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Different zooplankton structures in the German Bight

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ABSTRACT: In August 1982, a net of 48 stations with altogether 208 samples was investigated in the eastern German Bight with respect to temperature, salinity, as well as the amount and species composition of the mesozooplankton (> 80 μm). The data were arranged into different structures by means of a cluster analysis. Four different clusters were found: (a) a "Wadden Sea water" with few holoplankton organisms but a higher amount of spionid larvae; (b) a "German Bight water" with a maximum occurrence of turbellaria (*Alaurina composita*) and medium concentrations of copepods; (c) a mixing area between these two water masses with highest amounts of *Oikopleura dioica, Temora longicornis, Acartia* sp., mussel larvae and larvae of the spionid worms; (d) a "North Sea water" mass with highest concentrations of *Pseudocalanus elongatus, Paracalanus parvus* und *Oithona similis.* The differences in the concentrations of the species mentioned between the four clusters were significant on the 0.1%-level.

INTRODUCTION

Analyses of zooplankton populations have been repeatedly performed in the German Bight – one of the most frequently investigated areas by German marine researchers. At the beginning of this century, Kraefft (1908) reported an enrichment of worm larvae near the coast. Investigations of zooplankton distribution were performed by Künne (1937, 1952). Martens (1978) associated different zooplankton populations with defined water masses.

The complex hydrographic situation in the German Bight is caused by the mixing of North Sea water, coastal water and Elbe River runoff (Becker & Prahm-Rodewald, 1980; Becker et al., 1983). Therefore, ecological investigations require a high sampling resolution in order to distinguish water masses of different origin.

Martens (1978) investigated the distribution of mesozooplankton during winter, along a sampling grid of 46 stations in the eastern German Bight. This paper reports on the mesozooplankton distribution in a partially stratified German Bight in summer.

MATERIAL AND METHODS

From August 17 to 21, 1982, a net of 48 stations in the German Bight (North Sea) was investigated (Fig. 1):

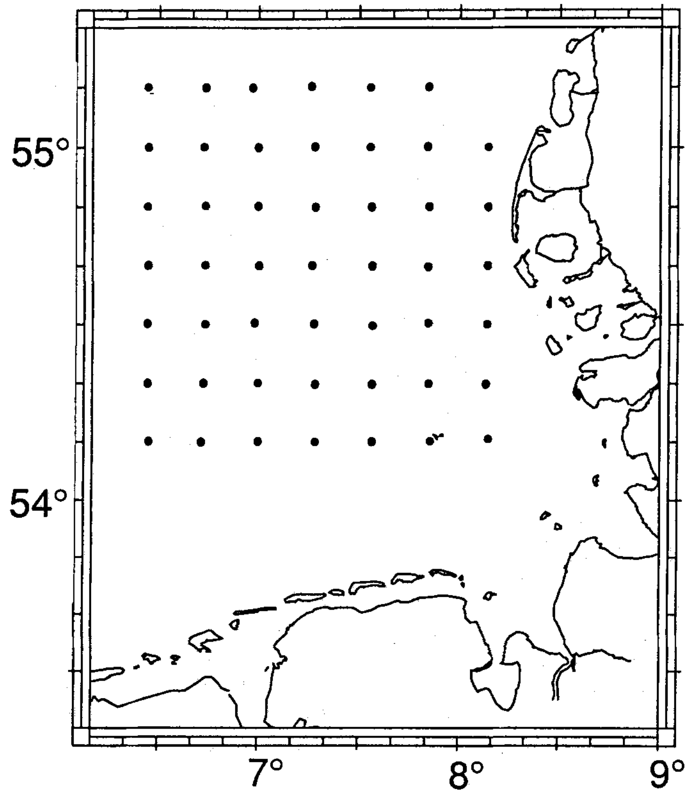

Fig. 1. Location of the sampling stations in the German Bight (North Sea)

The following parameters measured during the cruise are dealt with in this paper:

Temperature (± 0.01 °C) (Multi probe. System Meerestechnik Elektronik)
Salinity (± 0.01 S) (Multi probe. System Meerestechnik Elektronik)
Mesozooplankton (5-l PVS water samplers).

Temperature and salinity were profiled from the surface to the bottom. Zooplankton samples were taken in 0, 5, 10, 15, 20 and 30 m water depth (when possible). The plankton samples were sieved through 80 μm gauze, preserved in 2 % formaldehyde-sea water solution and analysed to the species level under the microscope in the laboratory. The larval stages of *Pseudocalanus elongatus* and *Paracalanus parvus* were not distinguished during the analyses.

Zooplankton dry weight was determined, using the results of the microscopic counts and empirical data sets of species mean dry weight (Hillebrandt, 1972; Martens, 1975).

Statistical methods

To find the optimum "partition" for dividing the total amount of samples into a number of clusters, a cluster analysis was performed. This served as a tool to organise the observed data into meaningful structures. The method used was a k-means-clustering algorithm.

The observed clusters were tested on significant differences in the concentration of the parameters in question by means of a Kruskal-Wallis ANOVA by ranks and a median-test.

All computations were performed using the statistical programme package CSS-Statistica (StatSoft 1991) under MS-DOS 5.0, on a Milan 386/40.

RESULTS

The T-S diagram (Fig. 2) shows the existence of different water masses. The best fit to the data sets, with respect to temperature and salinity, was achieved by means of a 4-means clustering analysis resulting in:

(1) a cold bottom water of relatively high salinity with a mean temperature of 13.99 °C and a mean salinity of 33.58 S;

(2) a "German Bight water", markedly warmer than the bottom water and of lower salinity (17.24 °C, 33.51 S);

(3) a "Wadden Sea water" at the eastern border of the research area, a warm water body with relatively low salinity (18.06 °C, 30.75 S);

(4) a mixing water body with a mean temperature of 17.14 °C and a mean salinity of 32.1 S. (see Fig. 2)

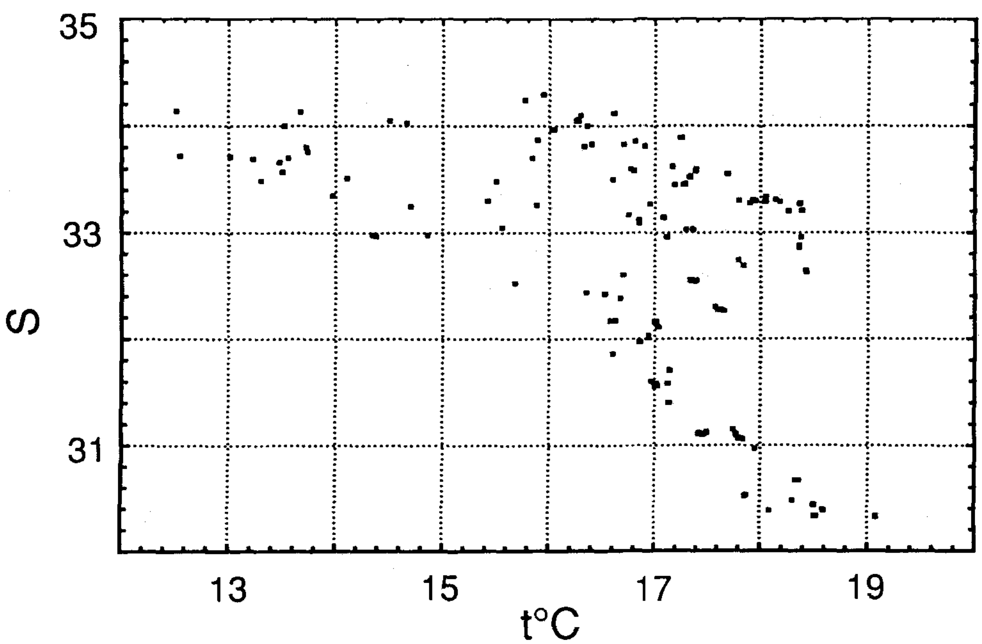

Fig. 2. Temperature-salinity diagram for the 48 stations (208 samples)

In order to ascertain whether this hydrographic structure is reflected by the species composition of the zooplankton, a cluster analysis was performed with respect not only to temperature and salinity, but also to the zooplankton species *Temora longicornis*, *Centropages hamatus*, *Acartia* sp. (mainly *Acartia clausi*), *Oithona similis*, *Pseudocalanus elongatus*, *Paracalanus parvus*, the larvae of the Ophiuroidea and the spionid worms, turbellaria, *Oikopleura dioica* and mussel larvae.

