HELGOLÄNDER MEERESUNTERSUCHUNGEN
Helgoländer Meeresunters. 33, 522–530 (1980)

The inner German Bight – an ecologically sensitive area as indicated by the bottom fauna

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ABSTRACT: The muddy sediments of the sublittoral area of the inner German Bight are inhabited by a specialized macrofauna with few species. Long-term investigations on community and population dynamics have shown that the majority of this fauna are very susceptible to environmental stress (e. g. oxygen deficiency), and that the impoverishment trend recorded in 1977 has continued. The special hydrographic conditions of the inner German Bight, especially a long flushing time and the possibility of thermohaline stratifications, together with its function as a sediment trap are discussed. It is proposed that such areas should be considered as sensitive, and hence be protected from avoidable additional stress, e. g. introduction of wastes. This proposal is discussed with regard to the dangers arising from the view that muddy areas enriched with organic matter are inhabited by organisms preadapted to the decomposition of additional waste matter.

INTRODUCTION

During the 1967 International Helgoland Symposium ("Biological and Hydrographical Problems of Water Pollution in the North Sea and Adjacent Waters"), Goedecke (1968) presented a comprehensive paper on the very complicated hydrographic structure of the German Bight. He concluded – in the face of increasing pollution – that the next aim of hydrographic research should be the drawing up of a synoptic map showing the residual currents in this area of the North Sea. Such a map is not yet available, although there have been several new approaches using models to predict currents, residual circulation and flushing time in the German Bight (Maier-Reimer, 1979; Backhaus, 1980). During the "Year of the German Bight" (1979) several hydrographic field measurements were taken to obtain better insight into the conditions which are decisive for the carrying capacity of this area. The capacity of a special marine region is easily overestimated with respect to its extension and supposed flushing properties.

During the International Helgoland Symposium in 1976 I called attention to a long-term trend of faunal impoverishment in the muddy-bottom biocoenosis of the inner German Bight (Rachor, 1977). Further research was done on this symptom of increased stress, and the present paper reports on developments after 1976 and draws conclusions under the aspect of "Protection of life in the sea," the guiding topic of the "14th European Marine Biology Symposium."

 0017-9957/80/0033/0522/$ 02.00

STUDY AREA

I investigated the sublittoral benthic macrofauna in the central part of the inner German Bight southeast of Helgoland, a zone of intensive convergence of North Sea and coastal waters, which are dominated by the runoff of the Rivers Elbe and Weser. This area is characterized by water depths of 20 to 30 m and by muddy bottoms. About 340 000 m^3 of digested sewage sludge from Hamburg are annually dumped a few

Table 1. Abundance figures (individuals per m^2) of the most frequent macrofauna species from selected samples in the period 1976–1979 at the "mud station" in the inner German Bight. The species are ranked according to frequency of occurrence in the preceding years (1969–1976, see Rachor 1977). Grab type: 0.1 and 0.2 = Van Veen grabs, covering the corresponding areas (in m^2); R = Reineck box sampler of 1/60 m^2. Reduced number of species: see legend to Figure 1

