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Influence of macrofauna long-term natural variability on benthic indices used in ecological quality assessment

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ABSTRACT

An essential prerequisite for the assessment of the ecological quality of marine ecosystems is the understanding of the natural variability and its effect on the performance of quality indices. This study is focused on the long-term natural variability of diversity, biotic and multimetric indices by using long-term macrofauna data of a coastal area in the southern North Sea (1978–2005). The univariate and most biotic and multimetric indices respond significantly on specific natural disturbance events such as cold winters, but the strength of response varied between indices as well as between events. As a result, the ecological quality status can decrease over a range of 3 (out of 5) classification units. The overall ecological quality was good to high, but an increase of indices occurred from the mid 1980s onwards due to changes in the climate regime. This long-term variability has to be considered within ecological quality assessment schemes.

1. Introduction

Due to the increasing impact of human activities on the marine ecosystem in the last decades the need for the assessment of the ecological quality status has become increasingly important. The European Water Framework Directive (WFD), which came into force in December 2000, emphasises in particular the ecological quality status of coastal and estuarine waters. This directive aims at achieving at least 'good ecological status' for all waters by 2015 and requires member states to assess the ecological quality status (Heiskanen et al., 2004; Borja, 2005). The assessments of the ecological status will combine physico-chemical, hydrodynamic and morphological characteristics as well as different biological components of the ecosystem (e.g. plankton, benthos, fish). Among these components the benthic fauna is of major importance, because on the one hand it plays a vital role in nutrient cycling, detrital decomposition and as food source for higher trophic levels and on the other hand benthic species are sensitive indicators of changes in the marine environment. Effects of anthropogenic disturbances on the benthos include changes in diversity, biomass, abundance of stress tolerant and sensitive benthic species, and the trophic or functional structure of the benthic community (Pearson and Rosenberg, 1978; Warwick and Uncles, 1980; Warwick, 1986; Warwick and Clarke, 1994; Kaiser et al., 2000; Grall and Chauvaud, 2002). A variety of indices are available, which indicate the status of ecological condition and trends in succession of marine benthic systems (reviewed in e.g. Diaz et al., 2004; Pinto et al., 2009). Univariate diversity indices such as the Shannon-Wiener Index were the most commonly used index in the past. In more recent studies more complex biotic and multimetric indices were developed to get a more sensible tool for the assessment of ecological quality in a benthic ecosystem. Based on the model of Pearson and Rosenberg (1978), many of these indices use indicator species or ecological groups of species according to their sensitivity to stress, such as the AZTI Marine Biotic Index (AMBI) (Borja et al., 2000) or used a combination of univariate and biotic indices within a multimetric approach such as the modified M-AMBI (Muxika et al., 2007) or the Danish Quality Index (DKI) (Borja et al., 2007).

However, most of these indices have been designed and used to differentiate anthropogenic impacted sites from undisturbed reference sites. Consequently, the effects of a variety of anthropogenic pressures on the performance of indices were extensively tested and described (e.g. van Dolah et al., 1999; Borja et al., 2003b; Muxika et al., 2005; Simboura et al., 2007). Of course, the implementation of the WFD need tools, which are able to detect anthropogenic impact, but being less or, ideally, not at all sensitive to natural variability. But univariate as well as multimetric indices may respond to any disturbance, man-induced or natural (Wilson and Jeffrey, 1994), and particularly information on the natural variability of indices is very meagre. Nevertheless, the knowledge about the natural dynamics of indices is essential for the continuous monitoring and assessment of ecological quality status and for defining reference and baseline conditions. Especially long-term background data are needed, if the management objective is to re-establish the structure of benthic communities in the past.

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Up to now, the natural variability of benthic indices and the consequences for the ecosystem quality classification was mainly assessed regarding seasonal changes (Reiss and Kröncke, 2005a; Chainho et al., 2007) or along salinity gradients (Muxika et al., 2007; Zettler et al., 2007), whereas very little information is available about the long-term variability of benthic indices and the impact of climate and hydrographic changes. Only Dauvin and Ruellet (2007) reported on the performance of the BOPA index over a period of 19 years. Other indices such as the M-AMBI and the Bentix were studied on shorter time scales from 10 to 15 years (Muxika et al., 2007; Simboura et al., 2007; Borja et al., 2009b).

Several long-term studies in the North Sea revealed a system shift accompanied by changes in plankton and benthic communities as well as in fish stocks, which were directly or indirectly correlated with the variability of the North Atlantic Oscillation Index (NAOI) in winter indicating the influence of extreme cold as well as mild winters on the community structure and function (e.g. Kröncke et al., 1998, 2001; Reid et al., 1998; Frid et al., 1999; Clark and Frid, 2001; Ehrich and Stransky, 2001; Wieking and Kröncke, 2001; Beaugrand, 2003; Franke and Gutow, 2004; Wiltshire and Manly, 2004; McQuatters-Gollop et al., 2007). Long-term changes of benthic communities are well described for several regions, but the effects of these changes on the performance of benthic indices used for ecological quality assessment were hardly addressed.

In this study, we examine and compare explicitly the long-term variability of ecological indices. We applied a variety of biotic indices on our macrofauna long-term data set off the island of Norderney (North Sea; 1978–2005) in order to (i) analyse the long-term variability of various indices and to (ii) evaluate their sensitivity/robustness against natural disturbance events.

2. Material and methods

2.1. Study site

The study site is situated north of the island of Norderney. Five stations are located in water depths between 12 m and 20 m (Fig. 1). Sediment analyses have revealed that fine sand with grain sizes between 63 and 250 μm has prevailed since 1978 at the study site. The macrofauna community in this area belongs to the coastal *Fabulina fabula* community (Salzwedel et al., 1985; Kröncke et al., 2001; Rachor et al., 2007) mainly characterized by the eponymous bivalve species *F. fabula*, polychaete species of the genus *Nephtys* and *Magelona*, as well as amphipod species of the genus *Bathyporeia*.

