

Biocoenotic changes of the zooplankton in the German Bight: the possible effects of eutrophication and climate

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Meso- and macrozooplankton have been sampled in the German Bight since 1974. Inter-annual changes in the dynamics of selected species have been analysed in terms of mean annual abundance and timing of abundance maxima. Information on new immigrants is also presented. Possible causes of the observed changes, particularly in relation to nutrient availability and climatic signals, are discussed.

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Key words: biocoenotic changes, German Bight, Helgoland Roads, immigrants, time series, zooplankton.

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Introduction

Comparison of the regional properties of the oceans was encouraged by satellite imagery (e.g. Holligan *et al.*, 1989), which allows visualization of productivity “hot spots”, such as the North Sea, within the northern temperate zone of the Atlantic and the German Bight within the North Sea. Phytoplankton is utilized by zooplankton and benthic organisms. The herbivorous or omnivorous zooplankton is then utilized by carnivorous zooplankton, fish and benthos. Steele (1965) suggests an invertebrate carnivore:fish utilization ratio of 40:60%. The seasonal succession of representatives of the different trophic links in the plankton of the German Bight follows the annual development of these pathways (Greve and Reiners, 1995) and exhibits regional patterns (Greve and Reiners, 1988).

In this context, it is important to note that zooplankton does not represent a single functional unit of herbivorous or even omnivorous animals. In order to understand changes in the dynamics of the zooplankton biocoenosis, the different trophic representatives within the marine food web deserve proper characterization, because different groups are controlled by different factors (Greve and Reiners, 1995). Since zooplankton development is characterized by succession within a season, and individual species (groups) may be subject to antagonistic trends, grouping into larger units may be misleading when studying inter-annual changes.

The Biologische Anstalt Helgoland has been documenting the plankton populations in the German Bight

since 1892. Initially, sampling procedures were largely aimed at providing qualitative or semi-quantitative information. However, quantitative sampling has been carried out continuously since 1974 and these data can be used for analysing inter-annual changes. Data on the biocoenotic composition have been discussed by Greve and Reiners (1995).

The river plumes of the Weser and Elbe reach as far as the Helgoland Roads, where the sampling station is located. Thus, the samples taken may represent coastal and estuarine waters or waters originating from stratified central parts of the North Sea, depending on hydrological and meteorological conditions. The inter-annual and seasonal variations of zooplankton measurements will thus depend on changes in the productivity and differences in the origin of the water masses sampled.

In total, approximately 600 000 biological observations have been collected. Measurements include 691 species, age classes, or collective groups which might be used to reveal detailed changes in the community. However, it is outside the scope of this contribution to analyse all the available information in detail and we restrict ourselves to the selection of key species (groups) in the zooplankton biocoenosis, to first records of species new to the German Bight, and to a variety of possible indicators of change, the objective being to discuss changes in relation to observed trends in eutrophication and climate change. The arbitrary selection encompasses species (groups) showing different types of response over the sampling period.

Methods

Meso- and macrozooplankton samples were taken every second work day in the Helgoland Roads (positioned about 50 km off the coast between the two islands at 54°11'3"N, 7°54'0"E. The tidal currents passing in between the islands rise from a depth of up to 50 m from the South, or 30 m from the North and mix the water in the shallow, 6 m deep passage between the islands. The mean residual current runs through the German Bight in a counter-clockwise direction.

Mesozooplankton was sampled with a (150 µm mesh) Hydrobios plankton net and macrozooplankton by means of a CalCoFi net (500 µm mesh). Oblique hauls were made with both nets, filtering approximately 0.6 m³ and 100 m³ of water, respectively. Each net was equipped with a flowmeter to allow the sample volume to be calculated. After sorting and counting, the marine biological information system MABIS (Greve and Reiners, 1989) was used for handling the data.

Each variable (population or group) is represented by a series of >1000 measurements. Since the biocoenosis may change from year to year in very different aspects, a variety of different parameters has been calculated annually. These include mean abundance, timing of the monthly mean abundance maximum, length of the season based on monthly means, and start of the season. Length of the season was arbitrarily defined as the period during which the abundance exceeded half the value of the mean abundance over all years. Start of the season was defined as the earliest month during which this criterion was met. Although linear regression analysis is not entirely appropriate for analysing these variables against time, it has been used as a first approximation to permit comparisons.

Based on visual inspection, the type of change in abundance of each species (group) has been classified according to four categories: (1) steadily increasing; (2) initial increase followed by a decrease; (3) initial decrease followed by an increase; (4) no obvious trends. A continuous decrease has not been recorded for any species (group).