The regional distribution of these four clusters was comparable to those of the previous cluster analysis only with regards to temperature and salinity.

Table 1. Descriptive statistics for cluster number 1 (23 cases)

Variable	Mean	Standard deviation	Variance
Temperature	17.03	0.69	0.49
Salinity	31.67	0.49	0.24
Centropages	3.17	3.65	13.33
Temora	19.70	10.17	103.40
Acartia	27.91	12.33	151.99
Oithona	30.96	18.36	337.13
P.-Calanus	41.22	14.88	221.36
Ophioplutei	5.35	6.09	37.06
Spionid larvae	10.65	14.28	203.87
Turbellaria	1.57	1.41	1.98
Oikopleura	46.43	15.99	225.62
Bivalve larvae	8.65	6.87	47.24

Table 2. Descriptive statistics for cluster number 2 (39 cases)

Variable	Mean	Standard deviation	Variance
Temperature	17.09	0.46	0.21
Salinity	32.81	0.56	0.32
Centropages	1.85	1.68	2.82
Temora	7.03	3.63	13.18
Acartia	22.13	7.82	61.17
Oithona	48.13	30.02	901.27
P.-Calanus	74.82	15.28	233.41
Ophioplutei	8.51	9.46	89.57
Spionid larvae	0.69	1.24	1.53
Turbellaria	4.49	3.56	12.68
Oikopleura	6.64	6.99	48.87
Bivalve larvae	3.95	4.17	17.36

Tables 1 to 4 give the descriptive statistics for the four clusters. Table 5 gives the cluster means for all four clusters.

As can be seen from Figure 3b, the "biological clusters" accord well with the "hydrographic clusters" (Fig. 3a).

Table 3. Descriptive statistics for cluster number 3 (94 cases)

Variable	Mean	Standard deviation	Variance
Temperature	17.08	1.04	0.108
Salinity	33.08	0.87	0.75
Centropages	1.21	1.42	2.02
Temora	8.59	6.06	36.78
Acartia	22.81	11.83	140.03
Oithona	22.76	13.37	178.66
P.-Calanus	37.56	11.95	142.90
Ophioplutei	3.13	6.54	42.76
Spionid larvae	2.72	7.76	60.27
Turbellaria	6.31	6.98	48.73
Oikopleura	6.62	6.25	39.12
Bivalve larvae	3.04	3.66	13.40

Table 4. Descriptive statistics for cluster number 4 (54 cases)

Variable	Mean	Standard deviation	Variance
Temperature	16.71	2.10	4.41
Salinity	32.25	1.54	2.38
Centropages	3.56	5.28	27.90
Temora	8.01	4.86	23.63
Acartia	10.54	7.40	54.80
Oithona	8.19	8.68	75.26
P.-Calanus	11.94	7.63	58.29
Ophioplutei	1.00	1.57	2.47
Spionid larvae	9.52	15.31	234.37
Turbellaria	3.87	6.86	47.10
Oikopleura	4.90	5.38	28.95
Bivalve larvae	2.33	3.37	11.36

Table 5. Mean values for the variables in all four clusters

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Temperature	17.03	17.09	17.08	16.71
Salinity	31.67	32.81	33.08	32.25
Centropages	3.17	1.85	1.21	3.56
Temora	19.70	7.03	8.59	8.01
Acartia	27.91	22.13	22.81	10.54
Oithona	30.96	48.13	22.76	8.19
P.-Calanus	41.22	74.82	37.56	11.94
Ophioplutei	5.35	8.51	3.13	1.00
Spionid larvae	10.65	0.69	2.72	9.52
Turbellaria	1.57	4.49	6.31	3.87
Oikopleura	46.43	6.64	6.62	4.90
Bivalve larvae	8.65	3.95	3.04	2.33

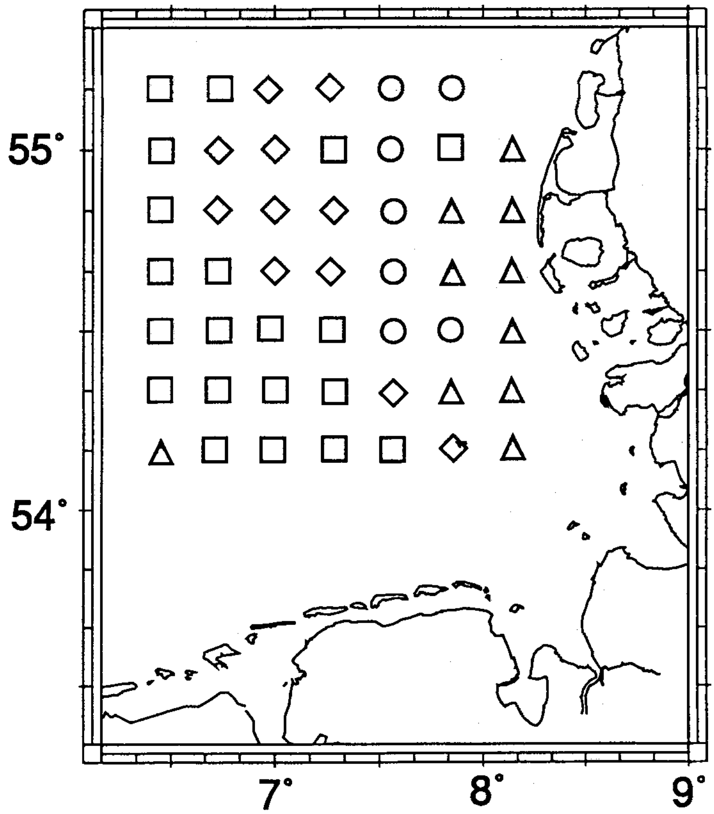

Fig. 3a. The location of the different zooplankton clusters in the German Bight (North Sea). ○ = stations belonging to cluster 1, △ = stations belonging to cluster 2, □ = stations belonging to cluster 3, ◇ = stations belonging to cluster 4

The 208 samples taken have been grouped into 4 clusters, with different concentrations in salinity, and all of the 10 animal species and groups tested. No significant difference was found in temperature (see Tables 6, 7 and Figs 4–14). The differences found in salinity and animals were significant – at least at the 0.1 %-level.

The four clusters can be biologically described in the following way:

Cluster 1: Maximum of *O. dioica, T. longicornis, Acartia* sp., mussel larvae and spionid larvae;

Cluster 1: Highest concentrations of *Pseudo-* and *Paracalanus* sp. and *O. similis* with minimum of spionid larvae;

Cluster 3: Maximum occurrence of turbellaria (*Alaurina composita*) with medium concentrations of copepods;

Cluster 4: Relatively high concentrations of spionid larvae, all other animal groups show minimum concentrations.