Date	23 Apr 1976	29 Apr 1977	22 Jun 1977	20 Oct 1977	26 Apr 1978	20 Jul 1978	2 Oct 1978	26 Apr 1979	20 Jun 1979	9 Oct 1979
Grab type	0.1	0.2	0.1	0.1	0.1/0.2	0.2/R	0.1	0.1	0.1	0.1
Number of grabs	5	3	5	6	3/2	2/6	3	5	5	5
Nucula nitidosa Winckworth	2	135	108	77	145	38	40	78	292	196
Diastylis rathkei (Kröyer)	6	124	1926	402	429	515	60	144	1132	170
Ophiura texturata Lamarck	8	149	112	28	20	38	90	80	120	34
Nephtys hombergii Savigny	12	212	136	153	324	79	7	42	98	12
Mysella bidentata Montagu	–	1	–	–	–	–	–	–	1	14
Abra alba (Wood)	–	15	554	20	28	128	10	–	172	–
Echiurus echiurus (Pallas)	–	20	2	–	–	15	–	–	62	44
Harmothoë sarsi sarsi (Kinberg)	–	5	16	–	1	8	–	–	66	50
Pholoe minuta (Fabricius)	–	1	22	–	–	8	–	–	6	30
Phoronis spec.	–	1	1	–	–	–	–	–	–	52
Ophiura albida (Forbes)	–	55	26	17	–	–	1	–	–	–
Anaitides groenlandica (Oersted)	–	1	24	–	–	1	–	–	12	–
Crangon crangon (Linné)	–	–	–	5	–	20	7	–	–	–
Scalibregma inflatum Rathke	–	–	82	–	6	–	–	–	2270	–
Pectinaria koreni Malmgren	–	–	10	–	–	263	–	–	166	516
Scoloplos armiger (O. F. Müller)	–	7	6	–	1	–	–	20	6	–
Ampelisca brevicornis Da Costa	–	1	1	17	5	–	–	–	–	–
Ophelina acuminata Oersted	–	–	10	–	–	–	–	–	568	–
Ampharete acutifrons (Grube)	–	–	2	–	1	–	–	–	4	–
Lanice conchilega (Pallas)	–	–	10	–	–	1	–	–	–	–
Macoma balthica (Linné)	–	–	–	–	–	–	–	26	38	4
Ensis ensis (Linné)	–	–	–	–	–	–	–	–	–	38
Cerianthus lloydii Gosse	–	–	114	–	–	24	–	–	4	–
Number of individuals of other species	–	17	7	2	3	95	2	–	35	208
Total number of individuals per m^2	28	744	3169	721	963	1233	217	390	5052	1368
Total number of species	4	21	23	10	13	17	9	6	22	15
Reduced number of species	4	10	17	8	7	12	5	6	17	13

Supplementary abundance figures about dominating species during the period 1976–1979: *Lanice conchilega* 4088 (22 Jun 1976), *Pholoe minuta* 306 (17 Aug 1976), *Diastylis rathkei* 3800 (24 May 1978), *Polydora pulchra* Carazzi 182 (6 Aug 1979), *Pectinaria koreni* 1466 and *Ensis ensis* 112 (29 Aug 1979) kilometres to the east of the investigated area. For further details on the study area and on methods used see Rachor (1977).

RESULTS

The impoverishment trend in macrofauna species number, as demonstrated by samples from our continuously investigated "mud station" during the period from 1969 until spring 1976, has become masked in the subsequent years by temporarily successful recolonization efforts during the early summer months (Table 1 and Fig. 1). However, in

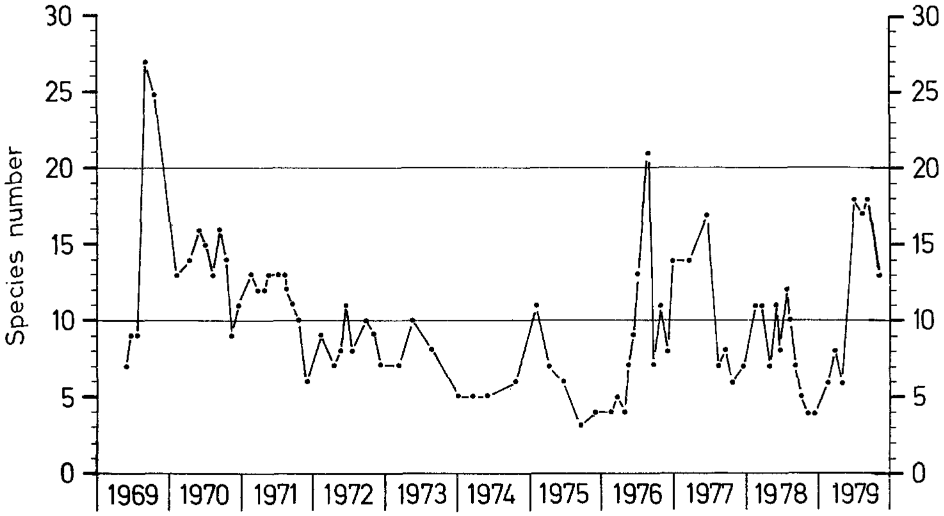

Fig. 1. Development of macrofauna species numbers from 1969 till 1979 at the "mud station" in the inner German Bight. Reduced numbers (single findings and highly mobile crustaceans omitted)

1976 as well as in 1977 and 1978, species numbers declined in late summer (August–September), and late in 1978 comparably low figures as in 1975/76 were reached (4 species per sampling date). The annual fluctuations in species richness – high values in early summer and a sudden decrease in high summer – as well as the long-term development can be shown better by a filtered curve (running means) which compensates the irregularities due to restricted sample sizes of the individual sampling dates (in most cases 5 grabs of the Van Veen type of 0.1 m^2). But, this method remains somewhat arbitrary when sampling is not regular. The long-term development may be shown by using only late winter (March/April) sampling data as these are most stable (Fig. 2).