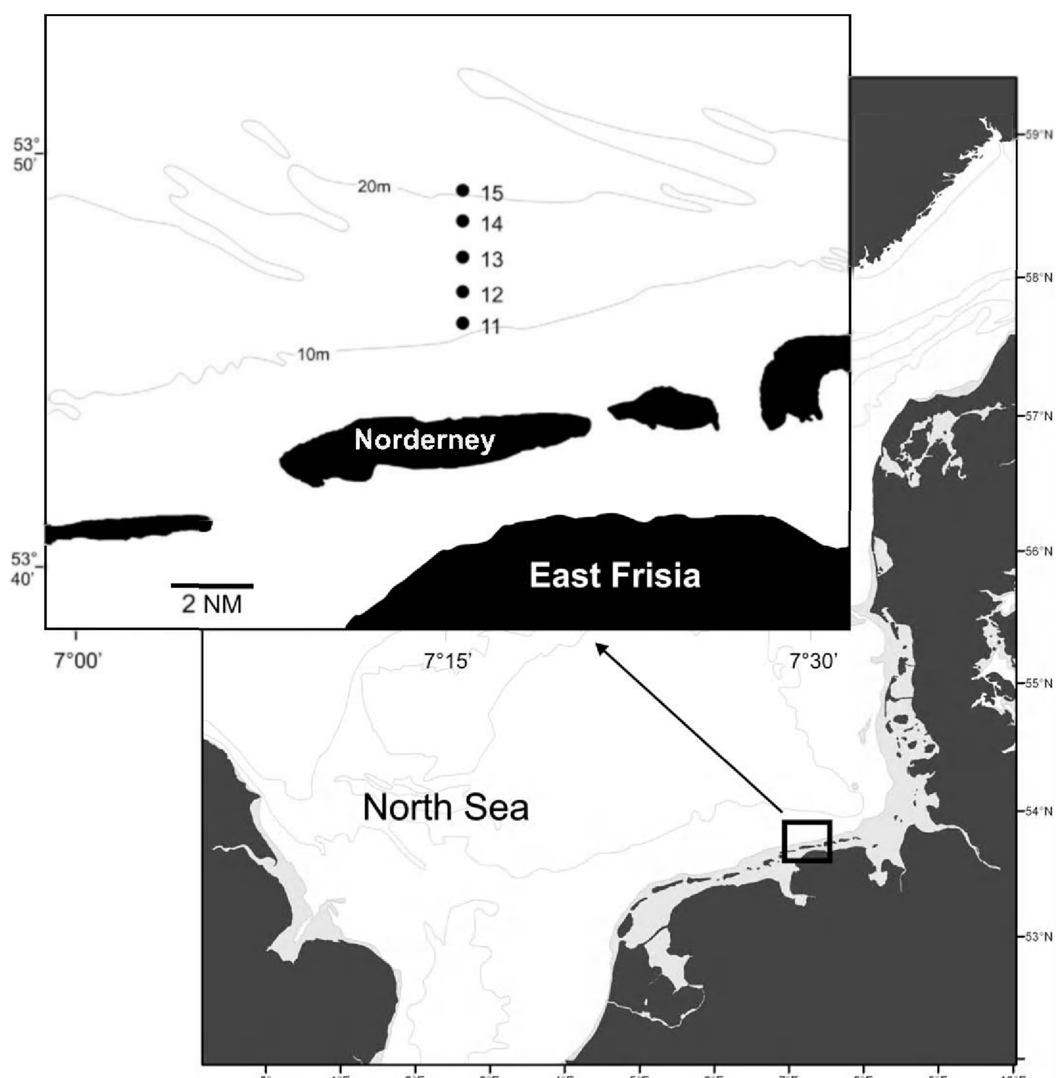

Fig. 1. Area of investigation in the North Sea with sampling sites.

The area is not fished by vessels >300 hp mainly due to the implementation of the Plaice Box in 1985 and seldom fished by smaller vessels (Dannheim, 2007). The mean annual fishing effort of the Dutch beam trawl fleet, the most important one in this area, was below 35 days-at-sea (1996–2005) for the ICES rectangle 36F7 covering our study site, which is among the lowest values for the southern North Sea (Reiss, unpubl. data).

2.2. Sampling

Sampling was carried out with R.V. 'Senckenberg'. A 0.2 m^2 van Veen grab was used for sampling. A single grab was taken at each of the five stations. The samples were sieved over 0.63 mm mesh size and fixed in 4% buffered formaldehyde. After sorting and determination of species abundance, the organisms were preserved in 70% alcohol. Data are available for each quarter from 1978 to 1993, for the 2nd and 3rd quarters from 1994 to 1999 and for the 1st, 2nd and 3rd quarters from 2000 to 2005.

2.3. Data analysis

The results for species number and abundance from the five stations were pooled and treated as replicates for the area, since the multivariate comparison of the five different sites has shown no significant difference between the macrofauna assemblages of the five stations. The data are given per quarter of each year from 1978 to 2005. Totals of species number and abundance are given as medians per quarter per year.

2.3.1. Univariate indices

A variety of diversity indices have been used in benthic ecology to assess the environmental quality and the effect of disturbances on benthic communities. In the present study, calculations of three diversity indices were carried out: the Shannon-Wiener Index, the Hurlbert Index and Pieloús Evenness.

The Shannon-Wiener Index (H') is the most commonly used diversity index in benthic ecology, which incorporates species richness as well as equitability. Pieloús Evenness (J) reflects the even occurrence of species within a community. Both indices, Shannon-Wiener and Pieloús Evenness, depend on the sample size. In contrast, the Hurlbert Index (ES*n*) is less sample size dependent and is based on the rarefaction technique of Sanders (1968) and was modified by Hurlbert (1971). In this index the expected number of species (ES) is calculated among the certain number of individuals, e.g. of 50 individuals (ES50) as used in the present study. The computer software PRIMER 6.1 (Clarke and Warwick, 1994) was used for calculating the indices.

2.3.2. Biotic and multimetric indices

In this study six biotic and multimetric indices were tested: AMBI, BOPA, M-AMBI, IQI, DKI and NQI (Table 1).

The AMBI (AZTI Marine Biotic Index) (Borja et al., 2000) is a widely used biotic index based on the classification of benthic species into five ecological groups ranging from disturbance sensitive species (group I) to species highly tolerant to stress (group V). A list of >4400 benthic species including their assignment to the ecological groups as well as the AMBI© program for calculations of the AMBI and the M-AMBI are available on the web page: http://www.azti.es.

The Benthic Opportunistic Polychaetes Amphipods Index (BOPA) is also based on the ecological characteristics of specific taxonomic groups and compares percentage ratios of opportunistic polychaetes and amphipods (Dauvin and Ruellet, 2007). The BOPA is low when the environment is good, it increases when the environmental conditions degrades (Table 1).

Table 1
Calculations and ecological classification threshold levels for biotic and multimetric indices. References for each index are indicated by superscript numbers (see footnotes).

