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Climate effects on zooplankton biomasses in a coastal Baltic Sea area

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To evaluate if climate influence zooplankton densities and dynamics in a coastal Baltic Sea area, we performed statistical analyses of two 12–13-year-long data series. The winter (December–March) North Atlantic Oscillation index (NAO) was used as the independent variable and monthly biomasses of seven groups of zooplankton as the dependent variables. Most of the statistically significant correlations were obtained for the spring–early-summer period and they all indicate higher zooplankton biomasses after winters with high NAO values (mild winters). This supports results from other Baltic Sea studies, indicating that winter/spring climate is important to the early summer zooplankton community.

Introduction

Climate variability influences various trophic levels in marine ecosystems, indicating that much of the inter-annual and inter-decadal biological variability can be attributed to physical forcing (e.g. Stenseth *et al*. 2002, Dippner *et al*. 2008). The North Atlantic Oscillation index (NAO, Hurrell 1995), derived as a normalized difference in sea-level air-pressure between the Azorean high and the Icelandic low pressure systems, is one climate measure that has been used in such studies (e.g. Alheit *et al*. 2005, Brander 2005). The sea-surface temperature anomaly during winter in the Baltic Sea is positively correlated with the NAO winter index, i.e. positive NAO index associated with mild winters (Dippner and Ikauniece 2001).

There are several recent reports on correlations between mild winters/springs and Baltic zooplankton densities in spring and summer (Dippner *et al*. 2000, 2001, Hänninen *et al*. 2000, 2003, Möllmann *et al*. 2000, 2002, Simm and Ojaveer 2000, Vuorinen *et al*. 2003, 2004). Such variability may also influence fish populations, as most Baltic fish are spring spawners with zooplanktivorous larvae. To these fish, food availability during the larval period is likely to constitute a recruitment bottleneck (Houde 1994, Cushing 1996). This is supported by the positive correlation between NAO and herring year class strength found by Axenrot and Hansson (2003).

The objective of this study is to analyse a new source of long-term data on the Baltic Sea zooplankton, to explore how generally valid the results in the earlier studies are. The data used in this study is the only existing zooplankton long-term dataset with high sampling frequency from the archipelago areas in the western side of the Baltic Sea.

Material and methods

Zooplankton abundance data were available from two stations (Fig. 1), one in a relatively open coastal area (water depth 38 m) and the other in a relatively large and sheltered bay (water depth 30 m). The summer surface water temperature reaches 17–21 °C, with 1–2 °C higher values in the bay. The salinity in the open coastal area is ~6.5 PSU at the surface and ~0.5 PSU higher at the bottom. Due to freshwater discharges, the salinity in the bay is ~0.5 PSU lower. The phytoplankton production during the study period was about 60% higher in the bay than in the open coastal area (Johansson 1992), but there was no general difference in the phytoplankton community structure between the areas (Hansson *et al*. 1990, Hajdu *et al*. 1996).

Zooplankton retained on a 90 μm net was sampled approximately every two weeks from March to October. The procedures are described in Johansson *et al*. (1993). Data from the coastal area and the bay are available for 1976–1988 and 1977–1988, respectively. Counts were converted to biomasses using published data on wet weights (Hernroth 1985, Hansson *et al*. 1990). Seven species and groups of zooplankton were included in the analyses: the copepods *Eurytemora affinis*, *Acartia* spp., *Temora longicornis* and *Pseudocalanus minutus elongatus*, the cladoceran *Bosmina longispina maritima*, all other cladocerans merged, and the rotifer *Synchaeta* spp. Together these taxa constituted the bulk of the net zooplankton biomass (Johansson 1992). Copepods were equally abundant at both sites and contributed most to the total biomass. Among copepods, *E. affinis* was the most abundant species in the bay and *Acartia* spp. in the open coastal area (Johansson 1992). Rotifers and cladocerans were relatively more abundant in the bay (Johansson 1992). Prior to the statistical analyses, biomasses were log-transformed to reduce the effects of outliers and the values used in the analyses were the biomass anomalies, estimated as biomass in a given month and year minus the long-term average for that month.