The species surviving the obviously detrimental late summer are usually the same: the bivalve *Nucula nitidosa*, the crustacean *Diastylis rathkei*, the brittle-star *Ophiura texturata*, and the polychaete worm *Nephtys hombergii*. Other species were conspicuous by temporarily colonizing the area sometimes in high to very high densities, but being unsuccessful in establishing perennial populations due to collapses during summer: the polychaetes *Lanice conchilega*, *Scalibregma inflatum*, *Pectinaria koreni*, *Ophelina acuminata*, *Pholoe minuta*, and *Polydora pulchra* and the bivalve *Ensis ensis* (Table 1).

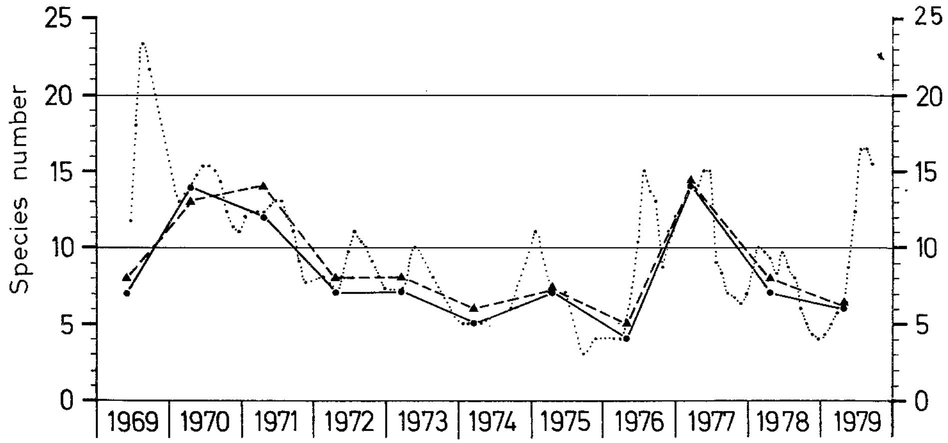

Fig. 2. Long-term development of macrofauna species richness at the "mud station". Dotted line = running 3-monthly means (same data as in Fig. 1); broken line = number of species per 200 individuals calculated by Sander's rarefaction method (diversity) for late winter samples; unbroken line = reduced species numbers for late winter samples

