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Differentiation of zooplankton populations in a polluted area

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ABSTRACT: Zooplankton composition and spatial distribution were studied in The Gulf of Thermaikos (Aegean Sea, Greece), a shallow, semi-closed area which is subjected to urban and industrial pollution and receives freshwater from 4 large rivers. These features, combined with the hydrology of the Gulf, influence the zooplankton, which is characterized by spatial differentiation depending upon the time of year (December, May and September). Within the northern part of the Gulf, where there is considerable waste discharge, zooplankton is abundant and communities are characterized by dominance of opportunistic species. In contrast, the eastern region is strongly influenced by incoming water masses from the Aegean Sea and zooplankton communities presented a much more diversified and stable situation. The pattern of zooplankton distribution off the river deltas is more complex and depends greatly on season.The differentiation of the zooplankton communities was quantified using non-metric multidimensional scaling and graphical descriptors.

INTRODUCTION

Many studies have assessed the biological effects of pollutants on different marine organisms. Some of these deal with population dynamics within a polluted area while others, more recent, assess the impact of pollution on marine communities (Pearson et al. 1983, Gray et al. 1988, Warwick 1986).

Zooplankton has occasionally been used as a tool to investigate the impact of pollution in marine communities (Blanc et al. 1975, Specchi 1976, Benon et al. 1977, EPOPEM 1979) or in river estuaries (Blanc et al. 1969). Therefore, it was considered valuable to examine the differentiation of zooplankton populations with respect to their tolerance to pollution and investigate whether a pollution-induced gradient could be discerned with respect to the zooplankton communities.

The Gulf of Thermaikos was chosen for this study. It is situated in northwestern Greece in the Aegean Sea and is considered to have unique characteristics (Fig. 1). This semi-enclosed environment is influenced by freshwater from 4 large rivers whose deltas are located in the western part of the Gulf. The mean flow of the River Axios, which receives industrial and agricultural wastes, is 170 m^3 s^{-1}, of the River Aliakmon, receiving mainly agricultural wastes, 100 m^3 s^{-1}, while for the River Loudias, receiving more than 5000 m^3 d^{-1} of industrial effluents, as well as some agricultural wastes, the maximum flow is 400 m^3 s^{-1} The River Gallikos is smaller and its flow has not been measured precisely (Ganoulis et al. 1988). Two separate but adjacent bays lie in the northern inner part of the Gulf: the Bay and the Gulf of Thessaloniki, which have maximum depths of about 25 m. The Bay of Thessaloniki receives about 20×10^4 m^3 d^{-1} of domestic wastes, while a considerable amount of pollution is due to effluents from the industrial area of greater Thessaloniki (6×10^4 m^3 d^{-1}; Ganoulis et al. 1988). An abrupt increase of nutrients occurs during the summer (irrigation period) as well as after heavy rainfall, when nutrients originating from applications of fertilisers, especially nitrates, are washed out and discharged into the Gulf of Thermaikos (Ganoulis et al. 1988). The Bay of Thessaloniki is characterised by high surface nutrient concentrations, while the Gulf of Thessaloniki has lower concentrations, similar to those reported in the literature for slightly polluted areas (Samanidou et al. 1987). An extremely high concentration of ammonium can be found in the Bay of Thessaloniki (6.25 µg-at. l^{-1}), as well as a raised nitrate concentration near the delta of the River Axios (5.31 µg-at. l^{-1}) (Samanidou et al. 1987). The low N/P ratio (2.71) observed in the Bay of Thessaloniki was related to the proximity of a sewage outfall

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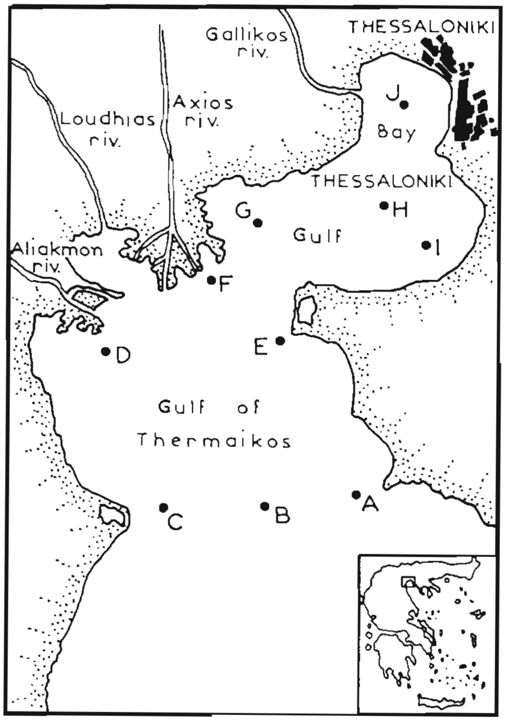


Fig. 1. Position of sampling stations

(phosphorus source), while an increase in the N/P ratio was observed away from the outfall (Samanidou et al. 1987). Comparisons of nutrient levels in the Gulf of Thermaikos with other coastal areas of the Aegean Sea revealed elevated phosphate and ammonium values in the Bay of Thessaloniki (Balopoulos & Friligos 1986); these authors found high nitrate and silicate values near the river estuaries in the western Gulf of Thermaikos.

