables that demonstrated the most pronounced changes over time (Figure 4.7.10). The initial period until the late 1980s was characterized by high values for salinity, summer Secchi depth, cod biomass, and the macrozoobenthic species *Monoporeia affinis* and *Harmothoë sarsi*. In the 1990s, these variables decreased, whereas the nitrogen load in central Baltic Sea waters increased. In recent years, perch and seals especially were more abundant. Furthermore, *Marenzelleria neglecta* invaded the area during this period.

Overall, a clear increase in temperature and a decrease in salinity were observed during the investigated period. Despite the fact that nutrient loads in run-off water were not well represented on the first factorial plane, eutrophication has increased, which is also evident from decreasing Secchi depth, increasing nutrient levels in the central Baltic Sea, and decreasing *Fucus* depth distribution. However, the last-mentioned was only monitored since 1989 and, therefore, was not included in the multivariate analyses. Among the biotic variables, the abundance of perch, saltwater clam *Macoma baltica*, and grey seal increased considerably. In the analyses, a relatively recent regime shift was indicated in 2002/2003. As this shift is close to the end of the investigated period, a thorough assessment is needed in the coming years.

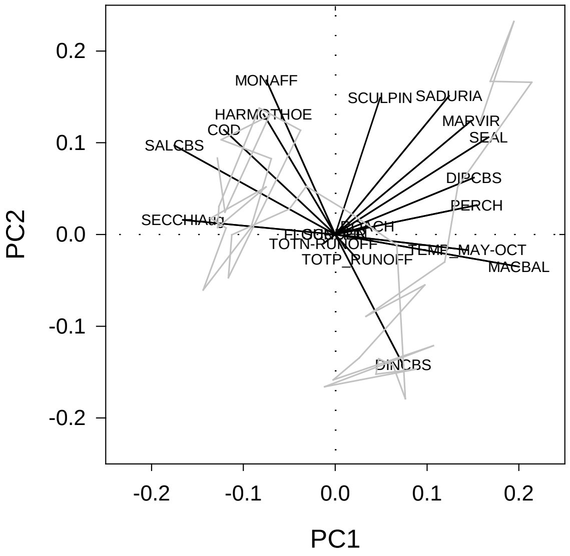


Figure 4.7.10. Results of the standardized principal component analysis (PCA) for the Kvädöfjärden area (COAST), using all of the 18 assembled variables, showing the variable loadings on the first factorial plane (for orientation, the time-trajectory from Figure 4.7.9 is shown in light grey).

5 Summary

The work presented in this report represents a comprehensive analysis of the temporal dynamics of Baltic Sea ecosystems during the past three decades. The WGIAB was able to collect a large number of biotic and abiotic datasets characterizing all ecosystem components and allowing IEAs of seven Baltic Sea areas. In all ecosystems, pronounced structural changes (i.e. regime shifts) were detected within the last two to three decades (Table 5.1).

Table 5.1. Summary of sudden changes/regime shifts (RS) detected in seven investigated ecosystems (TS = the Sound, CBS = central Baltic Sea, GoR = Gulf of Riga, GoF = Gulf of Finland, BoS = Bothnian Sea, BoB = Bothnian Bay, COAST = coastal area in the Baltic proper). Shifts were identified from the whole dataset for each ecosystem using chronological clustering (significance level $\alpha = 0.01$, connectedness level = 0.5).

System	Period covered	RS1	RS2	RS3	RS4
TS	1979–2005		1987/1988	1994/1995	2000/2001
CBS	1974–2007	1984/1985	1987/1988		
GoR	1973–2007		1988/1989	1997/1998	
GoF	1979–2008		1988/1989	1995/1996	2002/2003
BoS	1979–2006	1982/1983	1988/1989		
BoB	1979–2006		1987/1988	1993/1994	
COAST	1971–2008		1988/1989	1997/1998	2002/2003

Although the investigated sub-ecosystems are characterized by different environmental conditions and more or less influenced by either North Sea water (the Sound) or river run-off and freshwater conditions (e.g. Gulf of Finland, Bothnian Bay), the major period of reorganization in the Baltic was invariably found between 1987 and 1989. In these years, distinct, strong shifts were detected in all sub-ecosystems and with different types of discontinuity analyses. The timing of these shifts is in accordance with similar events detected in the northern hemisphere, especially in ecosystems of the North Atlantic (e.g. Hare and Mantua, 2000; Link *et al.*, 2002; Beaugrand, 2004; Choi *et al.*, 2005; Weijerman *et al.*, 2005). The event can be further described as low-frequent and abrupt, affecting multiple trophic levels, and occurring on the geographic scale of a large marine ecosystem, all characteristics of a genuine ecosystem regime shift (Bakun, 2006; Collie *et al.*, 2004; Cury and Shannon, 2004; de Young *et al.*, 2004; Lees *et al.*, 2006). In several of the systems, abrupt changes were also found during the mid-1990s, probably related to the major North Sea water inflow in 1993 following a long stagnation period. In a previous analysis, a shift in 1993/1994 was also identified in the central Baltic Sea ecosystem (Möllmann *et al.*, 2009). The years between 1988 and 1993 were therefore assumed to be form a transition period, characterizing both the beginning and end of the ecosystem reorganization. During this phase, extreme abiotic conditions, namely low salinity and dissolved oxygen conditions, and high temperatures and nutrient levels, as well as high cod fishing pressure co-occurred and pushed the biotic part of the ecosystem into a new state (Möllmann *et al.*, 2009). The results of the multisystem analysis presented here suggest that this period of reorganization between two ecological states also occurred in most other Baltic systems, although with slightly different timing.

As abrupt changes were mainly synchronous across the seven ecosystems, the time-trajectories resulting from the PCAs demonstrated similar features. In order to investigate this further, we extracted major common trends from the PC1 scores (derived from time-series of the seven systems) by using minimum/maximum autocorrelation factor analysis (MAFA; Shapiro and Switzer, 1989; Solow, 1994; Figure 5.1). The obtained axes are smooth curves describing overall temporal trends, the first MAF being the most important trend underlying the PC1 scores and the second MAF the second most important trend. The first MAFA increases until the early mid-1980s and is followed by a steady decline. The second MAFA is more variable, but follows an inverse, dome-shaped curve, with local minima in the period between the late 1980s and mid-1990s, which again indicates the period of ecosystem reorganization (shaded in grey, Figure 5.1). It is striking that the temporal trends of all PC1 axes are very close to each other, with major structural changes starting in the mid-1980s. Whether or not these temporal dynamics are of a cyclical nature, and whether or not changes will manifest in future, cannot yet be determined. Thorough monitoring is needed in the coming years, especially because there are further indications that a recent shift occurred in some systems (the Sound, Gulf of Finland, the coastal area).