Figs 15–18 show the occurrence of the dominating zooplankton species or groups, in relation to temperature and salinity (T-S-animal diagram). The spionid larvae (Fig. 18)

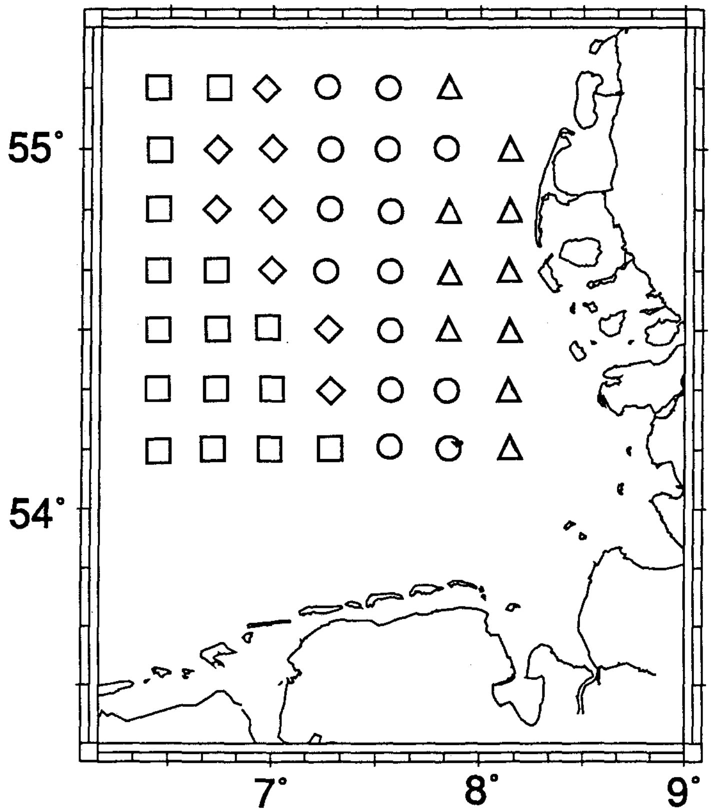

Fig. 3b. The location of the different hydrographic clusters in the German Bight (North Sea). ○ = stations belonging to cluster 1, △ = stations belonging to cluster 2, □ = stations belonging to cluster 3, ◇ = stations belonging to cluster 4

Table 6. Results of the median-tests for the significance of the differences in temperature, salinity and zooplankton concentrations between the four clusters

Variable	Cases above median (observed minus expected per cluster)				Chi-square	Probability level
	Cluster 1	Cluster 2	Cluster 3	Cluster 4		
Temperature	−6.5	4.5	4.5	−2.5	7.91	0.05
Salinity	−14.94	5.31	11.39	−1.76	35.49	<0.0001
Centropages	7.63	0.13	−3.49	−4.26	6.18	0.10
Temora	5.50	3.50	−9.50	0.50	18.30	0.0004
Acartia	−8.25	−7.25	−5.94	21.44	48.03	<0.0001
Oithona	−0.94	−14.69	−3.61	19.24	51.35	<0.0001
P.-Calanus	−4.38	−19.88	−2.72	26.97	95.58	<0.0001
Ophioplutei	3.94	−9.31	−4.16	9.53	19.60	0.0002
Spionid larvae	10.88	10.38	−13.93	−7.32	56.42	<0.0001
Turbellaria	−11.81	−7.06	6.17	12.71	29.63	<0.0001
Oikopleura	3.00	1.00	−12.38	8.38	32.48	<0.0001
Bivalve larvae	0.06	−1.69	−9.38	11.00	25.07	<0.0001

Table 7. Results of the Kruskal-Wallis ANOVA by Ranks as test on the significance of differences in temperature, salinity and zooplankton concentrations between the four clusters

Variable	H (3,N=208)	Probability level
Temperature	3.061	0.3822
Salinity	32.000	<0.0001
Centropages	10.391	0.0155
Temora	32.891	<0.0001
Acartia	67.231	<0.0001
Oithona	82.050	<0.0001
P.-Calanus	156.387	<0.0001
Ophioplutei	31.706	<0.0001
Spionid larvae	46.140	<0.0001
Turbellaria	26.118	<0.0001
Oikopleura	62.642	<0.0001
Bivalve larvae	28.546	<0.0001

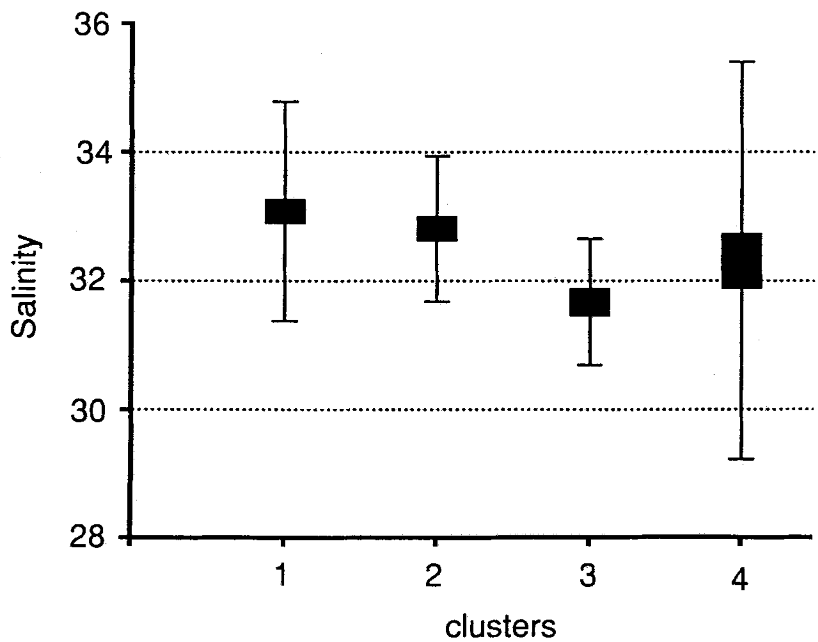

Fig. 4. Comparison of the four clusters with respect to salinity (box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

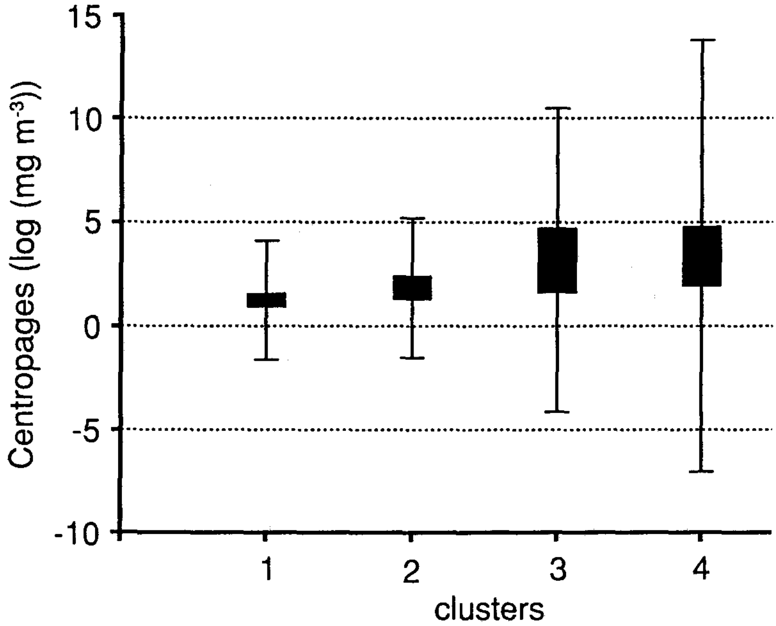

Fig. 5. Comparison of the four clusters with respect to dry weight of *Centropages hamatus* (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