The statistical method applied was statistical downscaling, a method developed by von Storch [von Storch *et al*. (1993), explained in an ecological context by Kröncke *et al*. (1998)]. The idea is to find independent variables that can explain the variation in dependent variables. In this study, we used climate, expressed by the winter NAO index (December–March; Hurrell 1995), as an independent variable and monthly biomass anomalies as dependent variables. The method allows inclusion of time lags between independent and dependent data. We explored effects of monthly time lags, from what we call a three-month (zooplankton in March related to the winter NAO index) to a ten-month lag (zooplankton in October). To keep this note short, we will not present further details of the statistical analyses, as this has been done in earlier publications on the data similar to ours (Dippner *et al*. 2000, 2001, Dippner and Ikauniece 2001).

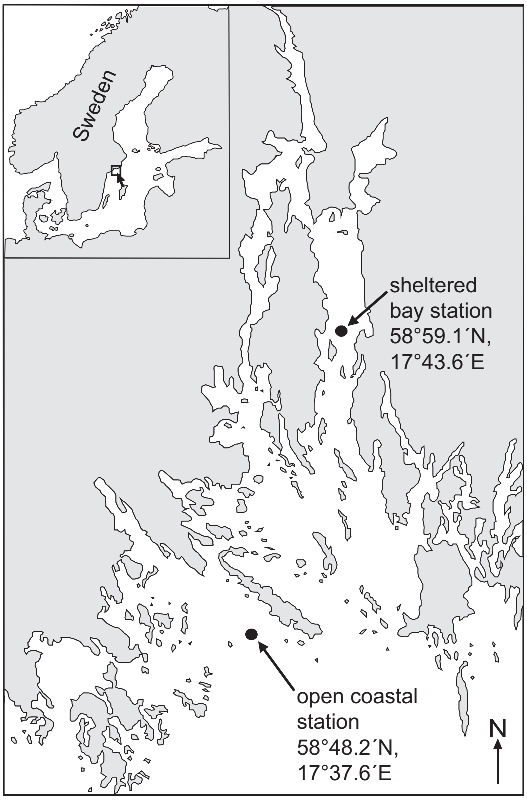

Fig. 1. Study area with the two sampling stations indicated.

