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Common trends in German Bight benthic macrofaunal communities: Assessing temporal variability and the relative importance of environmental variables

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ABSTRACT

We examined long-term variability in the abundance of German Bight soft bottom macro-zoobenthos together with major environmental factors (sea surface temperature, winter NAO index, salinity, phosphate, nitrate and silicate) using one of the most comprehensive ecological long-term data sets in the North Sea (1981–2011). Two techniques, Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA) were used to identify underlying common trends in the macrofaunal time series and the relationships between this series and environmental variables. These methods are particularly suitable for relatively short (>15–25 years), non-stationary multivariate data series. Both MAFA and DFA identify a common trend in German Bight macrofaunal abundance i.e. a slight decrease (1981–mid-1990s) followed by a sharp trough in the late 1990s. Subsequently, scores increased again towards 2011. Our analysis indicates that winter temperature and North Atlantic Oscillation were the predominant environmental drivers of temporal variation in German Bight macrofaunal abundance. The techniques applied here are suitable tools to describe temporal fluctuations in complex and noisy multiple time series data and can detect distinct shifts and trends within such time series.

1. Introduction

Benthic macrofauna plays an important role in the structure and functioning of marine ecosystems (Brey, 2012; Oug et al., 2012). Benthic species are consumed by fish, birds and mammals, thereby providing food for higher trophic levels (Iken et al., 2010). Macrobenthos is also important in nutrient and organic matter cycling and provides an important link between the benthic and pelagic compartment of marine ecosystems (Grall and Chauvaud, 2002; Hill et al., 2011). These functions as well as the relatively stationary habit of many benthic organisms make them sensitive bio-indicators of environmental change (Tomiyama et al., 2008). Benthic communities may fluctuate over time because of characteristics of the species' life cycles and/or in response to environmental variability (Convey, 1996; Sibly and Calow, 1989). In this context, assessing temporal patterns of benthic community development and their underlying drivers is critical for understanding the ecology of diverse marine ecosystems (Robinson and Sandgren, 1983; Zajac et al., 2013). In fact, understanding patterns of change in benthic fauna through the monitoring of communities (e.g., community structure and composition, species richness) might allow for separating effects of climate variability and anthropogenic disturbance on diversity and the functioning of the marine benthic ecosystem (Munari, 2011).

There are a number of multivariate analysis techniques (e.g. redundancy analysis and canonical correspondence analysis) available to analyze interactions between different variables in time. Here, we prefer Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA), since these two approaches allow estimation of common patterns and interactions in various time series and also inspection on the effect of explanatory time-dependent parameters (Ritter and Muñoz-Carpena, 2006; Zuur et al., 2007). MAFA and DFA are particularly suitable for relatively short (>15–25 years), non-stationary multivariate time series data. MAFA takes the temporal autocorrelation structure into account and extracts significant common trends from the data (Zuur et al., 2007). It also quantifies the canonical correlation between temporal trends and macrofaunal abundance time series (Nye et al., 2010). DFA is used to identify underlying common trends among multivariate time series while taking the effects of explanatory variables into account (Kuo and Lin, 2010; Zuur and Pierce, 2004). Here, we focus on a 30 year (1981–2011) time series of benthic macrofaunal abundance and environmental variables in the German Bight. The specific objectives of

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our study were (i) to analyze this data set for common temporal patterns and (ii) to identify the environmental factors affecting these temporal patterns.

2. Material and methods

2.1. Response variables

The database of this study consists of macro-zoobenthos samples collected at four stations in the German Bight in spring (i.e. prior to the main seasonal recruitment period) 1981 to 2011 (Fig. 1). The stations represent the typical bottom communities in this region, i.e. the *Nucula nitidosa*-, *Tellina fabula*- and *Amphiura filiformis*-associations (Salzwedel et al., 1985; Schröder, 2003). Samples were collected using 0.1 m^2 Van Veen grabs, sieved over 0.5 mm mesh and fixed in 4% buffered formalin. Macro-zoobenthic organisms were identified to species level as far as possible, counted and weighed (wet weight). The data used in this study are total taxa abundance per square meter and per sampling date and station. A total of 152 taxa were encountered during the entire sampling series. In order to identify those taxa which were most representative for the overall trend in community composition, data of all four stations were pooled and a Biota-Environment Stepwise Analysis (BVSTEP) (Clarke and Warwick, 1998) was applied to the 31 sampling dates × 152 taxa abundance matrix.