Index	Calculation	Ecological quality classification				
		High	Good	Moderate	Poor	Bad
AMBI[a]	$AMBI = 0.01\,(0 * \%EG_I + 1.5 * \%EG_{II} + 3 * \%EG_{III} + 4.5 * \%EG_{IV} + 6 * \%EG_V)$	<1.2	1.2–3.3	3.3–5.0	5.0–6.0	>6.0
BOPA[b]	$BOPA = \log((f_P/(f_A + 1) + 1)$	<0.04576	0.04576–0.13966	0.13966–0.19382	0.19382–0.26761	0.26761–0.30103
M-AMBI[c]	Factor analysis (FA) and discriminant analysis (DA) based on S, H′ and AMBI	>0.77	0.53–0.77	0.39–0.53	0.20–0.39	<0.20
IQI[d]	$IQI = (((0.38 * AMBI^{IQI}) + (0.08 * (1 - \lambda')^{IQI}) + (0.54 * S^{IQI\ 0.1})) - 0.4)/0.6$	>0.75	0.63–0.75	0.41–0.63	0.20–0.41	<0.20
DKI[d]	$DKI = (((1 - (AMBI/7)) + (H/H_{max}))/2 * ((1 - (1/S)) + (1 - (1/N)))/2)$	>0.72	0.58–0.72	0.35–0.58	0.16–0.35	<0.16
NQI[d]	$NQI = 0.5 * (1 - AMBI/7) + 0.5 * (SN/2.7) * (N/(N + 5))$	>0.78	0.50–0.78	0.36–0.50	0.36–0.25	<0.25

EG_{I-V} = number of individuals in each of the ecological groups I (sensitive) to V (opportunistic); S = species number; N = abundance; H' = Shannon-Wiener; λ' = Lambda index; f_P = frequency of opportunistic polychaetes; f_A = frequency of amphipods; $SN = \ln(S)/\ln(\ln(N))$.
[a] Borja et al. (2000).
[b] Dauvin and Ruellet (2007).
[c] Borja et al. (2009a).
[d] Borja et al. (2007).

The other indices tested in this study combine benthic indices and univariate indices within a multimetric approach (IQI, DKI and NQI) or use outputs from multivariate analysis (M-AMBI). The individual indices have been weighted and combined within these multimetric indices (Table 1), in order to best describe the changes in the benthic invertebrate community due to anthropogenic pressure.

The multivariate AMBI (M-AMBI) combines Shannon-Wiener diversity, species richness and AMBI in a factor analysis multivariate approach (Muxika et al., 2007). The reference conditions used for calculating the M-AMBI were those for coastal areas recommended by Borja et al. (2004b) and Muxika et al. (2007).

The IQI (Infaunal Quality Index) use AMBI, Simpson's Evenness and the number of taxa as parameters (Borja et al., 2007).

The Danish methodology (DKI) use the Shannon-Wiener Index, AMBI, the number of species and the number of individuals as parameters (see Borja et al., 2007; Perus et al., 2007).

The Norwegian methodology (NQI) (Borja et al., 2007) includes AMBI, the number of individuals, the Shannon-Wiener Index and the diversity index SN (combination of number of species and individuals).

Spearman rank correlation was used to determine the significance of the relationship between days with ice and NAOI with the univariate, biotic and multimetric indices. Here only the benthos data sampled during spring (2nd quarter) were used.

3. Results

3.1. Study area

The study area off the island of Norderney is rarely fished and no disturbances caused by other anthropogenic activities such as e.g. dumping or dredging occurred in the area. Thus, major disturbance events during the study period were natural, e.g. cold winters. Additionally, a gradual shift in the local hydroclimate occurred due to large scale changes of the climate regime in the Northeast Atlantic. During high NAOI winters, the moderating influence of the ocean results in unusually warmer winter temperatures, as have seen since 1988. The winters of 1978/79, 1981/82, 1984/85–1986/87 and 1995/96–1996/97 were cold, indicated by the number of days with ice coverage near Norderney, and were significantly related to a negative NAOI (Spearman rank, $R = -0.418$, $p < 0.05$; Fig. 2). The 1995/96 winter was connected with an extremely low NAOI in a period where the NAOI was in general positive. The NAOI started to drop again in 2000 (Fig. 2).

3.2. Long-term variability of univariate indices

The analysis of species number and univariate indices revealed similar general patterns across all indices with a slight increase from the mid 1980s onwards but with temporal declines of the indices during cold winter events and after 2002 (Figs. 3 and 4).

The Shannon-Wiener Index showed a strong interannual variability (Fig. 3b), during the early to mid 1980s it varied between 0.8 and 3.5. A significant negative correlation was found between H′ and the days with ice coverage, but not with the NAOI (Table 2). Thus the cold winter in 1978/79 did not affect the index as much as did the cold winters in 1982/83, 1984/85 and 1985/86. After 1986 during the period of increasing NAOI and mild winters the index increased from 2.7 to 4.2. During the cold winters 1995/96 and 1996/97 the index decreased to 1.6. After these winters, the index recovered and reached values as high as during the early 1990s, but decreased parallel to the NAOI since 2002.

The evenness showed a similar pattern as the Shannon-Wiener Index with highest interannual variability during the early and mid 1980s due to the cold winters and increasing values since 1986 (Fig. 4a). The decline of species numbers from 2002 onwards was accompanied by an increase of evenness resulting in rather constant but low diversity measures from 2002 until 2005 (Figs. 3 and 4). The correlation analysis revealed no significant relationships (Table 2).

The long-term pattern of the Hurlbert Index (ES50) (Fig. 4b) was very similar to that of the Shannon-Wiener Index (Fig. 3b), showing also a significant negative correlation with ice coverage (Table 2). The ES(50) varied between 5 and 13 in the early to mid 1980s. After 1986, it increased to more than 10, with the exception of the low ES(50) during the cold winters 1995/96 and 1996/97 as well as in 2002 and 2003.

3.3. Long-term variability of biotic and multimetric indices

The results for the biotic and multimetric indices resemble the general patterns already shown for the univariate indices with an

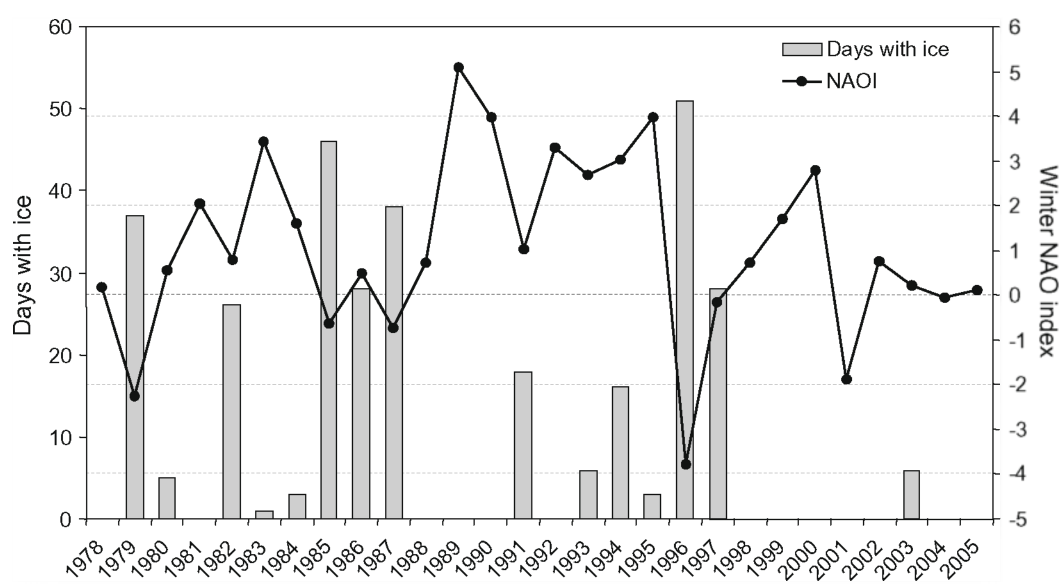

Fig. 2. North Atlantic Oscillation Index (NAOI) for winter (December through March) and the number of days with ice in the tidal channel system of Norderney.