Results

Combinations of different time lags between

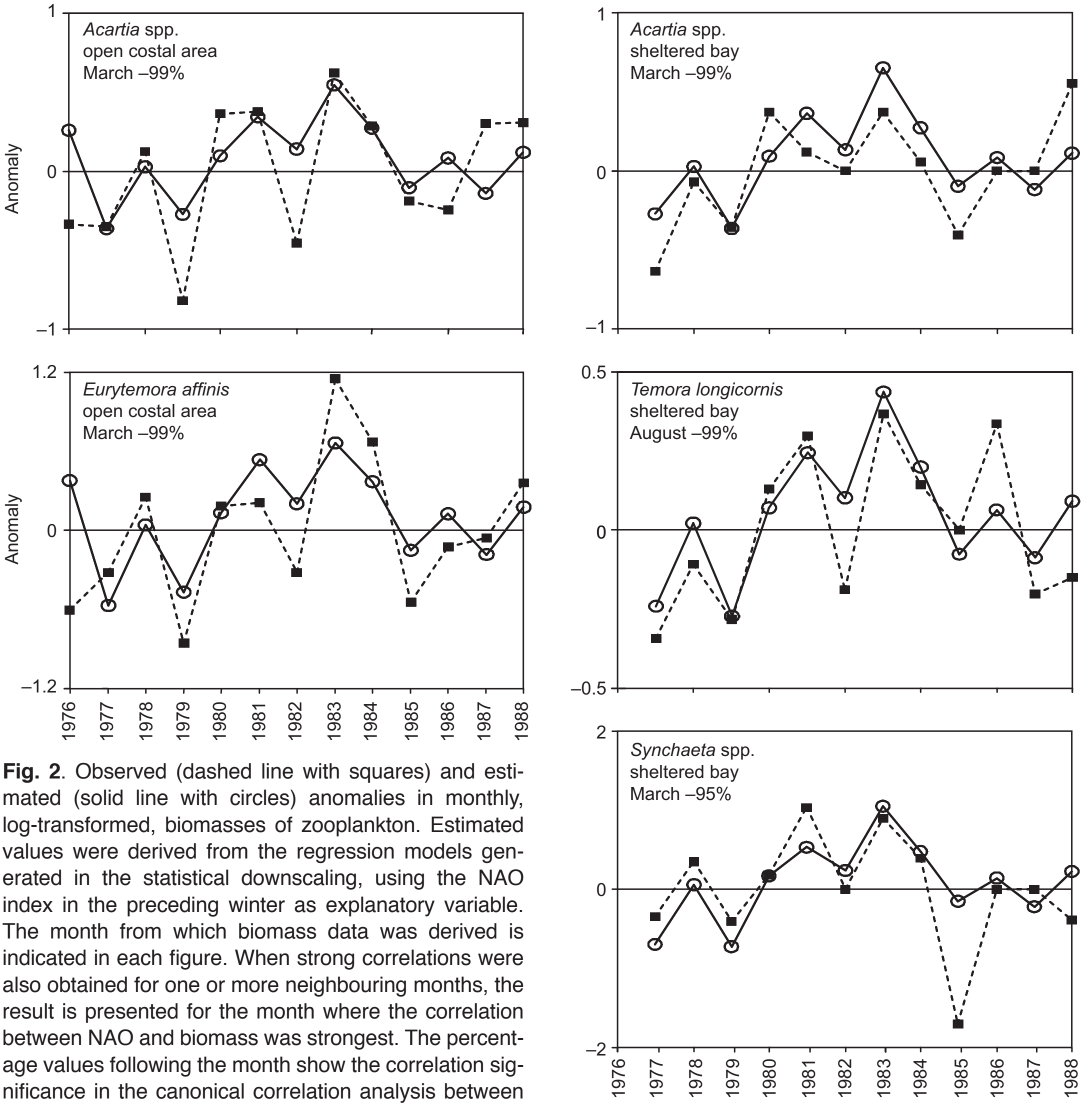

Fig. 2. Observed (dashed line with squares) and estimated (solid line with circles) anomalies in monthly, log-transformed, biomasses of zooplankton. Estimated values were derived from the regression models generated in the statistical downscaling, using the NAO index in the preceding winter as explanatory variable. The month from which biomass data was derived is indicated in each figure. When strong correlations were also obtained for one or more neighbouring months, the result is presented for the month where the correlation between NAO and biomass was strongest. The percentage values following the month show the correlation significance in the canonical correlation analysis between the leading eigenmodes of the climate predictor and the biological time series (method described in Dippner *et al*. 2000, 2001, Dippner and Ikauniece 2001).

climate predictors and the zooplankton data were analysed, resulting in 112 correlations (two stations, seven taxa, eight months). Nine of these correlations were statistically significant, though a number of correlations were from neighbouring months and in these cases results are given for the month where the correlation between NAO and biomass was strongest. Statistically significant correlations were found for the copepods *Acartia* spp., *E. affinis*, *T. longicornis* and the rotifers *Synchaeta* spp. (Fig. 2). For *Acartia* spp., the correlation was significant in both areas. No correlations were detected between climate variability and the biomass of *P. minutus elongatus*, *B. longispina*, and the other cladocerans. Most of the significant correlations were obtained for the spring and early summer and they all were positive. This implies higher zooplankton biomasses after mild winters (high NAO).

Discussion

Our results, positive correlations between NAO and spring–early-summer biomasses of copepods, are generally consistent with those reported for the central Baltic Sea (Dippner *et al*. 2000), the Baltic Archipelago Sea (Dippner *et al*. 2001) and a coastal lagoon in the southern Baltic (Feike *et al*. 2007). Our results are thus not novel, but their value lies in that they contribute to build a general understanding of the factors that determine the seasonal dynamics of Baltic Sea zooplankton. Given the current concern on possible ecological impacts of climate change, such consistent results among studies are important.

An attempt to explain the difference in response by different taxa would require much more detailed data than currently is available and general speculation is not productive. Because of this, we will not pursue that in this short note. There are results, however, that justify some discussion as to why the signal from winter conditions is primarily seen in spring and early summer. Later in the season other factors are likely to become more important. Johansson (1992) showed a drastic decrease in zooplankton biomass in late summer in this area, and Axenrot and Hansson (2004) showed that the pelagic fish biomass (mainly young-of-the-year herring) in the study area increased one order of magnitude over a six weeks period in July and August. This indicates that predation by fish may be a major driver of zooplankton variation in late summer and autumn, reducing the significance of the previous winter's climate.

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