Forecast of climate-induced change in macrozoobenthos in the southern North Sea in spring

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ABSTRACT: A multivariate regression model using observed climate data is used to forecast the climate-induced changes in macrozoobenthos in spring. This is demonstrated by a forecast over 6 yr of biomass, abundance and species number of macrozoobenthos communities in the southern North Sea. The partial linearity between climate and benthic variables, as well as the existence of a phase lag between climate variability during winter time and the response in macrozoobenthos in spring, makes the climate-induced variability in macrozoobenthos predictable. The results indicate that a major part of interannual and interdecadal variability of marine ecosystem, here demonstrated for macrozoobenthos, can be attributed to the physical forcing of winter climate.

KEY WORDS: Climate variability · Macrozoobenthos · Forecast · North Sea · Multivariate statistics

Many marine ecosystems around the world are currently undergoing dramatic changes in species composition due to the influence of human activity or due to climate events, resulting in a reduction in species diversity (Russell 1973, Avaria & Munoz 1989, Carrasco & Santander 1989). Changes in species composition, species richness, and/or functional diversity affect the sustainability of biological resources. Direct and indirect anthropogenic causes, such as overfishing, industrial and urban growth, pollution and eutrophication, losses of habitats, and changes in coastal morphology, suggest an ecosystem degradation (Goldberg 1994). The fact that marine ecosystem is extremely complex and processes within, such as trophic and non-trophic interaction, benthic-pelagic coupling and species interaction, are only partly understood leads to the conclusion that the system is inherently unpredictable.

However, various recent investigations in different parts of the world have shown that signals of climate variability can be detected at various trophic levels of the marine ecosystem, indicating that a major part of interannual and interdecadal biological variability can indeed be attributed to physical forcing (Cushing & Dickson 1976, Aebisher et al. 1990). Certain species show a linear response to climate variability in the northern hemisphere mainly during winter and spring. Correlations to climate variability have been identified for phytoplankton color index in the Northeast Atlantic (Reid et al. 1998, Edwards et al. 2001), for zooplankton in the Northeast Atlantic, the North Sea and the Baltic Sea (Taylor 1995, Fromentin & Planque 1996, Dippner et al. 2000, 2001), for benthos in the North Sea, the Kattegat and the Gulf of Riga (Kröncke et al. 1998, Tunberg & Nelson 1998, Dippner & Ikauniece 2001), and various species of fish in different areas (Mann & Drinkwater 1994, Binet 1997, Dippner 1997a, Mantua et al. 1997, Dippner & Ottersen 2001).

In contrast, during summer and autumn, ecosystems are controlled by reproduction, succession or nonlinear predator–prey interaction (Dippner et al. 2001). A general overview is given by Drinkwater et al. (2003). Often a phase lag appears between climate forcing and the response in biological systems (Kröncke et al. 1998, Dippner et al. 2000, Dippner & Ottersen 2001), which enables us to forecast climate-induced natural variability and changes in marine ecosystems. This is
demonstrated here on macrozoobenthos in the southern North Sea.

The benthic study area is situated north of the island of Norderney in the Wadden Sea (southern North Sea). Five monitoring stations were located at depths between 12 and 20 m. Samples were taken monthly that NAO(\(t\)) = \(C \times c(t)\), with \(C\) as a scalar constant, we can give explicitly equations for the 3 benthic quantities as function of the NAO winter index only:

**Biomass:**
\[
BM(t)_{spring} = 588.8 \times 10^{0.104 \times NAO(t) - 1}
\]

**Abundance:**
\[
AB(t)_{spring} = 1950 \times 10^{0.079 \times NAO(t) - 1}
\]

**Species number:**
\[
SN(t)_{spring} = 23.4 + 2.09 \times NAO(t)
\]

As skill factors for the quality of the model, the correlation coefficient between the prediction and the macrozoobenthos observations and the Brier-based score \(\beta\)
are used (Table 1). $\beta$ is defined as: $\beta = 1 - \sigma^2_e/\sigma^2_o$, where $\sigma^2_e$ and $\sigma^2_o$ are the variances of the error (i.e. observation minus model) and observation. $\beta = 1$ means that model and observation are identical, $\beta = 0$ that the error of the model has the same size as the variance of the observations (Livezey 1995). The high model skill indicates a linear response of the biological system in spring to climate variability during winter. Both the linear response and the phase lag make the climate-induced variability in the macrozoobenthos time series predictable.

Climatic factors play a dominant role in structuring macrozoobenthos communities in the North Sea, at least in winter and spring. The mediator between climate variability and benthic parameters is temperature, which is vertically homogeneous in the southern North Sea (Kröncke et al. 1998) due to the strong tidal mixing. Macrofauna communities are very sensitive to synergistic effects and are severely affected by temperature changes (Kröncke et al. 1998). Cold winters generally reduce species number, abundance and biomass of the macrozoobenthos in coastal regions of the North Sea (Kröncke et al. 1998). This was illustrated particularly well in the severe winter 1995/96 in the southern North Sea. In contrast, the extremely good correlation between NAO winter index and observations in the early 1990s can be explained by a high percentage of warm temperate macrofauna species in connection with mild winters (Kröncke et al. 1998).

The atmospheric winter circulation over the North Atlantic area and the NAO winter index are good predictors of the structure of the macrofauna communities in the following spring. Models which simulate climate-change scenarios are able to reproduce the past and predict the future NAO winter index (Cubasch et al. 1995, Hasselmann et al. 1995). Therefore, possible future developments of macrozoobenthos communities can be predicted for the next decades from those scenarios, and conclusions for long-term changes can drawn.

The knowledge of the response of macrozoobenthos in spring to climatic forcing during winter, and the predictability of the system some months in advance, will enable us in the future to differentiate between anthropogenic impact and natural climatic effects. The approach presented here, demonstrated on macrozoobenthos in the southern North Sea, is generally applicable to all areas in marine biology, from species level up to biodiversity, if a linear response and a phase lag can be identified. The forecasts are of vital interest for practical aspects of sustainable management of marine ecosystems or of integrated coastal zone management.

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