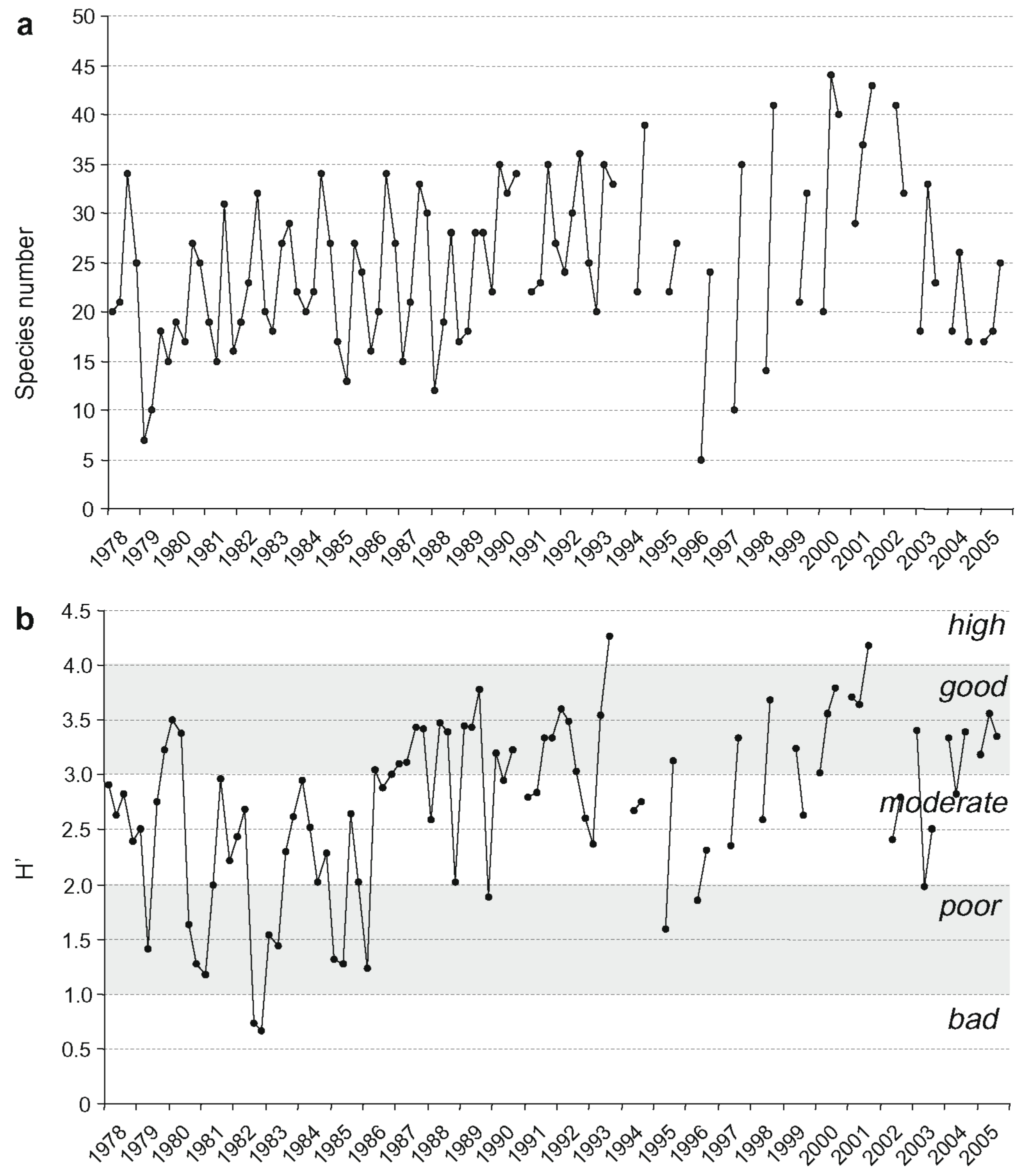

Fig. 3. Variation of species number (a) and Shannon-Wiener Index (b) over time (1978–2005). The classification of the ecological status based on Labrune et al. (2006) is indicated.

increase of most of the indices and, consequently, the ecological quality status during the study period and the short-term effects of cold winter events.

Fig. 5a shows the long-term pattern of the AMBI. The mean AMBI of 1–2 reflects a 'high' to 'good' quality status, with the exception of the cold winter 1978/79, when it dropped to 'moderate' (>3.3) mainly due to the dominance of the opportunistic polychaete species *Lagis koreni*, a species within the ecological group IV of AMBI. The slight increase of the AMBI since 1986 is in accordance to the patterns of the univariate indices.

The BOPA increased remarkably as a response on the cold winter of 1978/79 resulting in a shift of the corresponding ecological quality status from 'high' to 'poor' (Fig. 5b). During the following study period from 1980 until 2005 the index changed only slightly and remains in a 'high' quality status. The cold winters 1995–1997 had no detectable effect on the variation of the BOPA index. Also the increasing trend, which was found for the other multimetric indices from the mid 1980s onwards (see below), could not be detected with the BOPA since the index values already reached the maximum quality status most of the time (Fig. 5b). A significant correlation with ice coverage or NAOI was neither found for the AMBI nor for the BOPA (Table 2).

The M-AMBI showed also a similar pattern to the Shannon-Wiener Index, ES(50), and evenness, but differs slightly from the AMBI concerning the classification of the ecological quality status (Fig. 6a). According to the results of the M-AMBI the quality was classified as 'poor' after the cold winter 1978/79, but as 'moderate' during the early to mid 1980s and after the cold winters 1995–97. The index increased after 1986 and reached 'good' to 'high' quality status during the early 1990s and since 1999.

The long-term pattern of the DKI was similar to that of the M-AMBI (Fig. 6b), as was the IQI (Fig. 7a), but the latter showed generally a higher quality status than M-AMBI and DKI. The NQI showed hardly any variation with the exceptions, similar to the other indices, of the sharp decrease after the cold winter 1978/79 and a slight decrease during the cold winters 1995–1997 (Fig. 7b).

In general, all multimetric indices showed a significant negative correlation with ice coverage and no correlation with the NAOI, with the exception of the NQI, which was significantly correlated to the NAOI but not to the ice coverage (Table 2).