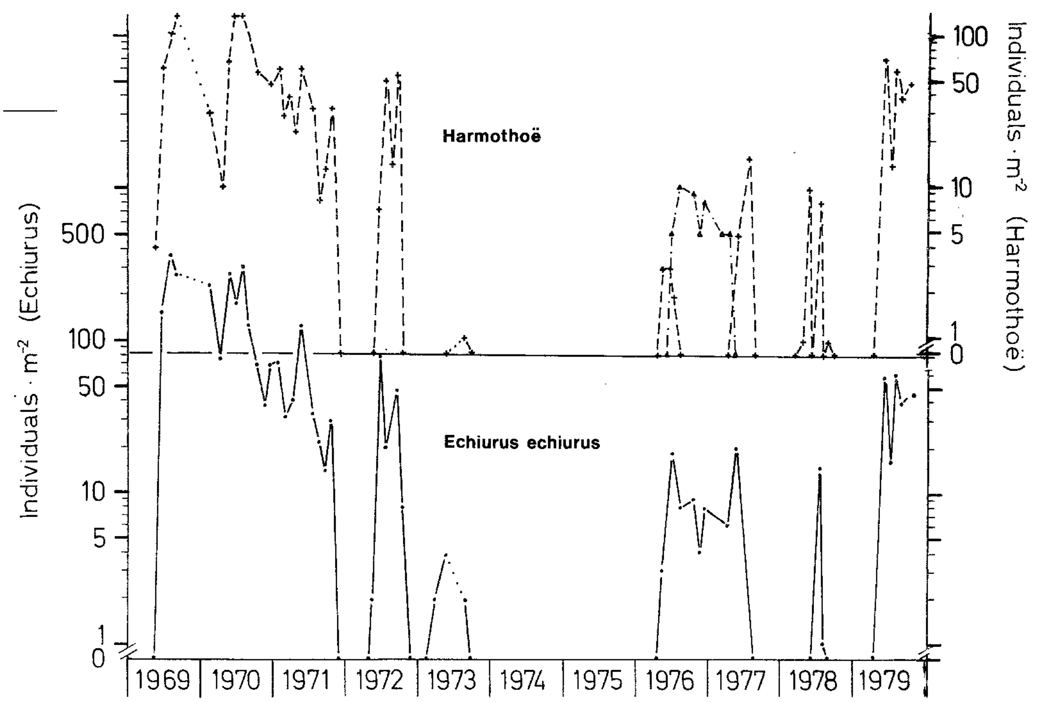

Fig. 3. Variations in numerical abundance of *Echiurus echiurus* compared with the variations in *Harmothoë* species. Cross = *Harmothoë sarsi sarsi*; triangle = *Harmothoë* spp.

The other bivalve present, *Abra alba*, showed a similar pattern, but in several years a few individuals were successful in surviving the detrimental late summer conditions. The same can be assumed for the burrow-building worm *Echiurus echiurus*, although it did not attain such high densities as in 1969 and 1970, or – in 1976/77 – in the neighbouring area more close to the Elbe River mouth (Bartel & Rachor, in preparation). As reported previously (Rachor, 1977), the presence of several other species is positively correlated with the occurrence of *Echiurus*, e. g. *Harmothoë sarsi* (Fig. 3), *Gattyana cirrosa*, *Notomastus latericeus*, and maybe also *Pholoe minuta*. As will be described (Bartel & Rachor, in preparation) *Echiurus* has indirect posotive effects by sediment reworking, burrow building and ventilation of the bottom substratum as well as direct effects by providing shelter for *Harmothoë* and *Gattyana*.

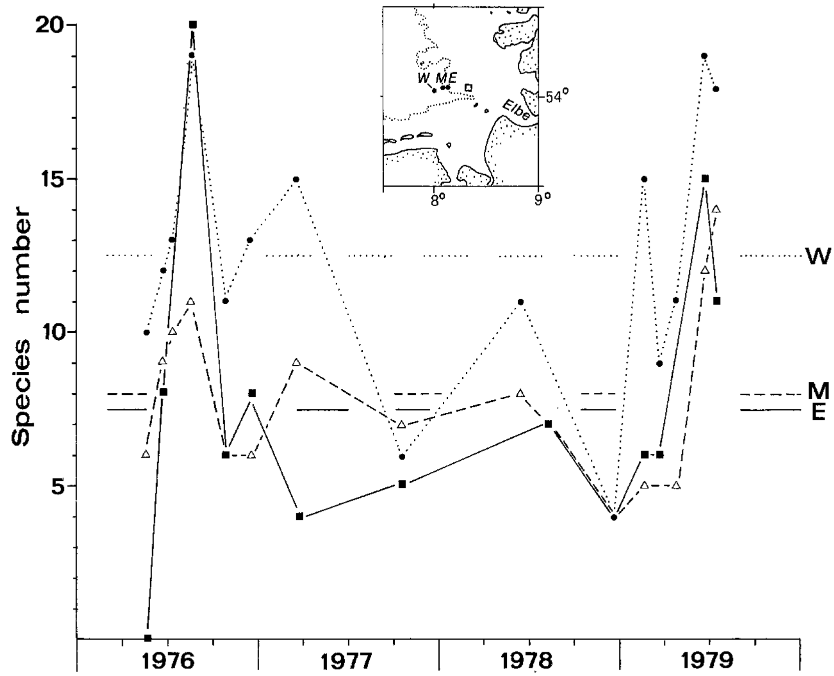

Fig. 4. Variations in macrofauna species number from 1976 till 1979 at the "mud station" (M) compared with the numbers at stations in the west (W) and in the east (E). The figures are derived from two grabs per sampling date. The horizontal lines indicate mean values of all samples. The locations of the stations are indicated in the small map; square = dumping site of sewage sludge