BVSTEP involves a stepwise 'forward selection and backward elimination' algorithm allowed determination of the small subset of species whose similarity matrix best matched that of the full data at $\rho > 0.95$ level of Spearman's rank correlation (Clarke and Gorley, 2006). This small subset of variables encapsulated most of the explanatory power of the original data and thus, was most representative for the overall trend in community composition. Abundance data were fourth-root transformed prior to analysis to reduce the influence of very abundant taxa on the relationship between samples (Clarke and Warwick, 1998). This analysis was performed using the PRIMER v6 (Plymouth Routines in Multivariate Ecological Research) (Clarke and Gorley, 2006).

2.2. Explanatory variables

Several environmental parameters were tested for their effects on the long-term trends of macrofaunal abundance: mean sea surface temperature (SST) during winter (Dec.–Mar.; SSTw) and summer of the preceding year (Jul.–Sep.; SSTs), mean salinity and dissolved inorganic nutrient concentrations (phosphate, nitrate and silicate) were derived from the Helgoland Roads long-term data set (Wiltshire et al., 2010); daily measurements at station "Kabeltonne" (54°11′3″ N, 7°54′0″ E) between the two Helgoland islands since 1962. The North Atlantic Oscillation annual (NAOI) and winter indices (NAOWI) (Dec.–Mar) were obtained from Climate Analysis Section, NCAR, Boulder, USA (http://www.cgd.ucar.edu/cas/jhurrell/indices.html). The variables were lagged up to two years in order to explore possible indirect or delayed effects of environmental pressures on benthic macrofauna.

2.3. Data exploration

Each macrofaunal and environmental parameter time series was standardized to mean = 0 and standard deviation = 1 to simplify the interpretation of the estimated regression parameters (Zuur et al., 2007). We applied variance inflation factor (VIF) analysis to identify and to eliminate the variables that are collinear (Zuur et al., 2007) as multi-collinearity may introduce bias into the analysis (Zuur et al., 2007). VIF is a scaled version of the multiple correlation coefficients between variable δ and the rest of the independent variables expressed as:

$$VIF_{\delta} = 1/\left(1-R_{\delta}^{2}\right) \quad (1)$$

where R^2_{δ} is the multiple correlation coefficient (Graybill and Iyer, 1994). A threshold VIF of 5 was set as the maximum, meaning that a value >5 indicates potential multi-collinearity (Ritter and Muñoz-Carpena, 2006).

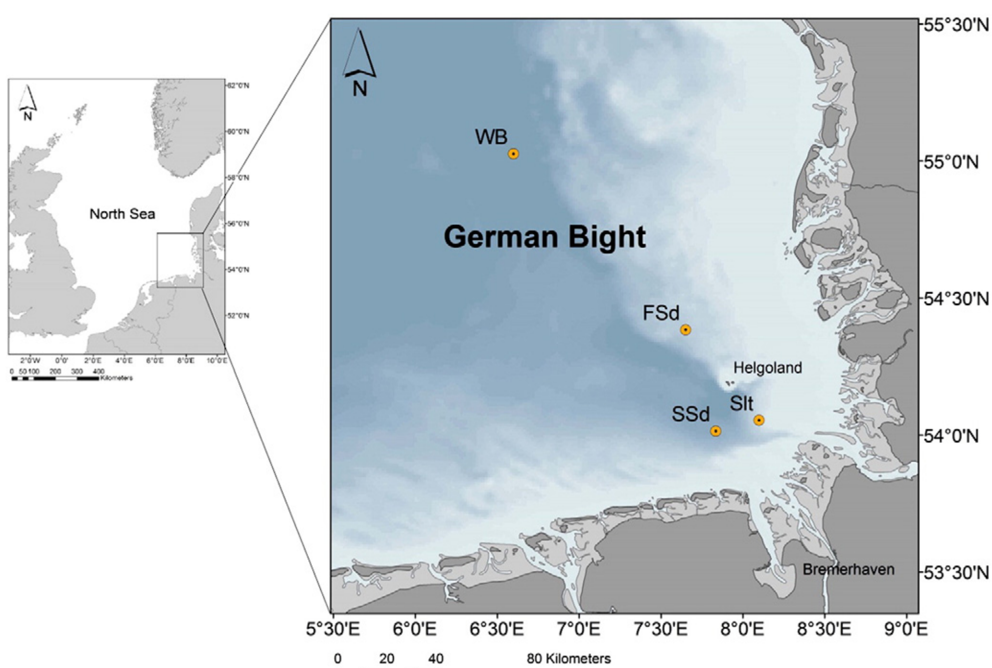

Fig. 1. Location of the four long-term monitoring stations for macro-zoobenthos in the German Bight, North Sea.