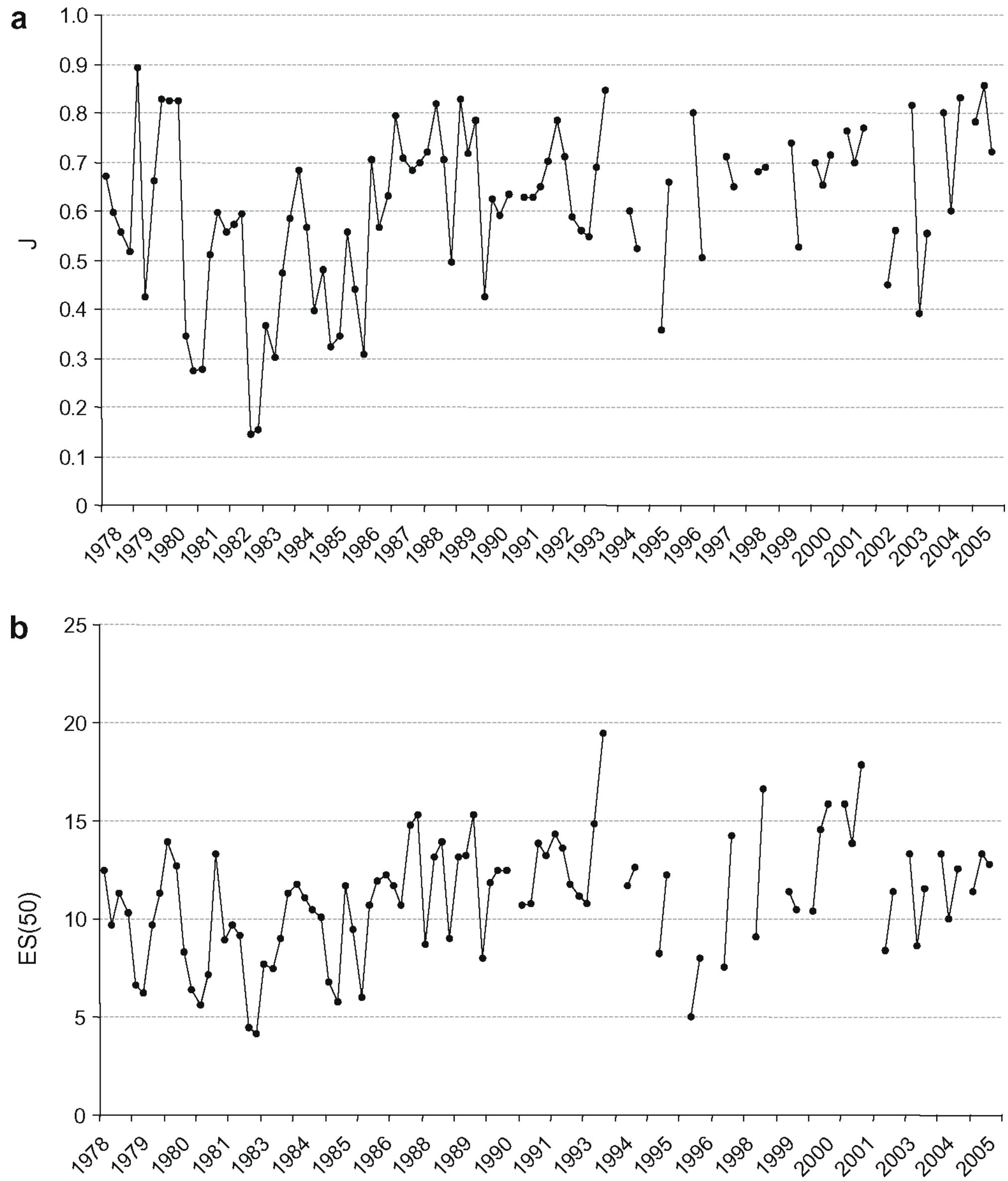

Fig. 4. Variation of evenness *J*′ (a) and Hurlbert Index ES50 (b) over time (1978–2005).

In order to compare the long-term variability across all the different univariate and multimetric indices the coefficient of variance (CV) was calculated for the entire study period. The results revealed that the univariate indices were more variable than the multimetric indices, whereas the biotic indices AMBI and BOPA showed the highest coefficients of variance of all indices (Fig. 8).

4. Discussion

The aim of the present study was to investigate the long-term variability of several indices used for the assessment of the ecological quality status and to test their responses to natural disturbance events. This is the first study of the temporal variability of biotic indices used for ecological quality assessment on such a long time scale (28 years).

Most recently developed benthic indices (Grall and Glémarec, 1997; Weisberg et al., 1997; Borja et al., 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004) have been mainly based on the model of Pearson and Rosenberg (1978). This model states that macrofauna communities along a gradient of increasing disturbance (primarily organic enrichment) change in diversity, abundance and species composition according to their tolerance against the disturbance. Many of these indices have been tested successfully to detect anthropogenic disturbances such as dredging, dumping, engineering works, sewage plans, gravel extraction (Muxika et al., 2005). However, most biological indices may be affected by any kind of disturbances whether caused by anthropogenic impacts or natural processes (Wilson and Jeffrey, 1994). Our results show that all indices tested in this study respond on natural disturbance events such as cold winters with the most pronounced effects after the severe winter 1978/79. As a result the ecological quality status changed from 'good' or 'high' ecological condition to 'moderate', 'poor' or even 'bad' conditions. However, not all indices respond on the disturbances in the same way and the strength of response varied remarkably between the indices and the different disturbance events. This is discussed in more detail below.

Table 2
Correlation coefficients relating the benthic indices and "days with ice coverage" and winter NAOI. Statistical significance ($p < 0.05$) is indicated in bold.

	Days with ice coverage		NAOI		*n*
	R	*p*	*R*	*p*	
Species number	**−0.424**	**0.0245**	**0.503**	**0.0064**	28
Abundance	−0.251	0.1981	**0.397**	**0.0362**	28
J'	−0.129	0.5140	−0.168	0.3941	28
H'	**−0.453**	**0.0156**	0.155	0.4303	28
ES(50)	**−0.466**	**0.0125**	0.345	0.0725	28
BOPA	0.301	0.1202	0.014	0.9443	28
AMBI	−0.069	0.7262	−0.352	0.0660	28
DKI	**−0.515**	**0.0050**	0.350	0.0675	28
UK Index	**−0.477**	**0.0102**	0.332	0.0843	28
NQI	−0.278	0.1522	**0.618**	**0.0005**	28
M-AMBI	**−0.534**	**0.0034**	0.369	0.0535	28

Furthermore, a slight general increase of most indices and the resulting ecological quality status occurred from the mid 1980s onwards probably due to changes in the climate regime.