The area, for which our results are considered to be representative, covers about 30 km^2. The centre of faunal impoverishment is east of our continuously investigated "mud station." There is a gradual increase in species numbers and total macrofauna abundance from this centre (water depth, about 20 m) to the west (Fig. 4); species numbers of our long-term "mud station" (M) are compared with those of stations about 2 km to the east and 5.5 km to the west. Figure 4 also shows that the west-to-east gradient has been a general feature for at least several years and that the very poor findings from autumn 1978 are valid for all the stations. At the worst, early in 1976, there was even no macrofauna found in the eastern station, which is only 5 to 6 km away from the dumping area of sewage sludge.

DISCUSSION

As discussed previously (Rachor, 1977), the fauna of the mud area south of Helgoland suffers from oxygen depletion and H_2S-formation in the muddy bottom substrate and in the near-bottom water. This seems to have become a more or less regular event during each summer. With regard to both elements of stability, namely resistance (constancy) and resilience (elasticity), the macrofauna community in the mud area of the inner German Bight is disturbed: wide fluctuations in abundance with sudden breakdowns of several populations have been accompanied by a steady impoverishment in species composition, which means degradation of the community structure. After reaching the highest degree of degradation to date after the winter storms of 1976, the community did not achieve its former complexity. Indeed, the overall conditions in the area allowed a great number of species to be successful in colonizing it again, but these species and especially characteristic key species (Stripp, 1969) like *Echiurus echiurus* could not establish perennial populations. It is assumed that the *Abra alba* community sensu Stripp (1969) represents a higher, more mature stage of succession than the transitory stages which are found there now during each summer. In accordance with the postulates of Pearson & Rosenberg (1978), these transitory succession stages are unpredictable so that species composition and dominances vary from year to year. During the last ten years the fauna was not successful in overcoming these transitory stages, but returned to a very simple and predictable stage during every high summer period. It is to be stressed that this predictable stage is composed only of deposit-feeding and predator species living in or just below the sediment surface. An increase or predominance of deposit-feeding species as well as an elimination of sub-surface species is regarded as an indication of increased organic input (Pearson & Rosenberg, 1978). Besides, the four species left are relatively tolerant of or insusceptible to oxygen deficiency, and therefore the reduced association of these species is regarded as an indicator "community" for temporarily anaerobic mud bottoms.

In conclusion, one cannot but accept that the impoverished and very unstable bottom fauna of the central mud area in the inner German Bight characterizes this region as ecologically sensitive. It is to be stressed that in 1976 parts of the mud area were already devoid of any macrofauna. This extreme finding can be explained by the combination of adverse factors such as the overall disturbed near-bottom oxygen regime late in 1975 and the devastating storm effects in January 1976. On the other hand, the striking explosion of several populations during early summer 1976 is to be attributed to beneficial effects of these storms, resulting especially in improved oxygen supply and rearrangement of the bottom sediment. The similar explosion of populations during the summer 1979 was presumably favoured by the cold temperatures of the preceding winter (cf. Ziegelmeier, 1970) and by a relatively undisturbed oxygen regime during the summer due to low water temperatures and effective vertical mixing.

Although the macrofauna of natural mud areas should be adapted to relatively high organic input and temporarily critical oxygen conditions in the bottom sediment, there are good reasons not to overestimate this adaptability. If organic input becomes too high and bacterial decomposing activity increases with rising temperatures, the endofauna is limited to the upper sediment layers (cf. Ankar & Jansson, 1973). Provided the sediment becomes anaerobic and the near-bottom water poor in oxygen or even contaminated with H_2S, the endofauna as well as the less mobile epifauna will collapse. Such a fauna cannot be used by, for example, demersal fish, as the near-bottom water quality prevents these fish from foraging there. This aspect – that a very high production of macrofauna cannot be optimally used by higher trophic levels – should be considered when evaluating the importance of an area and the effects of wastes mainly in respect to high productivity (see also Caspers, 1978). With regard to deposited waste matter containing harmful substances like heavy metals or toxic and persistent organics, it should also be considered that a high benthic production and its use by fish comprises the danger of re-activation and accumulation of such substances in the food web.