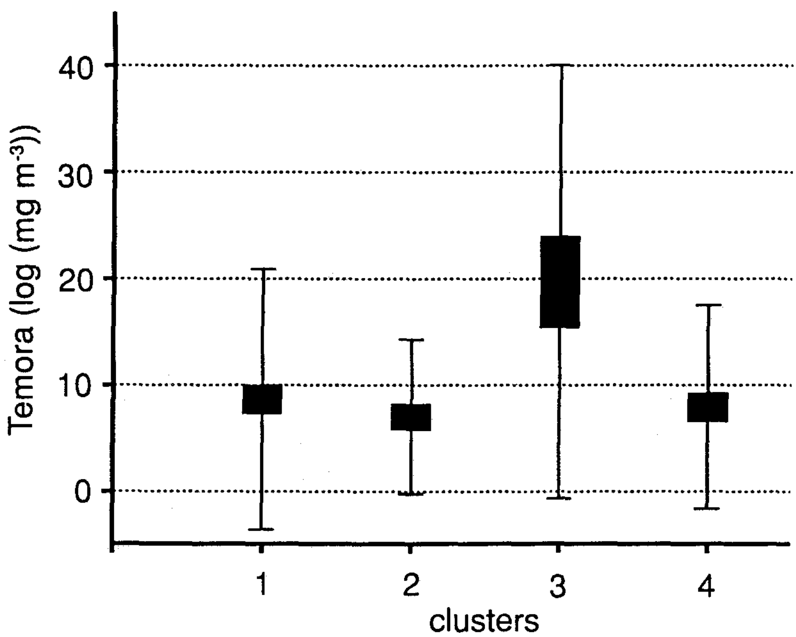

Fig. 6. Comparison of the four clusters with respect to dry weight of *Temora longicornis* (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

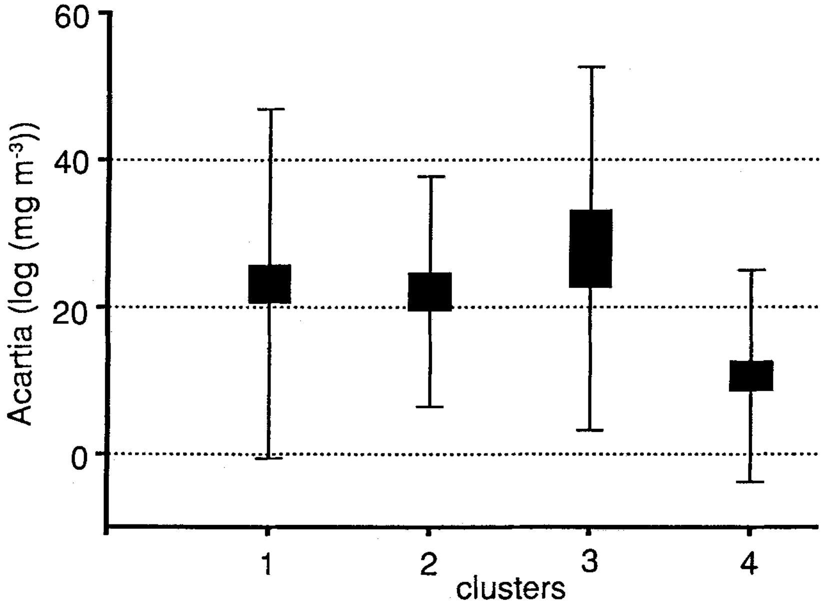

Fig. 7. Comparison of the four clusters with respect to dry weight of *Acartia* sp. (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

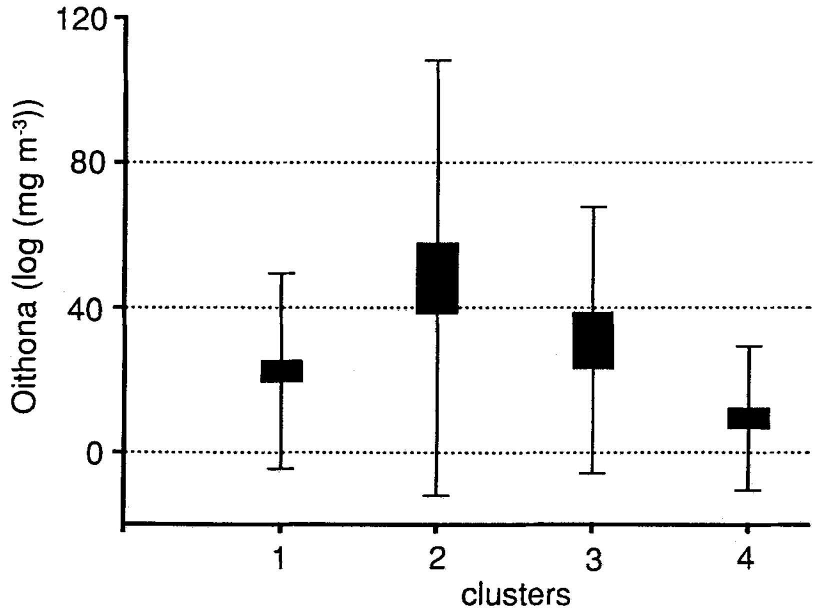

Fig. 8. Comparison of the four clusters with respect to dry weight of *Oithona similis* (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

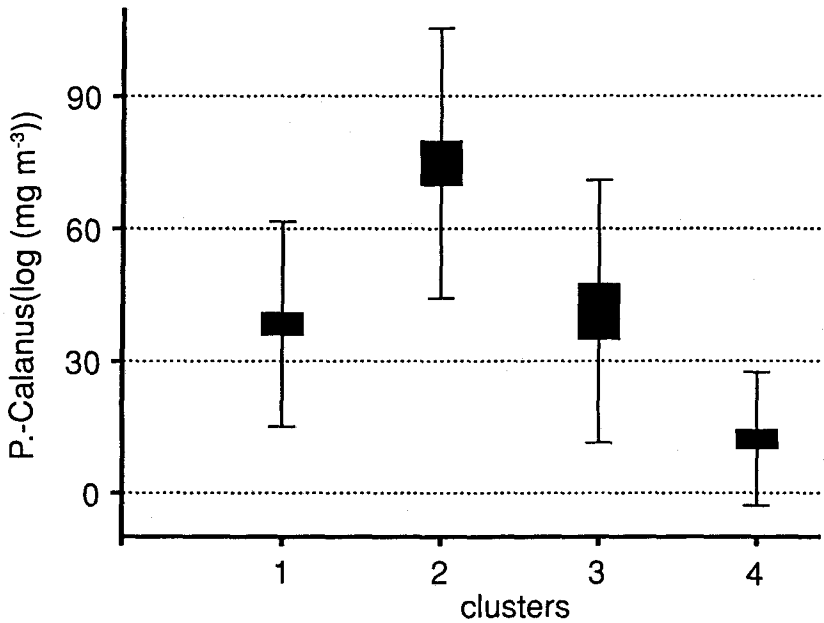

Fig. 9. Comparison of the four clusters with respect to dry weight of *Pseudo-* and *Paracalanus* sp. (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