4.1. Effects of natural disturbance events

Diversity indices such as Shannon-Wiener Index and the Hurlbert index (ES50) are common tools for measuring community changes in benthic ecology and are also widely used for the assessment of the ecological quality status. Our results show that the long-term variability was relatively high for the univariate indices and species number. The variability was high directly after extremely cold winters (e.g. 1978/79, in the mid 1980s; 1995–1997), although the strength of the index response varied between winters and following time periods. The correlation between diversity indices (species number, *H'* and ES(50)) and the days with ice coverage indicate that severe winters have a significant effect on the performance of the indices (Table 2). The direct response on these disturbance events was primarily caused by the decrease in total abundance and species number, whereas the following rather long period of high intra- and interannual variability can be caused by changes in recruitment success or predation pressure as shown for some benthic species in intertidal habitats. In the Wadden Sea, bivalve recruit densities were high after severe and low after

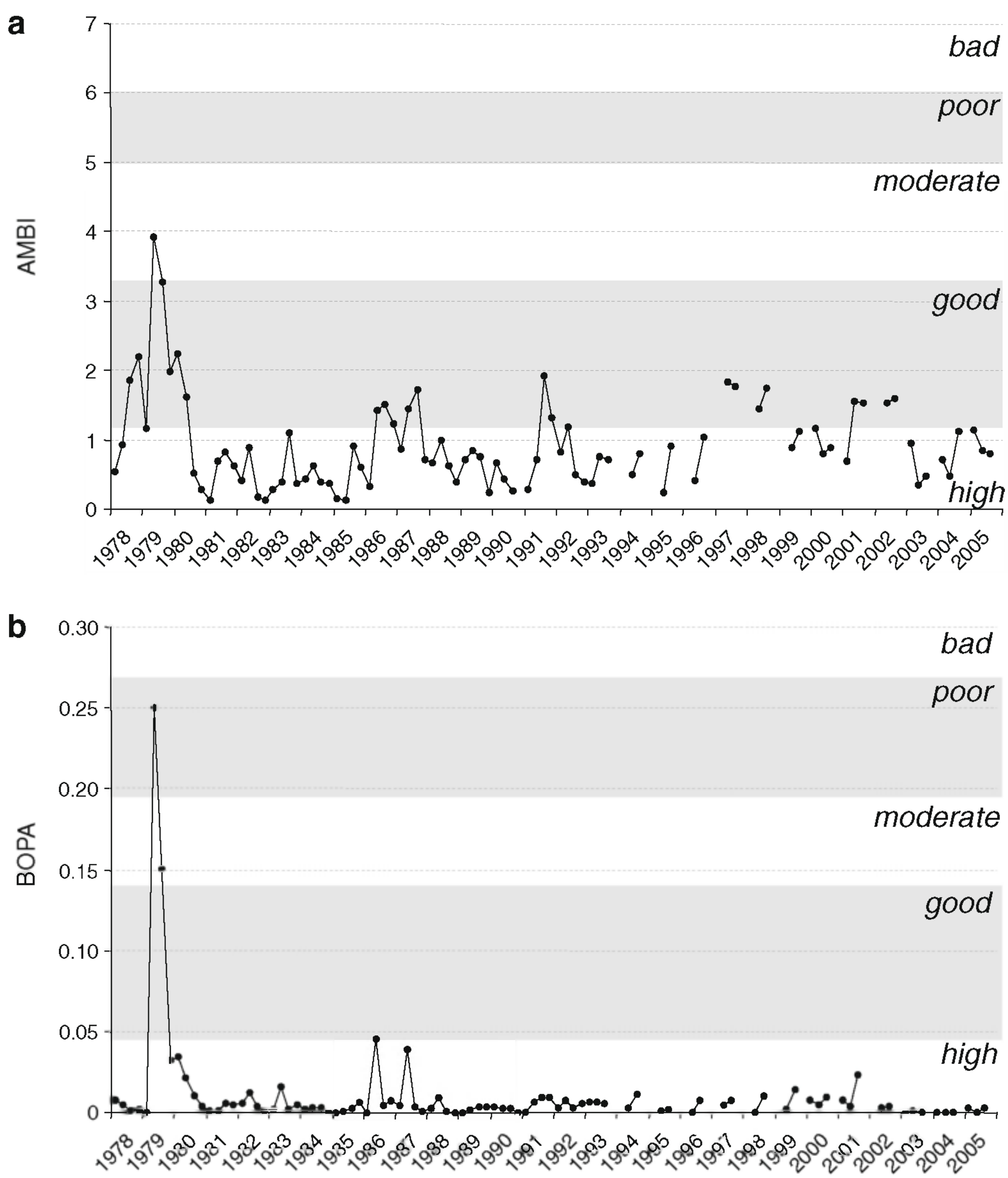

Fig. 5. Variation of AMBI (a) and BOPA (b) over time (1978–2005). The classification of the ecological status is indicated (see Table 1).