What are the environmental conditions that account for the faunal instability and impoverishment in the investigated area of the inner German Bight so that it may be considered sensitive?

(1) The area is geologically characterized as comprising – below 20 m depth – sediments with high proportions of clay and silt as well as organic matter (Reineck et al., 1968). Such sediments have a natural tendency to become anaerobic. Furthermore, this area is the only larger sublittoral environment in the German Bight with these features and thus the only place where a typical mud bottom community with *Abra alba* and *Nucula nitidosa* as characteristic species (see Stripp, 1969; Glémarec, 1973) can develop. With regard to sensitivity against perturbations one has to keep in mind that the high sedimentation rate of fine material favours the enrichment of the bottom substrate with noxious substances like trace metals and persistent organics. Although mud areas can be an ultimate sink of such noxious substances (GESAMP, 1975), it is thought that the inner German Bight is subjected to sediment resuspension and transport during heavy storm periods so that deposited substances can become mobilized again.

(2) The hydrographic conditions of the inner German Bight are very complex. Due to the convergence of coastal and North Sea waters and the very strong influence of Elbe and Weser runoff, relatively stable thermohaline stratifications of the water can develop especially during calm summer weather conditions. These stable conditions affect the oxygen regime in the near-bottom water by hindering vertical oxygen transport. Residual currents do not appear to guarantee efficient transport of surplus nutrients, wastes and other undesirable matter out of the Bight. This is indicated by Goedecke's (1968) data on eddies, as well as by current measurements and computer models on currents (Backhaus, 1980). These models even suggest that some eddy residual circulation exists in certain water layers. Moreover, westerly winds cause a rise of water level in the German Bight and a near-bottom compensation flow out of the Bight. Easterly winds lead to upwellings and near-bottom compensation flows into the Bight. Thus, the effects of water stratification will increase as no oxygen is supplied to the bottom water when easterly winds prevail. If flushing time is taken as a measure of the carrying capacity and accordingly the sensitivity of a marine area, the German Bight is to be considered as a very vulnerable part of the North Sea with a calculated flushing time of about 3 years compared with 1 to 2 years for the other larger areas of the North Sea (Maier-Reimer, 1979).

(3) Chemical and pollution aspects must also be considered. Nutrient supply is very high in the inner German Bight and has increased during recent years due to Elbe and Weser influx (for phosphorus see Lucht & Gillbricht, 1978, and Weichart, 1978). Thus, the primary production is stimulated (Hagmeier, 1978), which results in higher oxygen demands for the breakdown of organic matter. As the mud area of the inner German Bight is a sedimentation centre of matter produced (Goedecke, 1968), the oxygen regime in near-bottom waters will be influenced negatively by increased productivity in the euphotic zone.

Moreover, the introduction of digested sewage sludge into the eastern part of the inner Bight has increased organic input as well as direct input of nutrients. Hence, a negative influence on the oxygen regime is to be expected. A rough estimate of such an influence indicates additional reductions of oxygen saturation values of 10 % during calm summer periods in the water body below the thermocline.

CONCLUDING REMARKS

The inner German Bight has been demonstrated to be an ecologically sensitive area. Hence, it is not suited for the dumping of large amounts of wastes. Considering sensitivity one should also bear in mind that the island of Helgoland with its unique and very vulnerable hard-bottom flora and fauna is a part of this area. Furthermore, large areas of the German Wadden Sea are in direct connection with the inner German Bight. Catastrophic mass mortalities of bottom animals as occurred during the summer of 1976 in the middle Atlantic Bight off New York after severe oxygen depletion (Steimle & Sindermann, 1978) are possible events to be expected in the German Bight too. Besides the direct harmful effects, indirect effects of such disturbances on neighbouring areas and on migrating populations of animals like young fish cannot be excluded in such cases.

Acknowledgements. I wish to thank Mrs. I. Lerch, Miss S. Strauch and Mr. K.-H. Mantau for their helpful assistance in collection and treatment of the macrofauna samples. This research was supported by the Deutsche Forschungsgemeinschaft (Sonderprogramm "Meeresverschmutzung").

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