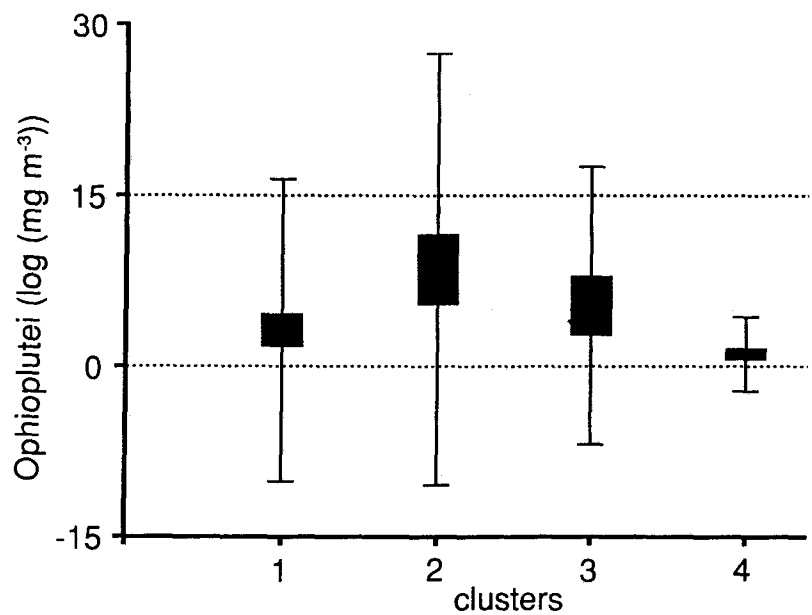

Fig. 10. Comparison of the four clusters with respect to dry weight of *Ophiopluteus*-larvae (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

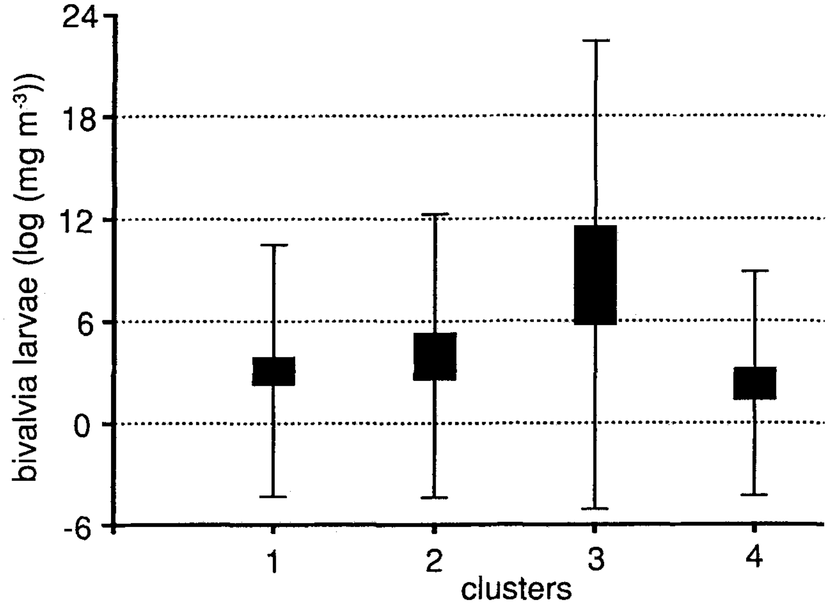

Fig. 11. Comparison of the four clusters with respect to dry weight of larvae of spionid worms (Polychaeta) (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

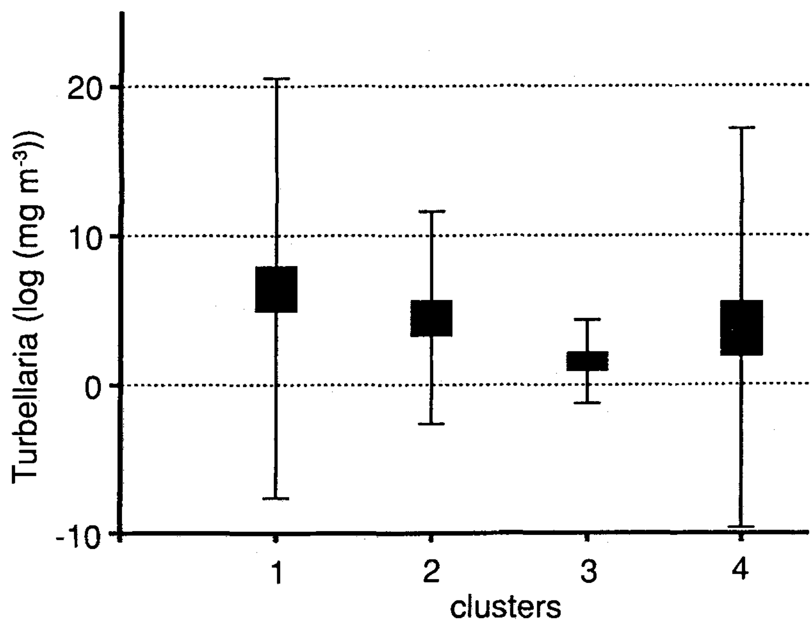

Fig. 12. Comparison of the four clusters with respect to dry weight of *Alaurina composita* (Turbellaria) (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

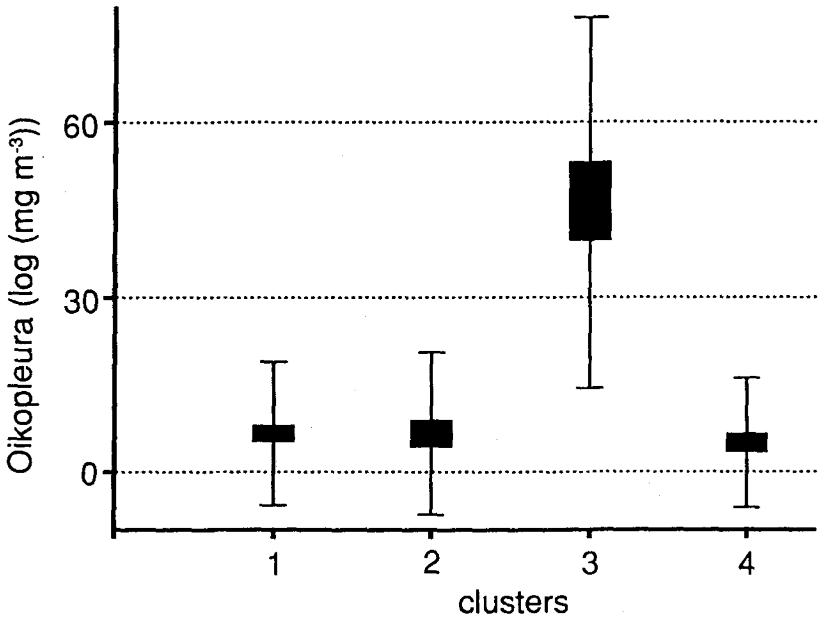

Fig. 13. Comparison of the four clusters with respect to dry weight of *Oikopleura dioica* (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