Results

Table 1 summarizes the results of the various analyses for selected species (groups), including the mean annual abundance (N m⁻³), the type of change and the regression coefficients of the trends in mean annual abundance, the month of the annual abundance maximum, the length of the season and the start of the season. M and H indicate classification to mero- and holoplankton, respectively. Examples of the various parameters calculated for selected species (groups) are given in Figures 1 to 6.

In addition, changes in the diversity of the biocoenosis were registered in relation to a number of species which

had not been reported from the German Bight before: *Nanomia cara*, *Muggiaea atlantica*, *Pseudomystides limbata* (Husemann, 1992), *Penilia avirostris*, *Diogenes pugilator*, *Metridia lucens*, *Thaumaleus longispinosus*, *Strilloma grandis*, *Doliolum nationalis*. These species are partly characteristic of the Channel plankton or Lusitanian plankton. Higher salinities and higher winter temperatures than normally occur in the Germany Bight appear to be common features of the ecological niches of these species.

Discussion

There have been considerable changes in the planktonic biocoenosis in the period from 1974 to 1994, in mero-plankton as well as in macroplankton. This is clearly demonstrated by the examples given. Population increases, decreases, the timing of the annual abundance maximum, the length of season, and the start of season provide variables which may be used to classify long-term trends in populations. Though periods of abundance decrease have obviously occurred, they did not last for the full investigation period for any of the species. Abundance increases, by contrast were a dominant feature, as exemplified by the mean regression of the populations shown here (0.38). The timing of the month of maximum abundance was generally shifted forward (mean regression: -0.15). The length of season is increasing (mean regression 0.44), and the start of season is generally earlier (mean regression -0.16). It should be noted, however, that these variables are not totally independent.

The annual changes in the structure of the zooplankton biocoenosis coincide with changes in the benthic biocoenosis (Lindley *et al.*, 1995). The causal factors are not clear, but the changes may be related to physical or biological short-term events or to long-term changes in the boundary conditions, such as intensity of westerly weather (Aebischer *et al.*, 1990) or regional eutrophication (Hickel *et al.*, 1993), possibly enhanced by the rainfall pattern and subsequent changes in river run-off. Other potential factors include changes in inflow of Atlantic water into the North Sea or winter temperature. North Sea fisheries may also have an impact.

The annual variations in abundance and timing of the species selected are assumed to be representative of the variability in synoptic biological signals within the biocoenosis of the German Bight. The time signal seems to be more sensitive than the abundance signal, suggesting that climate change may be involved. In the light of future marine management under climatic stress, marine stations may be used as "marine phenological gardens" by introducing comparable timing of biological phenomena as climatic indicators (Schnelle and Volkert, 1974).

Table 1. Summary statistics (A=mean abundance in numbers m^{-3} ; B=type of change; C, D, E, F=correlation coefficients for linear regressions of abundance, month of maximum abundance, length of season, and start of season, respectively, against time) for selected species (groups) of zooplankton in the German Bight 1974–1994. Figures in parentheses indicate that correlation coefficients are not significant. M and H indicate whether a species (group) belongs to mero- or holoplankton.