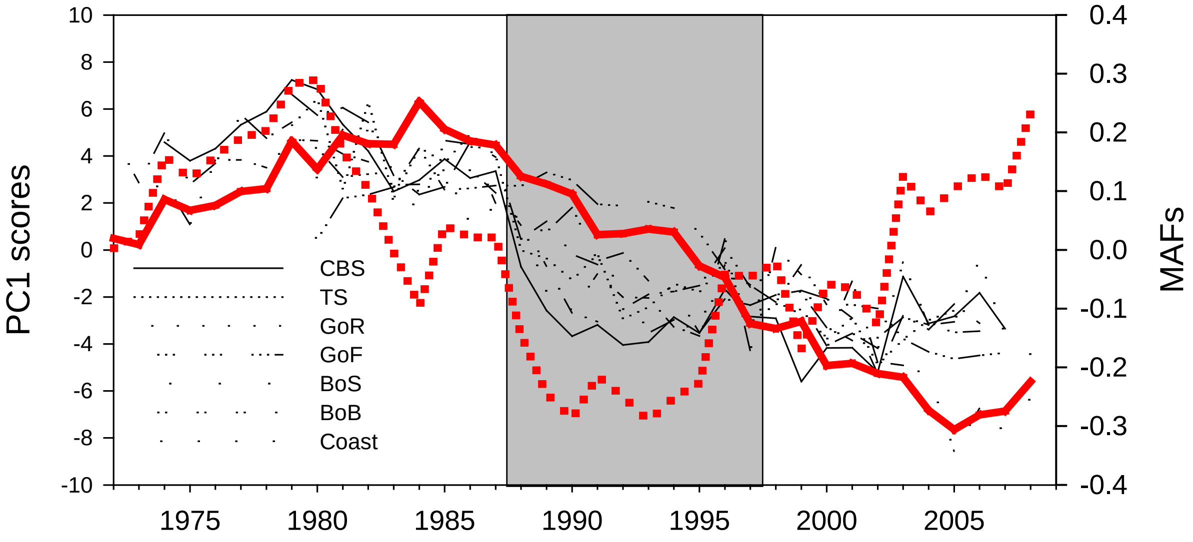


Figure 5.1. PC1 scores from the seven investigated systems derived from the respective principal component analyses. The first MAF axis (solid red line) and the second MAF axis (dotted red line) extract the major temporal trends from the principal component (PC) scores. The shaded area indicates the approximate period when major ecosystem reorganization took place, as identified by chronological clustering (see Table 5.1).

In summary, the results presented here indicate that changes in the Baltic subecosystems were driven by a combination of climate-induced, hydrographic variability, overfishing, and eutrophication. Work in progress, based on the datasets assembled here and using additive mixed models (T. Blenckner *et al.*, pers. comm.) indicates that hydrographic changes caused by large-scale atmospheric forcing are the overall driver in the Baltic Sea region, as illustrated by increasing water temperature and decreasing salinity in all systems. The effect in the different areas (e.g. on water column stability), however, varies. Similarly, overfishing and eutrophication are important factors in all areas, but contribute to changes in the biological system to a varying degree. As an example, fishing pressure seems to be very important in the central Baltic and Bothnian seas, whereas eutrophication has a stronger impact in the Gulf of Finland.

Detailed analysis of the central Baltic Sea dataseries confirmed that multiple drivers are usually needed to induce the major ecosystem reorganization. Although decreasing salinity and overfishing may have reduced the resilience of the central Baltic Sea ecosystem, the sudden temperature increase at the end of the 1980s seems to have eventually caused the regime shift (Möllmann *et al.*, 2009). Because of a salinity gradient, and, consequently, a biodiversity gradient, in the Baltic Sea, regional responses to external drivers obviously differ. Thus, more research effort is needed in order to identify and quantify the importance of the different abiotic driving forces in local ecosystems.

Another important observation from the IEAs, and especially the detailed analysis of the central Baltic Sea, is that a regime shift can be characterized as very rapid or discontinuous (Möllmann *et al.*, 2009). The presence of discontinuous regime shifts ("hysteresis") can be explained by the occurrence of feedback loops that stabilize the new regime (Scheffer *et al.*, 2001; Bakun, 2006). In the central Baltic Sea, there are two non-linear feedback mechanisms, both relating to interactions between cod and sprat. Currently, the predation rate on sprat is low because of the low cod biomass, and this, in turn, has had negative effects on the biomass of the copepod *P. acuspes*, which is currently controlled by the large sprat stock (Möllmann and Köster, 2002; Casini e*t al.*, 2008; Möllmann *et al.*, 2008). This trophic cascade has established a stabilizing feedback on cod, because *P. acuspes* is important for cod larval survival and hence for recruitment (Hinrichsen *et al.*, 2002, 2005; Köster *et al.*, 2005; Möllmann *et al.*, 2008). In addition, sprat may exert a second stabilizing feedback on cod, because they also prey on cod eggs (Köster and Möllmann, 2000). Thus, although a combination of hydrological effects and excess fishing has shifted the sub-ecosystem of the central Baltic Sea to its present regime, these feedback mechanisms seem to stabilize it in the current situation, which is characterized by low cod abundance. An indication of hysteresis caused by these mechanisms is the failure of *P. acuspes* and cod to recover after the inflows in 1993 and 2003 (Möllmann *et al.*, 2008). More work is needed to verify these feedback loops in the central Baltic Sea (e.g. through dynamic foodweb modelling) and to investigate and identify the potential of similar phenomena in the other sub-ecosystems.