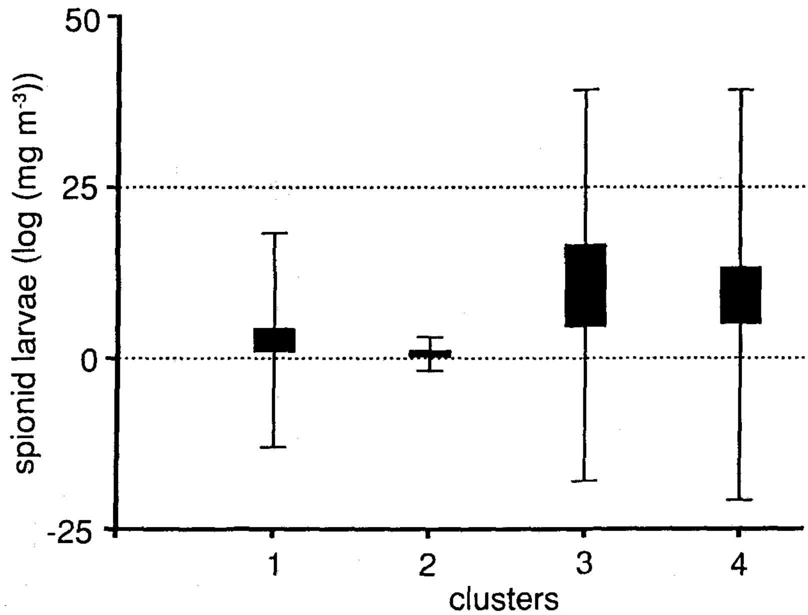

Fig. 14. Comparison of the four clusters with respect to dry weight of bivalve larvae (log values; box-and-whisker plot); box: ± 2 standard error; whisker: ± 2 standard deviation