Names of species (group)		A	B ¹	C	D	E	F
Mesoplankton (1974–1994)							
H	<i>Noctiluca scintillans</i>	10 751	1	0.45	(−0.20)	0.45	(0.13)
H	<i>Alaurina</i> spp.	155	2	(0.33)	(−0.12)	0.54	0.72
M	Spioniden Metatrocha	321	2	(−0.07)	(0.19)	(−0.28)	(0.29)
M	<i>Lanice conchilega</i>	21	4	(−0.08)	−0.48	(−0.15)	(−0.44)
M	<i>Magelona</i> spp.	51	1	(0.37)	(−0.21)	0.62	0.43
M	Cyphonautes	15	1	0.55	(−0.00)	0.62	(0.17)
M	Actinotrocha	49	3	0.42	(−0.29)	(0.08)	(0.09)
H	<i>Podon</i> spp.	155	4	(0.17)	(−0.07)	(0.33)	(−0.35)
H	<i>Evadne</i> spp.	435	1	0.44	−0.53	0.57	−0.65
H	<i>Para-, Pseudocalanus</i> spp.	1385	2	(0.32)	(−0.03)	(0.17)	(−0.26)
H	<i>Temora longicaudata</i>	808	2	(0.12)	(−0.01)	(0.14)	(−0.20)
H	<i>Acartia</i> spp.	1475	2	(0.22)	(−0.06)	(0.15)	(0.13)
M	Cirripedia (Nauplii)	147	1	0.72	(−0.20)	0.75	(−0.23)
M	Gastropoda (Veliger)	35	4	(0.35)	−0.42	0.46	(−0.37)
M	Lamellibranchia (Veliger)	155	4	(0.33)	(0.22)	(0.25)	(−0.09)
M	<i>Asterias rubens</i> Bip.	50	1	(0.22)	−0.41	0.56	−0.58
M	<i>Ophiura</i> spp.	174	2	(0.25)	(−0.03)	0.81	0.58
M	<i>Echinocardium cordatum</i>	125	1	(0.32)	−0.42	0.79	(−0.11)
H	<i>Oikopleura dioica</i>	311	1	0.55	−0.48	0.62	−0.48
H	<i>Fritillaria borealis</i>	45	4	(0.28)	(0.01)	0.51	(−0.15)
Macroplankton (1975–1993)							
M	<i>Aglantha digitale</i>	0.76	4	(−0.05)	(−0.09)	(0.23)	(0.35)
M	Arachnactes	0.07	1	(0.26)	(−0.29)	(0.34)	(−0.25)
M	<i>Carcinus maenas</i> (zoea)	1.95	4	(0.22)	(−0.30)	0.64	−0.45
M	Crangonidae	0.85	3	(0.06)	(−0.08)	0.65	−0.51
M	Fish (eggs)	3.38	1	(0.31)	−0.46	0.73	−0.75
M	Fish (larvae)	0.90	1	0.47	−0.53	0.72	−0.47
M	<i>Galathea</i> spp. (zoea)	1.51	1	0.41	(−0.12)	0.74	−0.53
M	<i>Liocarcinus</i> spp. (zoea)	4.51	1	(0.16)	(−0.17)	0.53	(−0.36)
H	<i>Mesopodopsis slabberi</i>	0.06	3	(−0.01)		(0.03)	(−0.05)
M	<i>Obelia</i> spp.	1.60	4	(−0.00)	(0.19)	(0.28)	(−0.03)
M	<i>Pagurus</i> spp. (zoea)	0.20	4	(0.33)	(0.33)	0.47	(−0.33)
H	<i>Paramysis</i> spp.	0.03	1	(0.33)	0.59	0.74	(−0.34)
M	<i>Pisidia</i> spp. (zoea)	0.54	1	0.54		0.58	(−0.31)
H	<i>Sagitta</i> spp.	7.82	4	(0.36)	(−0.29)	(0.34)	(−0.05)

¹Codes: 1=steadily increasing; 2=initial increase followed by a decrease; 3=initial decrease followed by an increase; 4=no obvious trend.

Influences of boundary conditions have been discussed by Lindeboom *et al.* (1994), who claim that there are sudden changes in biomass in the Wadden Sea and the German Bight at the end of the 1970s and beginning of the 1980s. Such an increase is also to be seen in German Bight fish-feeding birds (Hüppopp *et al.*, 1994).

Similar trends have been observed in the population classified as increasing (type 1) or increasing–decreasing (type 2). Copepods and fish larvae belong to these types. They do not follow the westerly wind-driven dynamics described by Fransz *et al.* (1991) for the North Sea.

Local effects of eutrophication (Hickel *et al.*, 1993) appear to have been of greater importance. The decrease in the abundance of copepods at the onset of the 1990s may be related to the reduction in phosphates. Although

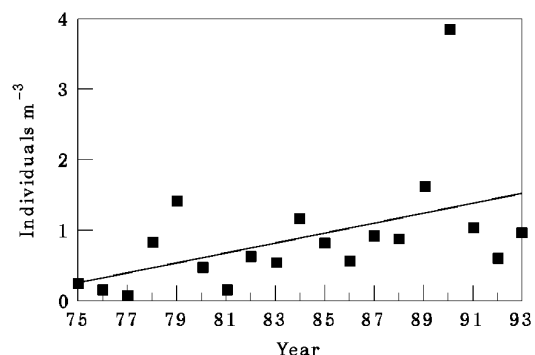


Figure 1. Example of a change classified as steady increase (type 1): mean annual abundance of fish larvae ($r=0.47$).