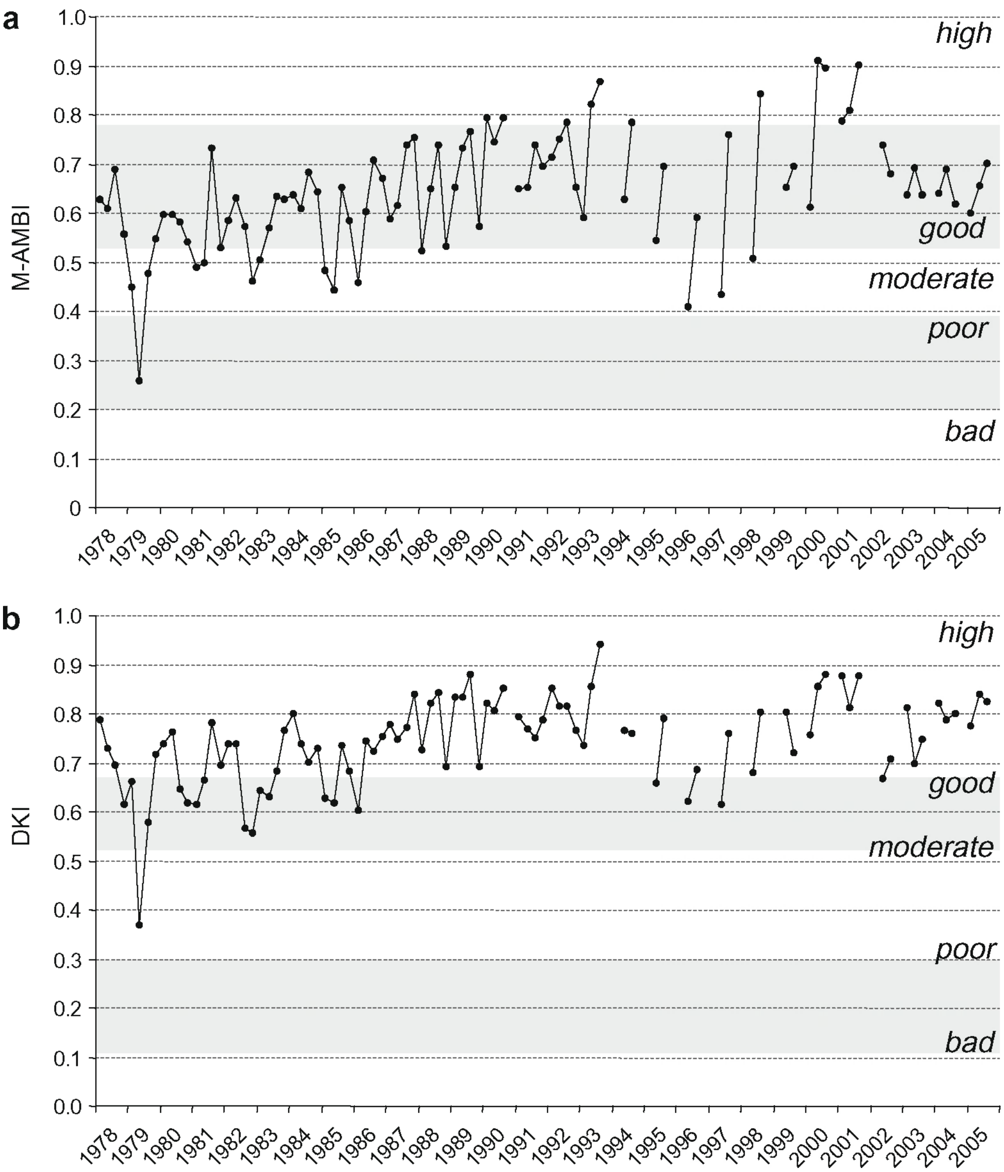

Fig. 6. Variation of M-AMBI (a) and DKI (b) over time (1978–2005). The classification of the ecological status is indicated (see Table 1).

mild winters, whereas predator pressure decreased after severe winters (Beukema et al., 1998; Strasser et al., 2001; Beukema and Dekker, 2003). Thus, the effects of cold winter on the benthic communities and their variability can persist for several years (e.g. Kröncke et al., 1998; Reiss et al., 2006; Neumann et al., 2008). However, the high variability found for the univariate indices after cold winters resulted in drastic changes of the corresponding ecological quality status across 2 to 3 classification units (Fig. 3).

The long-term variability of most biotic and multimetric indices was somewhat lower than that of the univariate indices (Fig. 8). Severe decreases were only found after cold winters (Figs. 5–7). The extreme response after the cold winter 1978/79, e.g. of the biotic indices BOPA and AMBI, was mainly due to the opportunistic polychaete species *L. koreni*, which is known to quickly recolonise defaunated sediments (Rees and Dare, 1993). The high abundance of a species within the ecological AMBI group IV led to the extremely low AMBI values after the winter 1978/79. Since this or other opportunistic species were not dominant after the following winters, a similar response of the BOPA and the AMBI was not found. Consequently, no significant correlation with ice coverage occurred. Thus, cold winters resulted in a decrease of diversity measures and abundance in almost all cases, but must not necessarily have an effect on opportunistic species, which in turn would largely determine the response of the biotic indices (see below). The extreme response after the cold winter 1978/79 has led to the overall high temporal variability reflected in the high coefficient of variance for the AMBI and BOPA index (Fig. 8).

In contrast, multimetric indices that are combinations of several indices such as the NQI, IQI, DKI and the M-AMBI have had the lowest coefficient of variance. Thus, the combinations of indices seem to buffer against the temporal variation resulting in a rather stabile performance of these indices over time (see also Salas et al., 2004). Nevertheless, the cold winter events were always detected by these indices with the most pronounced response after the winter 1978/79. The effects of this cold winter event resulted in a decrease of ecological quality status from 'high' or 'good' conditions to 'poor' or even 'bad' conditions, whereas the effects after the winter 1995–1997 were less distinct (Figs. 5–7).

In contrast to the univariate indices all biotic and multimetric indices incorporate the ecological preferences of benthic species and use ecological groups of species according to their sensitivity to stress, such as the AMBI (Borja et al., 2000, 2003a), the BOPA

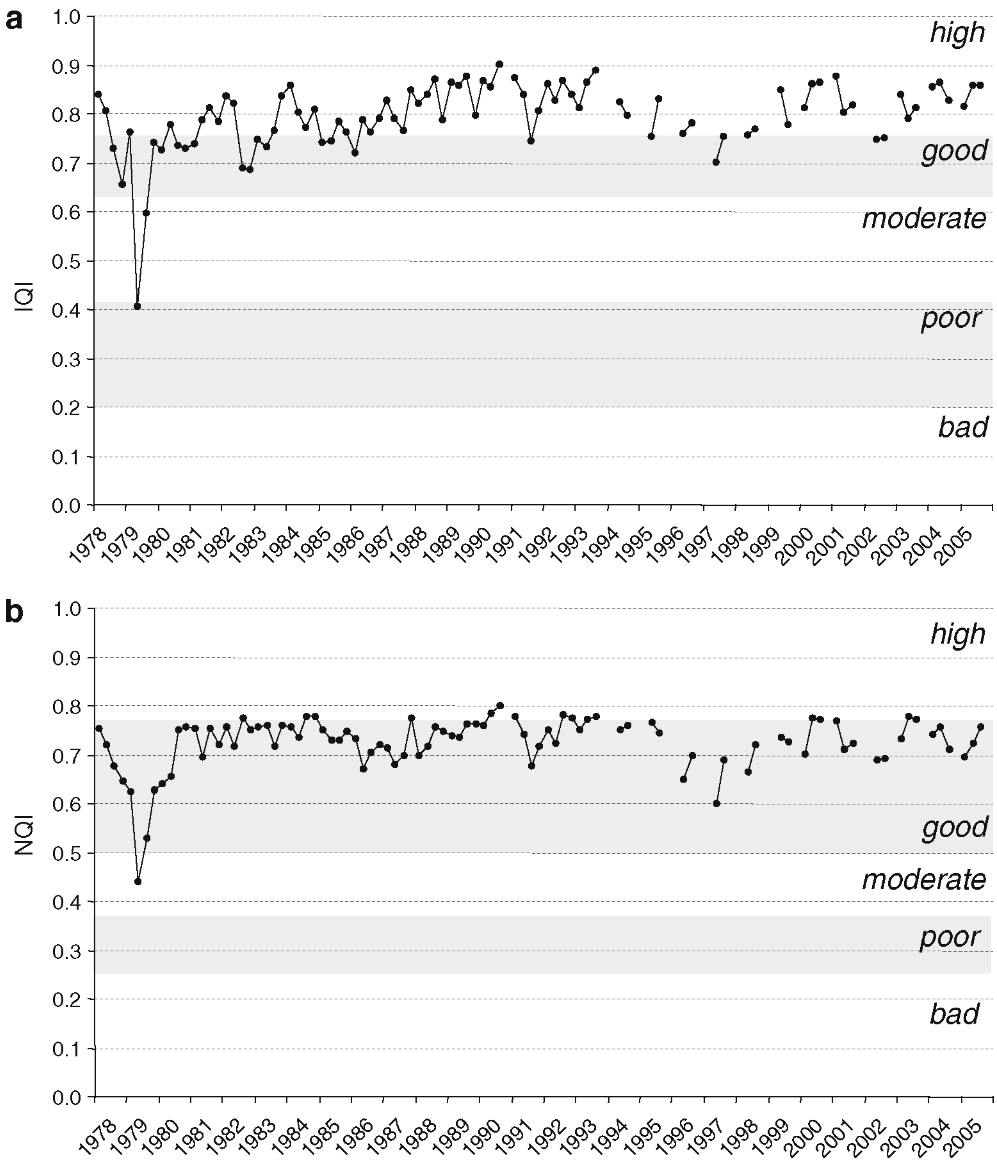

Fig. 7. Variation of IQI (a) and NQI (b) over time (1978–2005). The classification of the ecological status is indicated (see Table 1).