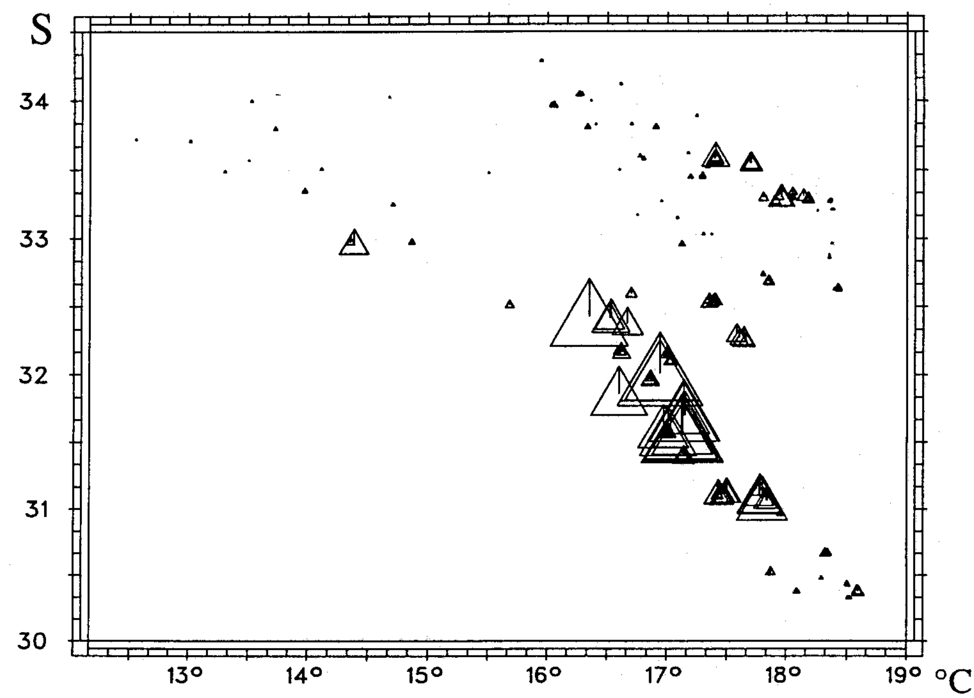

Fig. 15. Temperature-salinity-zooplankton diagram for *Oikopleura dioica*

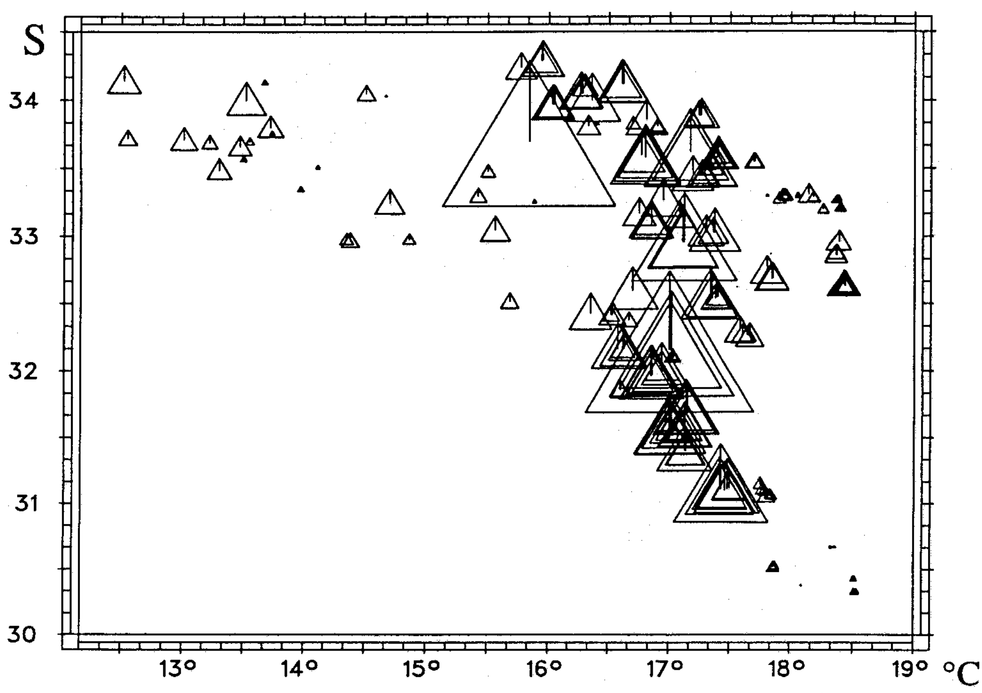

Fig. 16. Temperature-salinity-zooplankton diagram for *Oithona similis*

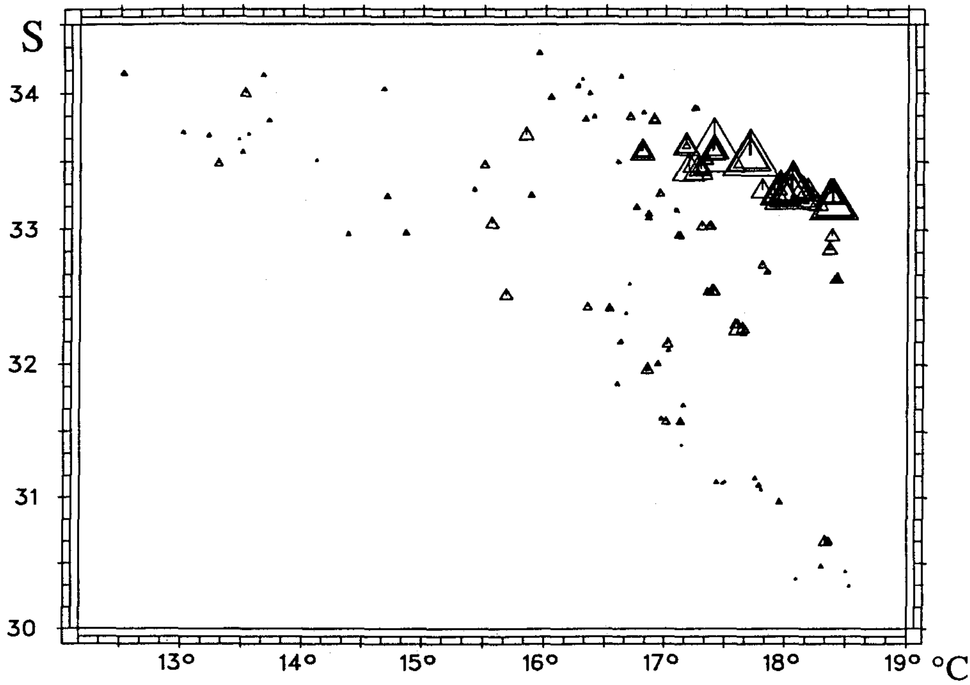

Fig. 17. Temperature-salinity-zooplankton diagram for *Alaurina composita*

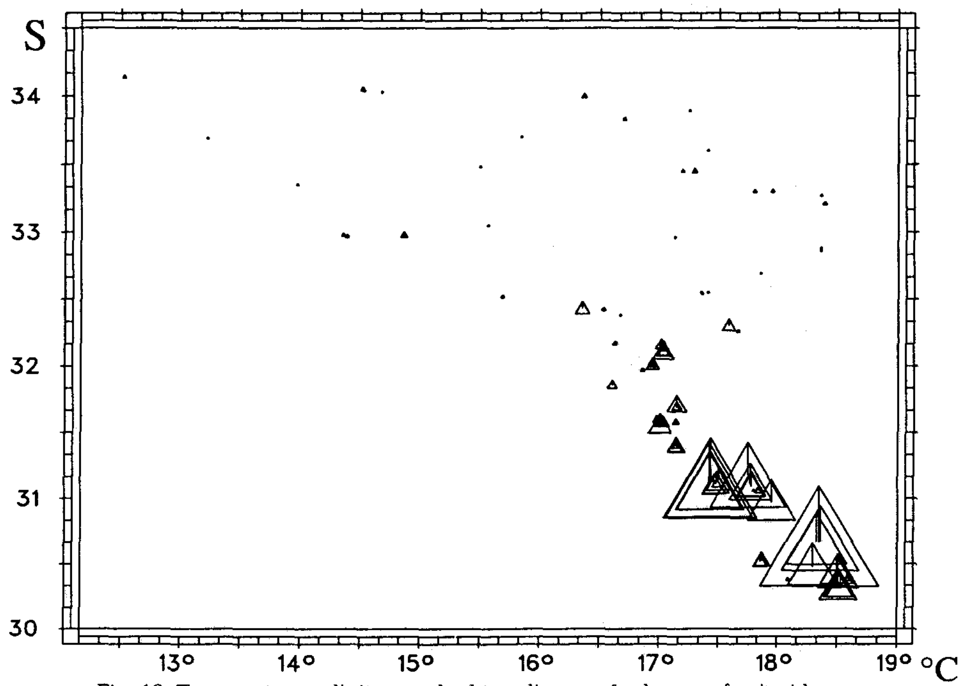

Fig. 18. Temperature-salinity-zooplankton diagram for larvae of spionid worms

show up in highest quantities in the warmest water of lowest salinity, the water mass being influenced by the outflow of the Wadden Sea areas. The turbellaria are found in relatively warm water of high salinity, which was, at the beginning, called a "German Bight" water. *O. dioica* is found in the mixing area between these two water masses. *O. similis* is, together with *P. elongatus* and *P. parvus*, the only species found in numerous quantities in the cold bottom water of high salinity with lowest concentrations, in the areas influenced by the Wadden Sea outflow.

This can be seen when looking at the spatial distribution of the above-mentioned species. Figures 19–22 show the concentration of spionid larvae, turbellaria, *O. dioica* and *O. similis* in the 10-m level. The spatial separation can be clearly seen by a comparison of biomass distribution.

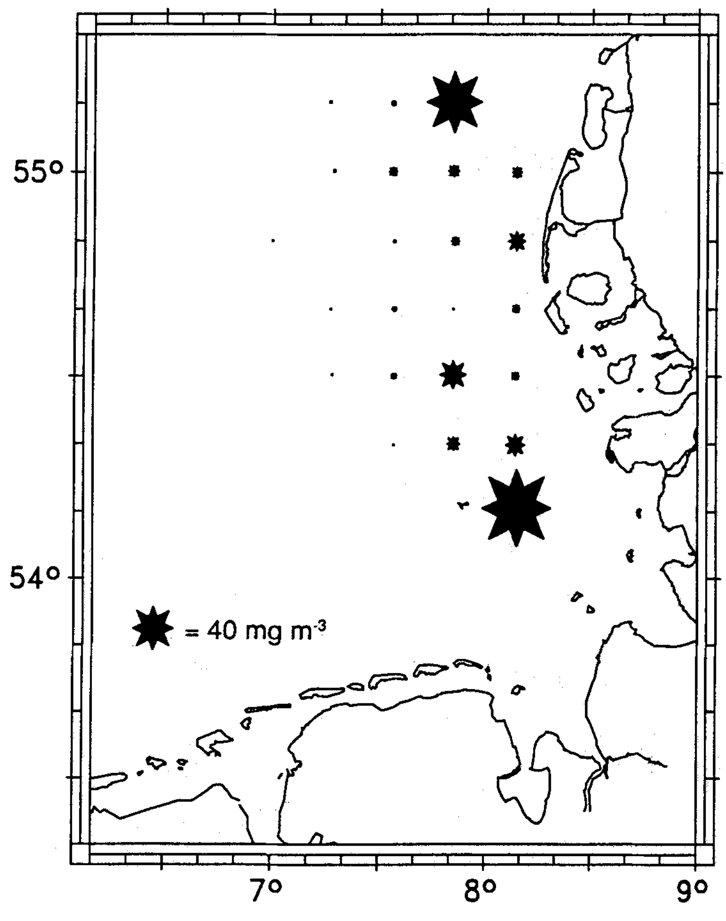

Fig. 19. Abundance of the larvae of spionid worms at the different sampling stations in 10 metre depth. 1 cm ∅ = 40 mg dry weight m^{-3}

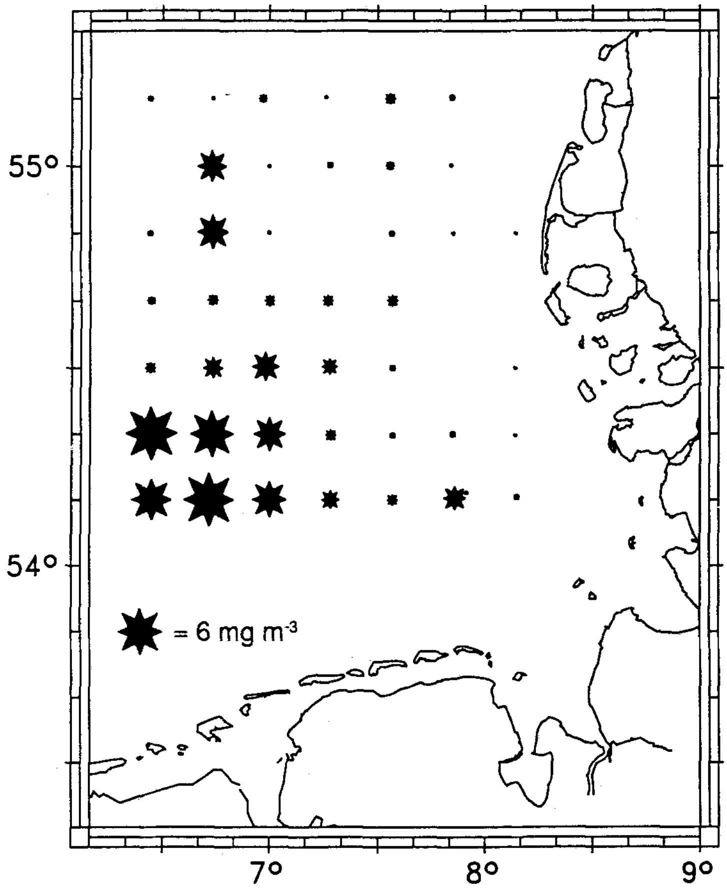

Fig. 20. Abundance of *Alaurina composita* at the different sampling stations in 10 metre depth. 1 cm ∅ = 6 mg dry weight m^{-3}