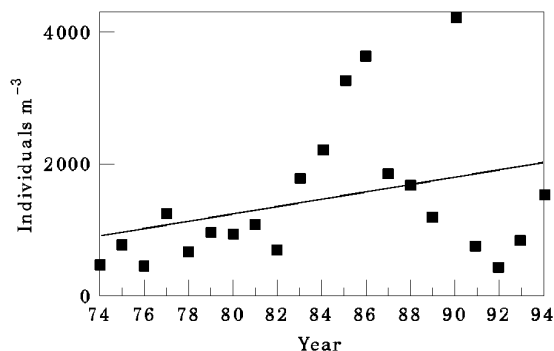


Figure 2. Example of a change classified as initially increasing followed by a decrease (type 2): mean annual abundance of the copepods *Paracalanus* sp. and *Pseudocalanus* sp. ($r=0.32$).

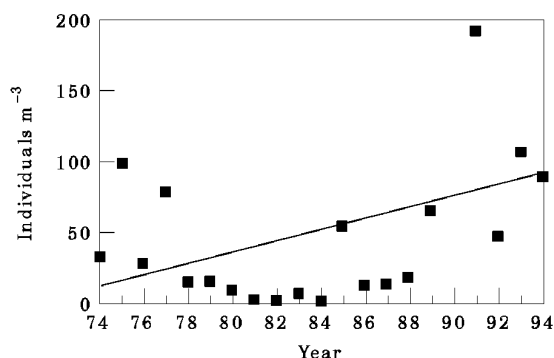


Figure 3. Example of a change classified as initially decreasing followed by an increase (type 3): mean annual abundance of the actinotrocha larvae of *Phoronis* sp. ($r=0.42$).

nutrients never limit production in the German Bight (Gillbricht, 1994), the decrease in the annual mean phosphate concentration observed in the Helgoland long-term time series since the mid-1980s (Fig. 7; Hickel *et al.*, 1993) appears to precede the reduction in the copepod abundance from the late 1980s, suggesting that the two phenomena are related. However, a causal relation between phytoplankton production and copepod has not been established.

Other signals are observed in temperature (Fig. 8) and salinity (Fig. 9), which both reached higher values in recent years than during most of the preceding period. These factors may be more important with respect to the appearance of species in Helgoland waters, which had never been detected before and indicate improved living conditions for Lusitanian plankton species or increased inflow of Channel water (Holligan *et al.*, 1989). The success of *Muggiaea atlantica* in 1989 (Greve, 1994), the year with the highest temperature and salinity conditions, is an impressive example of the possible alterations faced by local ecosystems under climatic change.

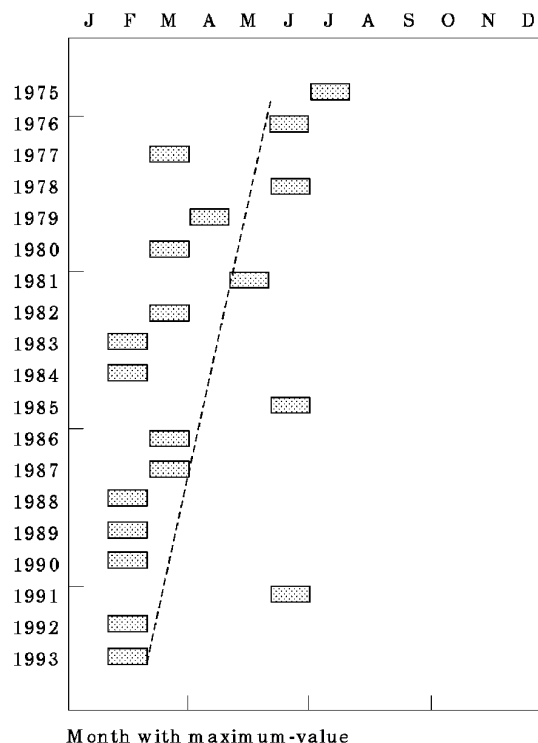


Figure 4. Example of a shift of the annual abundance maximum (monthly mean): fish larvae ($r = -0.53$).

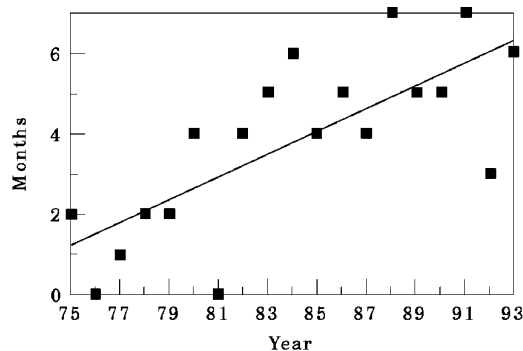


Figure 5. Example of a change in the length of season: fish larvae ($r=0.72$).