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8 Time-series and associated meta-data

The following abbreviations (in alphabetical order) are used throughout:

BED = Baltic Environmental Database of the Baltic Nest Institute; DMU = Danish National Environmental Research Institute; EMI = Estonian Marine Institute; FD = Danish Directorate of Fisheries; FGFRI = Finnish Game and Fisheries Research Institute; FIMR = Finnish Institute of Marine Research (now SYKE, see below); FMI = Finnish Metereological Institute; ICES = International Council for the Exploration of the Sea; IFM–GEOMAR = Leibniz Institute of Marine Sciences; IOW = Leibniz Institute for Baltic Sea Research; LATFRA = Latvian Fish Resources Agency; LATVENERGO = Latvian Energy Power Supply enterprise (www.latvenergo.lv); LHEI = Latvian Institute of Aquatic Ecology; NRM = Swedish Museum of Natural History; SBF = Swedish Board of Fisheries; SLU = Swedish University of Agricultural Sciences, Uppsala; SMHI = Swedish Meteorological and Hydrological Institute; SYKE = Finnish Environment Institute (includes former Finnish Institute of Marine Research, FIMR); UMF = Umeå Marine Sciences Centre, Umeå University; WGBFAS = Baltic Fisheries Assessment Working Group; XSA = Extended Survivors Analysis.

Table 8.1. Time-series used for the integrated ecosystem analysis of the Sound (TS).

Variable	Abbreviation	Unit	Season	Month	Source	References/Weblinks
Surface salinity (0–10 m)	Sal0–10_spr	psu	Spring	March–May	DMU/SMHI	www.dmu.dk, www.smhi.se
Surface salinity (0–10 m)	Sal0–10_sum	psu	Summer	June–September	DMU/SMHI	www.dmu.dk, www.smhi.se
Bottom salinity (30–50 m)	Sal30–50_spr	psu	Spring	March–May	DMU/SMHI	www.dmu.dk, www.smhi.se
Bottom salinity (30–50 m)	Sal30–50_sum	psu	Summer	June–September	DMU/SMHI	www.dmu.dk, www.smhi.se
Surface temperature (0–0 m)	Temp0–10_spr	°C	Spring	March–May	DMU/SMHI	www.dmu.dk, www.smhi.se
Surface temperature (0–10 m)	Temp0–10_sum	°C	Summer	June–September	DMU/SMHI	www.dmu.dk, www.smhi.se
Bottom temperature (30–50 m)	Temp30–50_spr	°C	Spring	March–May	DMU/SMHI	www.dmu.dk, www.smhi.se
Bottom temperature (30–50 m)	Temp30–50_sum	°C	Summer	June–September	DMU/SMHI	www.dmu.dk, www.smhi.se
Baltic Sea Index	BSI		Winter	December–February	IFM–GEOMAR	Lehmann *et al.* (2002)
Volume outflow	Outflow	km^3	Annual	–	SMHI	www.smhi.se
Volume inflow	Inflow	km^3	Annual	–	SMHI	www.smhi.se
Bottom oxygen (30–50 m)	O2_30–50_spr	$ml\ l^{-1}$	Spring	March–May	DMU	www.dmu.dk
Nitrate	N3N_win	$\mu mol\ l^{-1}$	Winter	December–February	DMU	www.dmu.dk
Ammonium	NH3N_win	$\mu mol\ l^{-1}$	Winter	December–February	DMU	www.dmu.dk
Total phosphorus	TP_win	$\mu mol\ l^{-1}$	Winter	December–February	DMU	www.dmu.dk
Silica	SIO_win	$\mu mol\ l^{-1}$	Winter	December–February	DMU	www.dmu.dk
Chlorophyll *a*	CHLU_sum	$\mu g\ l^{-1}$	Summer	June–September	DMU	www.dmu.dk
Diatomeae	Dia_spr2	$\mu gC\ l^{-1}$	Spring	March–May	DMU	www.dmu.dk
Dinoflagellata	Dino_spr2	$\mu gC\ l^{-1}$	Spring	March–May	DMU	www.dmu.dk
Cryptophyceae	Crypto_spr2	$\mu gC\ l^{-1}$	Spring	March–May	DMU	www.dmu.dk
Nanoplankton	Nanopl_spr2	$\mu gC\ l^{-1}$	Spring	March–May	DMU	www.dmu.dk

Diatomeae	Dia_sum2	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Dinoflagellata	Dino_sum2	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Cryptophyceae	Crypto_sum2	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Nanoplankton	Nanoplan_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Cyanobacteria	Cyano_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Dinoflagellata (microzooplankton)	Dinofl_spr	µgC l^{-1}	Spring	March – May	DMU	www.dmu.dk
Dinoflagellata (microzooplankton)	Dinofl_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Other microzooplankton	Other_mikzoopl_spr	µgC l^{-1}	Spring	March – May	DMU	www.dmu.dk
Other microzooplankton	Other_mikzoopl_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Acartia spp.	Acartia_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Centropages spp.	Centropages_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Pseudocalanus spp.	Pseudocalanus_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Temora spp.	Temora_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Evadne spp.	Evadne_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Oithona spp.	Oithona_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Podon spp.	Podon_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Bosmina spp.	Bosmina_sum	µgC l^{-1}	Summer	June – September	DMU	www.dmu.dk
Crustacea	Crustacea_w.w	g m^{-2}	Annual	–	DMU	www.dmu.dk
Echinodermata	Echinoderm_ww	g m^{-2}	Annual	–	DMU	www.dmu.dk
Mollusca	Mollusca_ww	g m^{-2}	Annual	–	DMU	www.dmu.dk
Polychaeta	Polychaeta _ww	g m^{-2}	Annual	–	DMU	www.dmu.dk
Silver eel landings	BLL	t year^{-1}	Annual	–	FD	www.fd.dk
Yellow eel landings	GLL	t year^{-1}	Annual	–	FD	www.fd.dk
Whiting landings	HVL	t year^{-1}	Annual	–	FD	www.fd.dk
Dab landings	ISG	t year^{-1}	Annual	–	FD	www.fd.dk
Plaice landings	RSP	t year^{-1}	Annual	–	FD	www.fd.dk
Flounder landings	SKR	t year^{-1}	Annual	–	FD	www.fd.dk
Cod landings	TOR	t year^{-1}	Annual	–	FD	www.fd.dk
Herring landings	SIL	t year^{-1}	Annual	–	FD	www.fd.dk

(Data info and requests to Martin Lindegren (mli@aqua.dtu.dk))

Table 8.2. Time-series used for the integrated ecosystem analysis of the central Baltic Sea (CBS).