DISCUSSION

In November 1976, Martens (1978) found four different water masses in the eastern German Bight. Besides the water of the River Elbe (this area was not sampled in 1982), the other water masses with their biological peculiarities could be again detected during this study. The most eastern water body is the Wadden Sea water, with relatively few zooplankton individuals beside meroplanktonic larvae, given here as an example by the larvae of the spionid worms. This has been earlier shown by Martens (1980). The Wadden Sea areas seem to have a negative effect on the inflowing zooplankton organisms. The nature of this effect is not fully understood as yet. One possible influence might be the large amount of inorganic seston in the water column. Barnes et al. (1978) showed a negative influence of a protein-poor diet on the cirripedes. Chervin et al. (1981) found an inhibitory effect of non-phytoplankton carbon on copepods in the plume of the Hudson River.

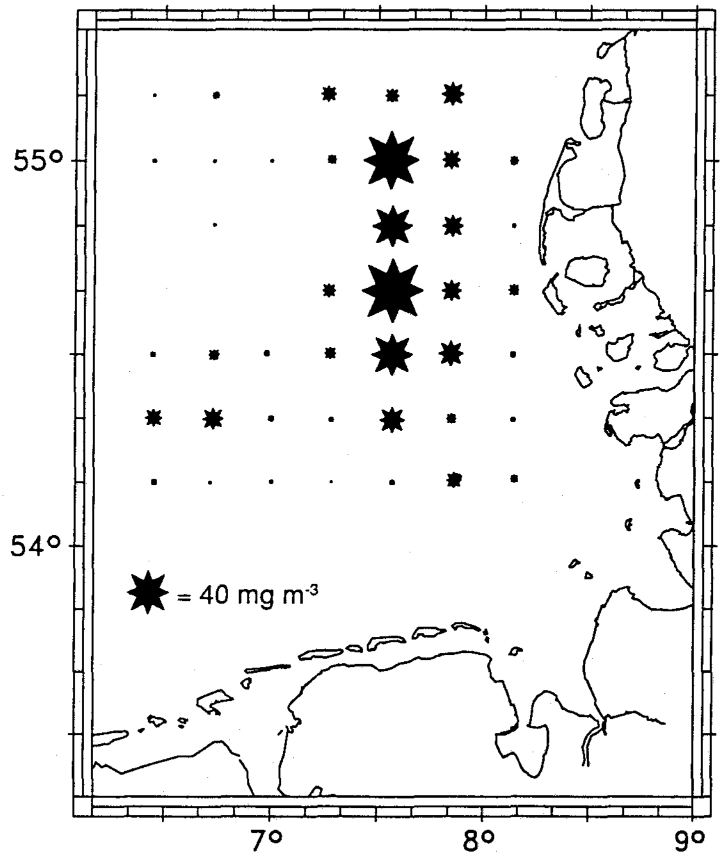

Fig. 21. Abundance of *Oikopleura dioica* at the different sampling stations in 10 metre depth. 1 cm ∅ = 40 mg dry weight m^{-3}

West of the Wadden Sea water lies a "mixing area" with a higher amount of neritic copepod species, and the maximum abundance of *Oikopleura dioica.* This was identical in 1976 and 1982, even though the investigation in 1976 was performed in November and the latter in August – a remarkably stable zooplankton structure in this hydrographically very turbulent area.

The cold bottom-water of cluster 2 has a relatively higher amount of *Oithona similis, Pseudocalanus elongatus* and *Paracalanus parvus.* During the investigation period, the prevailing winds were of a westerly direction, causing an inflow of "North Sea water". As shown by Krause & Martens (1990), the species in question can preferably be found in the central parts of the North Sea as opposed to more neritic species like *Acartia* sp.

Unfortunately the investigation area did not extend in a more southwesterly direction, due to technical reasons. Cluster 3, with its high concentrations of *Alaurina composita* (Turbellaria), is situated at the south-western border of the investigation area. This euryhaline species has its main dispersal area in the southern coastal areas, with

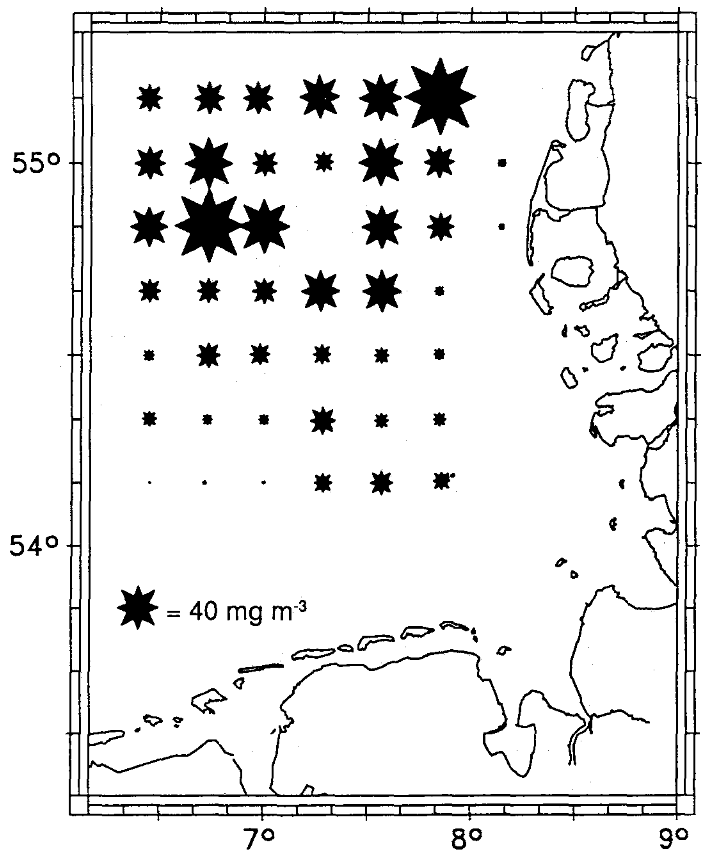

Fig. 22. Abundance of *Oithona similis* at the different sampling stations in 10 metre depth. 1 cm Ø = 40 mg dry weight m^{-3}

high concentrations in the Dutch Wadden Sea (Giere, 1968). Its occurrence seems to indicate an inflow of south-western water into the German Bight.

As Künne (1937) mentioned: "Different water masses contain peculiar plankton communities according to the different seasons. Within these communities characteristic forms can be found . . . giving a special quality to the plankton, due to their high concentrations . . . Leading forms only occur in a specific water body being totally absent in neighbouring water masses" (translated from the German). Following this characterisation, no leading forms were found during this investigation in the German Bight. All zooplankton species were found in every water mass detected. The significant differences became obvious by comparing the different species and animal groups, and the environmental parameters like temperature or salinity. The often-used determination of leading species for the definition of water masses is not sufficient in this hydrographically very dynamic and complex area.

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