The population dynamics of the zooplankton of the German Bight may be compared with information collected off the Northumberland coast (Roff *et al.*, 1988; Frid *et al.*, 1994), a system characterized by lower productivity and little coastal influence, and from the Continuous Plankton Recorder (CPR; e.g. Fransz *et al.*, 1991). A recent study (Broekhuizen and McKenzie, 1995) established multi-annual trends and annual cycles of small copepods in the German Bight on the basis of the CPR data. The findings partially contradict our results. Neither the trend in abundance of small

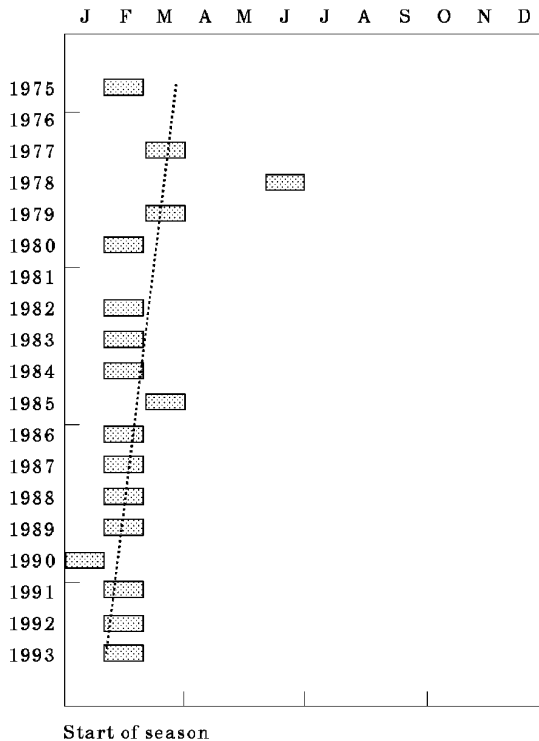


Figure 6. Example of a change in the start of season: of fish larvae ($r = -0.47$).

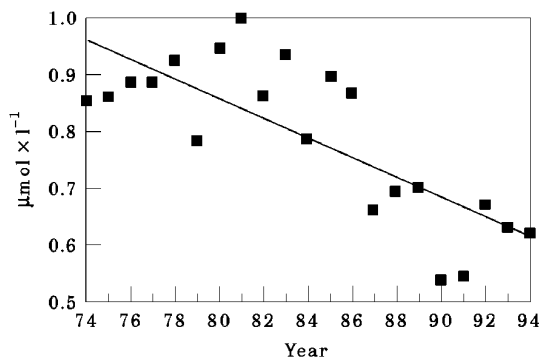


Figure 7. Mean annual phosphate concentration at Helgoland Roads.

copepods nor the distinct annual depression in abundance around June corresponds with our measurements (Greve and Reiners, 1988). The Elbe–Humber CPR tow starts close to the island of Helgoland and the zooplankton populations extend into the centre of the German Bight only for a restricted time period. It is possible that the monthly sampling effort and the offshore course of the CPR are responsible for the under-representation of the highly productive coastal biota.

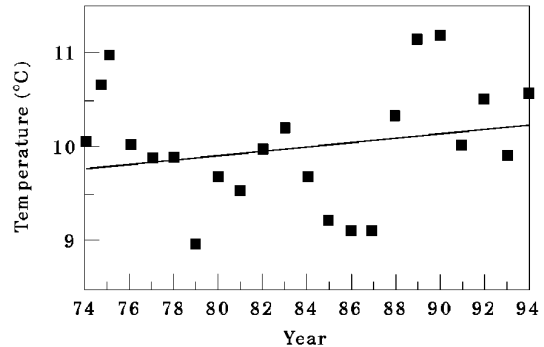


Figure 8. Mean annual temperature at Helgoland Roads.

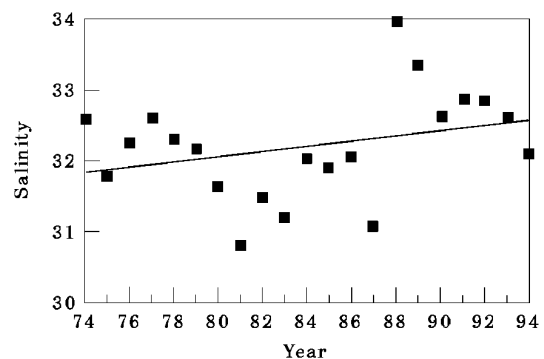


Figure 9. Mean annual salinity at Helgoland Roads.

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