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	References/Weblinks
Maximum ice cover	MaxIce	km^2	Baltic	Annual		1974–2006	FIMR	Visual air-borne and satellite data	www.fimr.fi
Baltic Sea Index	BSI	-	Central Baltic	Winter	December –February	1974–2006	IFM–GEOMAR	Air pressure measurements	Lehmann *et al.* (2002)
Depth of 11-psu isocline	11 psu_GBAnn	m	Gotland Basin	Annual		1974–2006	LATFRA		www.lzra.gov
Sea surface temperature	SST_BB_Spr	°C	Bornholm Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Sea surface temperature	SST_BB_Sum	°C	Bornholm Basin	Summer	July	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Sea surface temperature	SST_GB_Spr	°C	Gotland Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Sea surface temperature	SST_GB_Sum	°C	Gotland Basin	Summer	July	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Midwater temperature (40–60 m)	T_BB_60_spr	°C	Bornholm Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Midwater temperature (40–60 m)	T_BB_60_sum	°C	Bornholm Basin	Summer	July	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Midwater temperature (40–60 m)	T_GB_60_spr	°C	Gotland Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Midwater temperature (40–60 m)	T_GB_60_sum	°C	Gotland Basin	Summer	July	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Sea surface salinity	SSS_BB	psu	Bornholm Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Sea surface salinity	SSS_GB	psu	Gotland Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Halocline salinity (70–90 m)	S90_BB	psu	Bornholm Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Halocline salinity (80–100 m)	S100_GB	psu	Gotland Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Deep-water oxygen	O2_BB	ml l^{-1}	Bornholm Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Deep-water oxygen	O2_GB	ml l^{-1}	Gotland Basin	Spring	May	1974–2006	BED, ICES, IOW, FIMR, SMHI		
Dissolved inorganic nitrogen (surface)	DIN_BB_10_win	μmol l^{-1}	Bornholm Basin	Winter	January	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic phosphorus (surface)	DIP_BB_10_win	μmol l^{-1}	Bornholm Basin	Winter	January	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic nitrogen (surface)	DIN_GB_10_win	μmol l^{-1}	Gotland Basin	Winter	January	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	

Variable	**Abbreviation**	**Unit**	**Area**	**Season**	**Month**	**Years**	**Source**	**Method/Gear**	**References/Weblinks**
Dissolved inorganic phosphorus (surface)	DIP_GB_10_win	µmol l^{-1}	Gotland Basin	Winter	January	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic nitrogen (deep water)	DIN_BB_90_sum	µmol l^{-1}	Bornholm Basin	Summer	July	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic phosphorus (deep water)	DIP_BB_90_sum	µmol l^{-1}	Bornholm Basin	Summer	July	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic nitrogen (deep water)	DIN_GB_220	µmol l^{-1}	Gotland Basin	Summer	July	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Dissolved inorganic phosphorus (deep water)	DIP_GB_220	µmol l^{-1}	Gotland Basin	Summer	July	1980–2006	BED, ICES, IOW, FIMR, SMHI	Water sampler	
Chlorophyll *a*	Chla_BBSpr	mg m^{-3}	Bornholm Basin	Spring	April–May	1979–2006	ICES	Water sampler	Wasmund and Uhlig (2003)
Chlorophyll *a*	Chla_BBSum	mg m^{-3}	Bornholm Basin	Summer	June–September	1979–2006	ICES	Water sampler	Wasmund and Uhlig (2003)
Chlorophyll *a*	Chla_GBSpr	mg m^{-3}	Gotland Basin	Spring	April–May	1980–2006	ICES	Water sampler	Wasmund and Uhlig (2003)
Chlorophyll *a*	Chla_GBSum	mg m^{-3}	Gotland Basin	Summer	June–September	1979–2006	ICES	Water sampler	Wasmund and Uhlig (2003)
Diatomeae	dia_BB_spr	mg m^{-3}	Bornholm Basin	Spring	April–May	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Dinoflagellata	dino_BB_spr	mg m^{-3}	Bornholm Basin	Spring	April–May	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Cyanobacteria	cyano_BB_spr	mg m^{-3}	Bornholm Basin	Spring	April–May	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Diatomeae	dia_BB_Sum	mg m^{-3}	Bornholm Basin	Summer	June–September	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Dinoflagellata	dino_BB_sum	mg m^{-3}	Bornholm Basin	Summer	June–September	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Cyanobacteria	cyano_BB_sum	mg m^{-3}	Bornholm Basin	Summer	June–September	1979–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Diatomeae	dia_GB_spr	mg m^{-3}	Gotland Basin	Spring	April–May	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Dinoflagellata	dino_GB_spr	mg m^{-3}	Gotland Basin	Spring	April–May	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Cyanobacteria	cyano_GB_spr	mg m^{-3}	Gotland Basin	Spring	April–May	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Diatomeae	dia_GB_sum	mg m^{-3}	Gotland Basin	Summer	June–September	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Dinoflagellata	dino_GB_sum	mg m^{-3}	Gotland Basin	Summer	June–September	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)
Cyanobacteria	cyano_GB_sum	mg m^{-3}	Gotland Basin	Summer	June–September	1980–2006	IOW	Water sampler	Wasmund and Uhlig (2003)

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	References/Weblinks
Acartia spp.	Acartia_Spr	mg m^{-3}	Gotland Basin	Spring	May	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Acartia spp.	Acartia_Sum	mg m^{-3}	Gotland Basin	Summer	August	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Temora longicornis	Temora_Spr	mg m^{-3}	Gotland Basin	Spring	May	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Temora longicornis	Temora_Sum	mg m^{-3}	Gotland Basin	Summer	August	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Pseudocalanus acuspes	Pseudo_Spr	mg m^{-3}	Gotland Basin	Spring	May	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Pseudocalanus acuspes	Pseudo_Sum	mg m^{-3}	Gotland Basin	Summer	August	1974 – 2006	LATFRA	Juday net	Möllmann *et al.* (2000), www.lzra.gov
Cod spawning-stock biomass	CODSSB	t	SD 25 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Cod recruitment at age 2	CODR2	N	SD 25 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Cod weight at age 3	CODWC3	kg	SD 25 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Cod fishing mortality at age 4 – 7	COD_F47	–	SD 22 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Sprat spawning-stock biomass	SPRSSB	t	SD 22 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Sprat recruitment at age 1	SPRR1	N	SD 22 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Sprat weight at age 3	SPRWC3	kg	SD 22 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Sprat fishing mortality at age 3 – 5	SPR_F35		SD 22 – 32	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Herring spawning-stock biomass	HERSSB	t	SD 25 – 29 + 32excl. GoR	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Herring recruitment at age 1	HERR1	N	SD 25 – 29+32excl. GoR	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Herring weight at age 3	HERWC3	kg	SD 25 – 29+32excl. GoR	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk
Herring fishing mortality at age 2 – 6	Her_F26		SD 25 – 29+32excl. GoR	Annual	–	1974 – 2006	ICES	XSA	ICES (2007b), www.ices.dk

(Data info and requests to Christian Möllmann (christian.moellmann@uni-hamburg.de))

Table 8.3. Time-series used for the integrated ecosystem analysis of the Gulf of Riga (GoR).