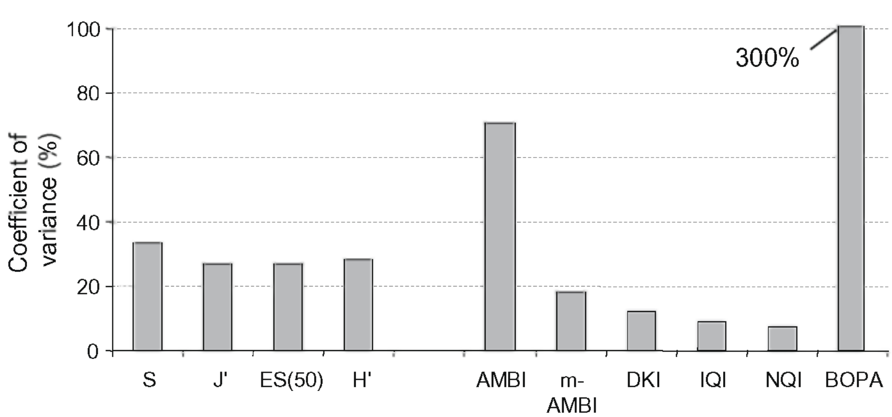

Fig. 8. Coefficient of variance (CV) of the different indices based on data of the entire study period (1978–2005).

(Dauvin and Ruellet, 2007) or the Biotic Quality Index (BQI) (Rosenberg et al., 2004). The classification of benthic species into ecological groups or as indicators of stress is a crucial issue, which has lead to intense debates about the appropriate classification schemes (Borja et al., 2004a; Simboura, 2004; Dauvin, 2005). However, this classification may explain the different variability of univariate and biotic indices after cold winter events. Univariate indices will respond on any changes in abundance or species number in benthic communities regardless of the ecological role of the affected component. Thus, fluctuations in abundance of non-sensitive or non-opportunistic species caused by e.g. an increased variability of recruitment success or predation pressure (see above) will inevitably increase the variability of univariate but not necessarily of biotic or multimetric indices. Similar to Reiss and Kröncke (2005a), who showed that multimetric indices seem to be a promising approach for ecological quality assessment in order to avoid drawbacks by the seasonal variability of benthic communities, our results indicate a higher robustness of multimetric indices also against the interannual variability.

4.2. Effects of gradual changes in the climate regime

The long-term trend of diversity indices, evenness and species number show a slight but conspicuous increase from the mid 1980s onwards (Figs. 3 and 4). This trend coincides with a general shift in faunal characteristics of the North Sea ecosystem in the mid- to late 1980s, which has been ascribed to a 'regime shift'. Community changes were found for phytoplankton and zooplankton (e.g. Reid et al., 1998; Edwards et al., 2002; Alheit et al., 2005; Kirby et al., 2007), benthos (e.g. Kröncke et al., 1998; Warwick et al., 2002) and fish (e.g. Clark and Frid, 2001), which were associated with increases in the North Atlantic Oscillation Index (NAOI) and, linked to this, the influential role of water temperature. Mild meteorological conditions connected with a rising NAOI have resulted in an increase of macrofauna abundance, species number and biomass since 1988 (Kröncke et al., 2001).

This general increasing trend was only detected by the multimetric indices, which incorporate diversity measures such as the DKI, NKI, IQI, and M-AMBI, although a significant correlation with the NAOI was only found for abundance, species number and the NQI (Table 2). However, this correlation analysis can only be a rough estimation to reveal relationships between the indices and a climatic index, which integrates a variety of causal forces.

However, the changes in diversity since the late 1980s resulted in an increase of the ecological quality status from 'moderate' to 'good' (H' and M-AMBI) or 'good' to 'high' (DKI and IQI). In contrast, the AMBI and the BOPA, which are mainly based on the ecological grouping of species, were inadequate to detect these gradual changes of the benthic community. But it has to be mentioned here that the values of these biotic indices were in general very high at our study site and additional slight increases might hardly be detected.

However, these slight community changes over time and the regime shift may not be the targeted monitoring objectives within the WFD, since only anthropogenic disturbances should be detected, but they have to be considered when setting reference conditions for ecosystem quality status. Benthic communities may have reached a new stable state so that efforts towards a retrogression of community parameters and, in consequence ecological status might be inappropriate.

4.3. Implications for ecological quality assessment

The choice of a suitable biotic index or group of indices for ecosystem quality assessment is crucial for addressing specific management objectives. All indices are confronted with the problem that they detect disturbances or evaluate environmental conditions regardless of whether they were influenced by anthropogenic impacts or natural processes. The Water Framework Directive, which is the main driver for the development of biological indices for ecosystem quality assessment in European waters, is mainly focused on coastal marine environments (Vincent et al., 2002). But especially coastal areas are at the same time influenced by strong natural fluctuations or environmental gradients such seasonal changes (cold winters, warm summers) and salinity gradients (Reiss and Kröncke, 2004, 2005b; Zettler et al., 2007) and by a variety of anthropogenic activities such as fishing, eutrophication, shipping or construction work. Thus, the evaluation of the natural 'background' variability and the corresponding response of indices are an essential requirement before establishing quality assessment strategies.

Our result show that gradual shifts of benthic communities and the corresponding changes of ecological quality status were inadequately detected by biotic indices, which are mainly based on the sensitivity of species. This should not be regarded as a significant disadvantage of these indices since these gradual changes may not be the targeted monitoring objectives (see above).

However, diversity indices and multimetric indices incorporating diversity measures (e.g. IQI, DKI, M-AMBI) better detect the gradual changes in benthos and the multimetric indices showed the lowest long-term variability in our study. Nevertheless, single natural disturbance events such as cold winters can significantly reduce the ecological quality status independent from the applied index, which has to be considered in ecological assessment schemes. This might be accomplished by excluding data collected after extreme natural events for the assessment of ecosystem quality and by the adaption of reference conditions when natural gradual changes were detected. Due to the observed difference in the performance of the indices, it is necessary to include different indices in the assessment schemes to make sure that the natural variability can be detected and considered.

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