Variable	**Abbreviation**	**Unit**	**Area**	**Season**	**Month**	**Years**	**Source**	**Method/Gear**	**Contact**	**References/ Weblinks**
Baltic Sea Index	BSI	-	Central Baltic	Winter	December–February	1973–2006	IFM–GEOMAR	Air pressure measurements	Lehmann *et al.* (2002)	
Salinity (0–50 m)	S_aug50	psu	Gulf of Riga	Summer	August	1973–2006	LATFRA	CTD, bottle data	Viesturs Bērziņš	
Temperature (0–20 m)	T_aug20	°C	Gulf of Riga	Summer	August	1973–2006	LATFRA	CTD, bottle data	Viesturs Bērziņš	
Temperature (0–20 m)	T_may20	°C	Gulf of Riga	Spring	May	1973–2006	LATFRA	CTD, bottle data	Viesturs Bērziņš	
Dissolved inorganic phosphorus (surface)	PO4_win	μmol l^{-1}	Gulf of Riga, outside coastal/transitional	Winter	January–March	1973–2004 (6 years missing)	LHEI	Bottle samples (0–10 m)	B. Müller-Karulis	www.lhei.lv
Run-off	Runoff	m^3 s^{-1}	Run-off Daugava River at Pļaviņas	Annual	January–December	1973–2006	LATVENERGO	Gauge measurement	B. Müller-Karulis	
Chlorophyll *a*	Chla_spr	mg m^{-3}	Gulf of Riga, outside coastal/transitional	Spring	April–May	1973–2006	LHEI	Bottles or integrated water sample, 0–10 m	B. Müller-Karulis	www.lhei.lv
Chlorophyll *a*	Chla_sum	mg m^{-3}	Gulf of Riga, outside coastal/transitional	Summer	June–August	1973–2006	LHEI	Bottles or integrated water sample, 0–10 m	B. Müller-Karulis	www.lhei.lv
Secchi depth	Sec_spr	m	Gulf of Riga, outside coastal/transitional	Spring	April–May	1973–2006	LHEI	Secchi according to HELCOM	B. Müller-Karulis	www.lhei.lv
Secchi depth	Sec_sum	m	Gulf of Riga, outside coastal/transitional	Summer	June–August	1973–2006	LHEI	Secchi according to HELCOM	B. Müller-Karulis	www.lhei.lv
Acartia spp.	AC_spr	mg m^{-3}	Gulf of Riga, depth >30 m	Spring	May	1973–2006	LATFRA	Juday net	G. Kornilovs	
Acartia spp.	AC_sum	mg m^{-3}	Gulf of Riga, depth >30 m	Summer	August	1973–1977, 1979–2006	LATFRA	Juday net	G. Kornilovs	
Cercopagis pengoi	Cerc	mg m^{-3}	Gulf of Riga, depth >30 m	Summer	August	1973–1977, 1979–2006	LATFRA	Juday net	G. Kornilovs	
Eurytemora affinis	Eury_spr	mg m^{-3}	Gulf of Riga, depth >30 m	Spring	May	1973–2006	LATFRA	Juday net	G. Kornilovs	
Eurytemora affinis	Eury_sum	mg m^{-3}	Gulf of Riga, depth >30 m	Summer	August	1973–1977, 1979–2006	LATFRA	Juday net	G. Kornilovs	
Limnocalanus grimaldii	Limno_spr	mg m^{-3}	Gulf of Riga, depth >30 m	Spring	May	1973–2006	LATFRA	Juday net	G. Kornilovs	
Limnocalanus grimaldii	Limno_sum	mg m^{-3}	Gulf of Riga, depth >30 m	Summer	August	1973–1977, 1979–2006	LATFRA	Juday net	G. Kornilovs	

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Herring yield/SSB	Her_yield		ICES SD 28.1 (+28.2, if GoR herring)	Annual	January – December	1977 – 2006	ICES	XSA		ICES (2007a)
Herring spawning-stock biomass	Her_SSB	t year^{-1}	ICES SD 28.1 (+28.2, if GoR herring)	Annual	At the beginning of year	1977 – 2006	ICES	XSA		ICES (2007a)
Herring weight at age 3	Her_W	kg	ICES SD 28.1 (+28.2, if GoR herring)	Annual	January – December	1973 – 2006	ICES	XSA		ICES (2007a)
Herring recruitment at age 1	Her_R	N	ICES SD 28.1 (+28.2, if GoR herring)	Annual	At the beginning of year	1977 – 2006	ICES	XSA		ICES (2007a)
Cod landings	Cod	t year^{-1}	ICES SD 28.1	Annual	January – December	1973 – 2006	LATFRA, EMI	Fishery statistics	M. Plikshs	Pers. comm.
Eelpout abundance (cpue)	ELP	kg h^{-1}	ICES SD 28.1	Summer, autumn	June, July, October	1975 – 1998, 2000, 2003 – 2006	LATFRA	Demersal trawl survey, average cpue	M. Plikshs	Pers. comm.
Eelpout weight	ELP_W	kg	ICES SD 28.1	Summer, autumn	June, July, October	1975 – 1998, 2000, 2003 – 2006	LATFRA	Demersal trawl survey, average weight/number	M. Plikshs	Pers. comm.

(Data info and requests to Bärbel Müller-Karulis (baerbel@latnet.lv))

Table 8.4. Time-series used for the integrated ecosystem analysis of the Gulf of Finland (GoF).

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Maximum ice cover	MaxIce	km^2	Baltic	Annual		1979–2008	FMI	Visual air-borne and satellite data	patrick.eriksson@fmi.fi	www.fmi.fi
Temperature (0–10 m)	F2TEMPUp	°C	Central GoF	Winter	January or February	1979–2008	ICES+EMI	CTD	A. Põllumäe	
Temperature (0–10 m)	F5TEMPUp	°C	Central GoF	Spring	May	1979–2008	ICES+EMI	CTD	A. Põllumäe	
Temperature (0–10 m)	F8TEMPUp	°C	Central GoF	Summer	August	1979–2008	ICES+EMI	CTD	A. Põllumäe	
Salinity (0–10 m)	F2SLOAUp	psu	Central GoF	Winter	January or February	1979–2008	ICES+EMI	CTD	A. Põllumäe	
Salinity (0–10 m)	F8SALUp	psu	Central GoF	Summer	August	1979–2008	ICES+EMI	CTD	A. Põllumäe	
Salinity (30 m–bottom)	Salin_sum_bot	psu		Summer	August	1979–2008	SYKE	CTD	janne.bruun@ymparisto.fi	
Oxygen bottom	Oxy_bot_sum	$ml\ l^{-1}$		Summer	August	1979–2008	SYKE	CTD	janne.bruun@ymparisto.fi	
Phosphates	PO4_sum	$mmol\ m^{-3}$		Summer	August	1979–2007	SYKE	CTD	janne.bruun@ymparisto.fi	
Nitrates	NO3_sum	$mmol\ m^{-3}$		Summer	August	1979–2007	SYKE	CTD	janne.bruun@ymparisto.fi	
Phosphates	PO4_win	$mmol\ m^{-3}$		Winter	January	1979–2008	SYKE	CTD	janne.bruun@ymparisto.fi	
Nitrates	NO3_win	$mmol\ m^{-3}$		Winter	January	1979–2008	SYKE	CTD	janne.bruun@ymparisto.fi	
Chlorophyll *a* (0–20 m)	Chla_sum	$mg\ m^{-3}$		Summer	August	1979–2007	SYKE	CTD	janne.bruun@ymparisto.fi	
Acartia spp.	Acart_spring	$mg\ m^{-3}$	Central GoF (st 16, 17, 18, 18°, F3)	Spring	May or June	1979–2008	EMI	Juday net (90 µm)	A. Põllumäe	
Acartia spp.	Acartia_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Eurytemora affinis	Eury_spring	$mg\ m^{-3}$	Central GoF (st 16, 17, 18, 18°, F3)	Spring	May or June	1979–2008	EMI	Juday net (90 µm)	A. Põllumäe	
Eurytemora affinis	Eury_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Pseudocalanus acuspes	Pseu_spring	$mg\ m^{-3}$	Central GoF (st 16, 17, 18, 18°, F3)	Spring	May or June	1979–2008	EMI	Juday net (90 µm)	A. Põllumäe	
Pseudocalanus acuspes	Pseudo_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Temora longicornis	Temo_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Limnocalanus lacustris	Limn_spring	$mg\ m^{-3}$	Central GoF (st 16, 17, 18, 18°, F3)	Spring	May or June	1979–2008	EMI	Juday net (90 µm)	A. Põllumäe	
Limnocalanus lacustris	Limno_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Bosmina coregoni maritima	Bosm_sum	$mg\ m^{-3}$		Summer	August	1979–2008	SYKE	WP-2 (100 µm)	J. Flinkman	
Herring landings	HERRcatch	$kg\ year^{-1}$		Annual		1980–2007	FGFRI		eero.aro@rktl.fi	

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Sprat landings	SPRATcatch	kg year^{-1}		Annual		1980–2007	FGFRI		eero.aro@rktl.fi	
Salmon landings	SALMONctch	kg year^{-1}		Annual		1980–2007	FGFRI		eero.aro@rktl.fi	
Trout landings	TROUTcatch	kg year^{-1}		Spring		1980–2007	FGFRI		eero.aro@rktl.fi	
Sprat weight at age 3	SprWA3	G		Annual		1979–2007	EMI		A. Põllumäe	
Herring total spawning-stock biomass	HERtotSPBio	t year^{-1}	GoF	Annual		1979–2007	FGFRI		eero.aro@rktl.fi	
Sprat total spawning-stock biomass	SPRATSpBio	10^3 t year^{-1}	GoF & CBS	Annual		1979–2007	FGFRI		eero.aro@rktl.fi	

(Data info and requests to Juha Flinkman (Juha.Flinkman@ymparisto.fi))

Table 8.5. Time-series used for the integrated ecosystem analysis of the Bothnian Sea (BoS).

Variable	Abbreviation	Unit	Area	Season	Months	Years	Source	Method/Gear	Contact/ Weblinks
Maximum ice coverage	maxice	km^2	Baltic Sea	Winter	NA	1979–2006	FIMR	Satellites, icebreaker reports	Juha Flinkman, FIMR
Winter surface temperature (0–10 m)	Tempwsurf	°C	Bothnian Sea offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Summer surface temperature (0–10 m)	Tempssurf	°C	Bothnian Sea offshore	Summer	July–September	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Summer bottom temperature (30 m–bottom)	Tempsbottom	°C	Bothnian Sea offshore	Summer	July–September	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Salinity bottom (30 m–bottom)	Salwbottom	psu	Bothnian Sea offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Average pH	pH		Bothnian Sea offshore	Annual	January–December	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Dissolved inorganic nitrogen (0–10 m)	NOwsurf	µmol l^{-1}	Bothnian Sea offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Dissolved inorganic phosphorus (0–10 m)	POwsurf	µmol l^{-1}	Bothnian Sea offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Total load of dissolved inorganic nitrogen from river run-off	DINrunoff	t	West Bothnian Sea coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Total load of dissolved inorganic phosphorus from river run-off	POrunoff	t	West Bothnian Sea coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Total load of silicate from river run-off	Sirunoff	t	West Bothnian Sea coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Chlorophyll *a*	Chl A	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Total phytoplankton biomass (0–10 m)	TotPhyto	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Diatom biomass (0–10 m)	Diatoms	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Dinoflagellate biomass (0–10 m)	Dinoflagellates	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Cyanobacteria biomass (0–10 m)	Cyanobact	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Acartia spp. biomass (water column average)	Acartia	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Bosmina spp. biomass (water column average)	Bosmina	mg m^{-3}	Bothnian Sea offshore	Summer	July–September	1979–2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR

Variable	**Abbreviation**	**Unit**	**Area**	**Season**	**Months**	**Years**	**Source**	**Method/Gear**	**Contact/ Weblinks**
Eurytemora spp. biomass (water column average)	Eurytemora	mg m^{-3}	Bothnian Sea offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Limnocalanus spp. biomass (water column average)	Limnocalanus	mg m^{-3}	Bothnian Sea offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Evadne spp. and *Podon* spp. biomass (water column average)	Evadne+Podon	mg m^{-3}	Bothnian Sea offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Pseudocalanus spp. biomass (water column average)	Pseudocalanus	mg m^{-3}	Bothnian Sea offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Coastal *Macoma balthica* biomass	MacomaC1	g m^{-2}	Southwest Bothnian Sea coast		April – June	1980 – 2006	SBF	Ekman, van Veen sampler	Anna Gårdmark, SBF
Coastal *Monoporeia affinis* biomass	MonopC1	g m^{-2}	Southwest Bothnian Sea coast		April – June	1980 – 2006	SBF	Ekman, van Veen sampler	Anna Gårdmark, SBF
Coastal *Saduria entomon* biomass	SaduriaC1	g m^{-2}	Southwest Bothnian Sea coast		April – June	1980 – 2006	SBF	Ekman, van Veen sampler	Anna Gårdmark, SBF
Offshore *Monoporeia affinis* biomass	mMonopOS	g l^{-1}	Bothnian Sea offshore		May – June	1983 – 2006	UMF	van Veen sampler	www.smhi.se
Offshore *Saduria entomon* biomass	SaduriaOS	g l^{-1}	Bothnian Sea offshore		May – June	1983 – 2006	UMF	van Veen sampler	www.smhi.se
Perch catch per unit effort	Perch cpue	N net^{-1} night^{-1}	Southwest Bothnian Sea coast	Summer	August	1979 – 2006	SBF	Coastal monitoring net fishing	Anna Gårdmark, SBF
Roach catch per unit effort	Roach cpue	N net^{-1} night^{-1}	Southwest Bothnian Sea coast	Summer	August	1979 – 2006	SBF	Coastal monitoring net fishing	Anna Gårdmark, SBF
Herring total-stock biomass	TSB Herr	t	Bothnian Sea offshore	Annual	NA	1979 – 2006	ICES WGBFAS	XSA	www.ices.dk
Herring recruitment at age 1	Recr Herr	N	Bothnian Sea offshore	Annual	NA	1979 – 2006	ICES WGBFAS	XSA	www.ices.dk
Herring weight at age 5	Sizeat5 Herr	kg	Bothnian Sea offshore	Annual	Quarterly	1979 – 2006	ICES WGBFAS	Sampling commercial fisheries	www.ices.dk
Commercial trawl effort	Trawlh	h (size corrected)	Bothnian Sea offshore	Annual	NA	1980 – 2006	ICES WGBFAS	Hours trawl size coefficient	www.ices.dk
Commercial trapnets	trapnets	N (of nets)	East Bothnian Sea coast	Annual	NA	1980 – 2006	ICES WGBFAS	Logbook count	www.ices.dk
Number of counted grey seals at Märket	Sseals	N	Southwest Bothnian Sea coast		May – June	1989 – 2006	NRM	Monitoring through aerial counts, ship-based counts	Olle Karlsson, NRM

(Data info and requests to Anna Gårdmark (anna.gardmark@fiskeriverket.se))

Table 8.6. Time-series used for the integrated ecosystem analysis of Bothnian Bay (BoB).

Variable	Abbreviation	Unit	Area	Season	Months	Years	Source	Method/Gear	Contact/ Weblinks
Maximum ice coverage	maxice	km²	Baltic Sea	Winter	NA	1979–2006	FIMR	Satellites, icebreaker reports	Juha Flinkman, FIMR
Winter surface temperature (0–10 m)	Tempwsurf	°C	Bothnian Bay offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Summer surface temperature (0–10 m)	Tempssurf	°C	Bothnian Bay offshore	Summer	July–September	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Summer bottom temperature (30 m)	Tempsbot	°C	Bothnian Bay offshore	Summer	July–September	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Salinity bottom (30 m)	Salwbot	psu	Bothnian Bay offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Average pH	pH		Bothnian Bay offshore	Annual	January–December	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Total load of dissolved inorganic nitrogen from river run-off	DINrunoff	t	West Bothnian Bay coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Total load of dissolved inorganic phosphorus from river run-off	POrunoff	t	West Bothnian Bay coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Total load of silicate from river run-off	Sirunoff	t	West Bothnian Bay coast	Annual	January–December	1979–2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Dissolved inorganic nitrogen (0–10 m)	NOwsurf	µmol l⁻¹	Bothnian Bay offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Dissolved inorganic phosphorus (0–10 m)	POwsurf	µmol l⁻¹	Bothnian Bay offshore	Winter	November–March	1979–2006	SMHI	At-sea monitoring	www.smhi.se
Chlorophyll *a*	Chl A	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Total phytoplankton biomass (0–10 m)	TotPhyto	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Diatom biomass (0–10 m)	Diatoms	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Dinoflagellate biomass (0–10 m)	Dinoflagellates	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Cyanobacteria biomass (0–10 m)	Cyanobact	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	Water sample at sea	Juha Flinkman, FIMR
Bosmina spp. biomass (water column average)	Bosmina	mg m⁻³	Bothnian Bay offshore	Summer	July–September	1979–2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR

Variable	**Abbreviation**	**Unit**	**Area**	**Season**	**Months**	**Years**	**Source**	**Method/Gear**	**Contact/ Weblinks**
Eurytemora spp. biomass (water column average)	Eurytemora	mg m^{-3}	Bothnian Bay offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling WP-2 (100 µm)	Juha Flinkman, FIMR
Limnocalanus spp. biomass (water column average)	Limnocalanus	mg m^{-3}	Bothnian Bay offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Evadne spp. and *Podon* spp. biomass (water column average)	Evadne+Podon	mg m^{-3}	Bothnian Bay offshore	Summer	July – September	1979 – 2006	FIMR	At-sea sampling: WP-2 (100 µm)	Juha Flinkman, FIMR
Number of counted grey seals at Sydvästbrotten	Nseals	N	Southwest Bothnian Bay coast		May – June	1989 – 2006	NRM	Monitoring through aerial counts, ship-based counts	Olle Karlsson, NRM
Herring total stock biomass	TSB Herr	t	Bothnian Bay offshore	Annual	NA	1980 – 2006	ICES WGBFAS	XSA	www.ices.dk
Herring recruitment at age 1	recr Herr	N	Bothnian Bay offshore	Annual	NA	1980 – 2006	ICES WGBFAS	XSA	www.ices.dk
Herring weight at age 5	Weightat5Herr	kg	Bothnian Bay offshore	Annual	Quarterly	1980 – 2006	ICES WGBFAS	Sampling commercial fisheries	www.ices.dk
Commercial trawl effort	trawl h	h (size corrected)	Bothnian Bay offshore	Annual	NA	1980 – 2006	ICES WGBFAS	Hours trawl size coefficient	www.ices.dk
Commercial trapnets	trapnets	N (of nets)	East Bothnian Bay coast	Annual	NA	1980 – 2006	ICES WGBFAS	Logbook count	www.ices.dk

(Data info and requests to Anna Gårdmark (anna.gardmark@fiskeriverket.se))

Table 8.7. Time-series used for the integrated ecosystem analysis of the coastal area of Kvädöfjärden in the northern Baltic proper (COAST).

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact/ weblink
Coastal temperature average for growth season (10 m)	TEMP_MAY-OCT	°C	SD27 (mean value for Va06, Va09, Va10, and Va11)	Summer	May–October	1975 – 2005	SMHI	Water sample	www.smhi.se
Offshore salinity in surface water (0 – 10 m)	SALCBS	psu	Northen Baltic proper (mean value for BY15, BY20, BY29, BY31, BY32, and BY38)	Annual	January–December	1971 – 2006	SMHI	Water sample	www.smhi.se
Nitrate run-off from land	TOTP_RUNOFF	t year^{-1}	Total estimate for Swedish National Area E	Annual	January–December	1971 – 2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Phosphate run-off from land	TOTN_RUNOFF	t year^{-1}	Total estimate for Swedish National Area E	Annual	January–December	1971 – 2006	SLU	Concentration in rivers total run-off volume	www.ma.slu.se
Offshore nitrate in surface water (0 – 10 m)	DINCBS	μmol l^{-1}	Northen Baltic proper (mean value for BY15, BY20, BY29, BY31, BY32, and BY38)	Winter	January–February (mean value)	1971 – 2006	SMHI	Water sample	www.smhi.se
Offshore phosphate in surface water (0 – 10 m)	DIPCBS	μmol l^{-1}	Northen Baltic proper (mean value for BY15, BY20, BY29, BY31, BY32, and BY38)	Winter	January–February (mean value)	1971 – 2006	SMHI	Water sample	www.smhi.se
Water transparency	SECCHIAug	M	SD27 (Kvädöfjärden)	Summer	August	1971 – 2006	SBF	Secchi disc	SBF
Soft-bottom benthos: *Macoma baltica*	MACBAL	N m^{-2}	SD27 (Kvädöfjärden)	Spring	April–June	1971 – 2006	SBF	Van veen sampler	SBF
Soft-bottom benthos: *Monoporeia affinis*	MONAFF	N m^{-2}	SD27 (Kvädöfjärden)	Spring	April–June	1971 – 2006	SBF	Van veen sampler	SBF
Soft-bottom benthos: *Saduria entomon*	SADURIA	N m^{-2}	SD27 (Kvädöfjärden)	Spring	April–June	1971 – 2006	SBF	Van veen sampler	SBF
Soft-bottom benthos: *Marenzelleria viridis*	MARVIR	N m^{-2}	SD27 (Kvädöfjärden)	Spring	April–June	1971 – 2006	SBF	Van veen sampler	SBF
Soft-bottom benthos: *Harmothoe sarsi*	HARMOTHOE	N m^{-2}	SD27 (Kvädöfjärden)	Spring	April–June	1971 – 2006	SBF	Van veen sampler	SBF
Fish abundance: sculpins	SCULPIN	N net^{-1} night^{-1}	SD27 (Kvädöfjärden)	Autumn	October	1972 – 2006 (1989 – 2006)	SBF	Coastal monitoring net fishing	SBF
Fish abundance: cod	COD	N net^{-1} night^{-1}	SD27 (Kvädöfjärden)	Autumn	October	1971 – 2006 (1989 – 2006)	SBF	Coastal monitoring net fishing	SBF
Fish abundance: perch	PERCH	N net^{-1} night^{-1}	SD27 (Kvädöfjärden)	Summer	August	1971 – 2006 (1989 – 2006)	SBF	Coastal monitoring net fishing	SBF
Fish abundance: roach	ROACH	N net^{-1} night^{-1}	SD27 (Kvädöfjärden)	Summer	August	1971 – 2006 (1989 – 2006)	SBF	Coastal monitoring net fishing	SBF

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact/ weblink
Fish abundance: flounder	FLOUNDER	N net $^{-1}$ night $^{-1}$	SD27 (Kvädöfjärden)	Summer	August	1971–2006 (1989–2006)	SBF	Coastal monitoring net fishing	SBF
Grey seals	SEAL	N	SD27 (Gryt Archipelago and St Anna Archipelago)		May–June	1989–2006	NRM	Counted from boat	www.nrm.se

(Data info and requests to Lena Bergström (lena.bergstrom@fiskeriverket.se))

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10 List of abbreviations

BSI	Baltic Sea Index
COAST	the coastal area of Kvädöfjärden
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
EAM	ecosystem approach to management
HELCOM	Helsinki Commission
IEA	integrated ecosystem assessment
MAFA	minimum/maximum autocorrelation factor analysis
NAO	North Atlantic Oscillation index
PCA	principal component analysis
PC1	principal component 1
PC2	principal component 2
RSI	regime shift index
SSB	spawning-stock biomass
SST	sea surface temperature
STARS	sequential regime shift analysis
TSB	total-stock biomass
WGBFAS	Baltic Fisheries Assessment Working Group
WGIAB	ICES/HELCOM Working Group on Integrated Assessments for the Baltic Sea