An interesting comparison can be made with the oxygen content, where a gradient can be observed through the Bay and Gulf of Thessaloniki and the Gulf of Thermaikos; in the Bay it is 4.4 mg l^{-1}, near the river estuaries 5.5 mg l^{-1}, in the Gulf of Thessaloniki 6.0 mg l^{-1} and in the outer Gulf of Thermaikos 6.4 mg l^{-1} (Ganoulis et al. 1988). Domestic and industrial effluents as well as the riverine freshwater input produce the high turbidity observed in the Gulf of Thermaikos; this is especially evident in the northern and western part (Samanidou et al. 1987, Gotsis-Skretas & Friligos in press). In contrast the southern and eastern part is characterized by cleaner waters coming from the open Aegean Sea (Balopoulos 1986). The slow cyclonic circulation comprises an input of clean waters from the Aegean Sea along the east coast of the Gulf and an output along the west coast; only through the action of north winds, which are dominant in the region, do domestic, agricultural and industrial effluents reach the exit of the Gulf to the south (Robles et al. 1983, Balopoulos 1986). Four water masses have been identified during November and May: (1) water of the Gulf of Thessaloniki, (2) water of north Thermaikos, off the river estuaries, (3) water of eastern Thermaikos, and (4) water of western Thermaikos (Balopoulos 1985).

Several previous studies on the phytoplankton and zooplankton of the area investigated the structure of the community based on dominant groups and/or biomass (Papadimitriou 1979, Yannopoulos 1979). In addition, Siokou-Frangou & Akepsimaides (1986) attempted to describe the zooplankton composition based on species tolerance to pollution.

The aim of the present study was to determine the biological effects of pollution at the zooplankton community level in a Mediterranean gulf, using appropriate multivariate techniques. In addition the study provides information regarding the zooplankton composition in the Gulf.

MATERIALS AND METHODS

Three major oceanographic cruises were carried out in the Gulf of Thermaikos in December 1984, May 1985 and September 1985. Zooplankton samples were collected from 10 stations (Fig. 1), taking into account the preliminary interpretation of the physical and chemical data (Friligos 1977, Balopoulos 1985), as follows: one station (J) was located in the Bay of Thessaloniki, 3 stations (I, H, G) in the Gulf of Thessaloniki, 2 stations (D, F) near the river estuaries and 4 stations (A, B, C and E) in the greater Gulf of Thermaikos. During May no samples were collected at Stns G and I due to unexpected rough seas. The samples were taken with double-oblique hauls using a WP-2 net (200 µm mesh size, 57 cm diameter) from the bottom to the surface of the sea. The volume of the filtered seawater was measured using a 'Hydrobios' flowmeter. Species identification and specimen counts were made in aliquots varying from 1/4 to 1/64.

The species diversity of the population was estimated according to the Shannon-Wiener diversity index using logarithms to base 2 (Shannon & Weaver 1963), and dominance was calculated according to the formula described by Hulburt (1963).

In addition, a graphical representation of *k*-dominance curves for each station based on ranked species abundances (in decreasing order) was examined as a possible procedure to describe spatial patterns of zooplankton distribution (Lambshead et al. 1983, Warwick 1986). Univariate statistics included analysis of variance in order to identify any differences in abundance between stations and seasons. In order to delimit zones of faunal similarity, non-metric multi-dimensional scaling (MDS) was employed, following the method described by Field et al. (1982) and Clarke & Green (1988). The raw data, expressed as number of individuals per m^3, were transformed using the transformation $y_{ij} = \sqrt{x_{ij}}$ due to the very non-normal and heterogeneous variance data, which may otherwise result in domination of samples by certain species, obtained from zooplankton counts (Field et al. 1982) The Bray-Curtis similarity matrix was used for all computations.

Principal components analysis (PCA) was performed on the environmental data collected during the same cruise and analyzed by N. Friligos (Gotsis-Skretas & Friligos 1990).

The multivariate statistical analysis and the *k*-dominance plots were carried out using the software package PRIMER developed at the Marine Laboratory, Plymouth, UK, while univariate statistics were calculated using the software package STATGRAPHICS.

RESULTS

Surface temperature, salinity, nutrients and chlorophyll *a* values are given in Table 1, based on measurements made simultaneously with the zooplankton sampling (Gotsis-Skretas & Friligos 1990). Temperatures were higher at the southern stations than at the northern ones during December, while during May the difference was reversed. Salinity values were lower off the river estuaries (Stn F) and at neighbouring stations (Stns D & C). Nutrient values showed no clear patterns, but chlorophyll *a* was generally lower at the southern stations than at the northern ones and off the river estuaries (Table 1).

The zooplankton composition and abundance of dominant species was different between sites as well as between seasons (Tables 2 & 3). The total zooplankton abundance also fluctuated between seasons and sites (Table 3). In December copepods and cladocerans were by far the most abundant groups, with extremely high numbers of copepods in the northern part of the Gulf (Stns H, J, I, G, F) (Table 2). The dominant species were *Acartia clausi* followed by *Oithona nana* and *Podon polyphemoides* (Table 3). Total zooplankton abundance was lower at the southeastern stations (A, B); however, the number of species increased, especially at Stn A, where many of the typical Aegean species

Table 1. Physio-chemical parameters and chlorophyll *a* values during simultaneous measurements by Gotsis-Skretas & Friligos (1990)

Parameters	Stations A	B	C	D	E	F	G	H	I	J
December 1984										
Temperature (°C)[a]		16.60	16.00	15.70	16.00	15.50	15.50	15.70		15.10
Salinity[a]	37.20		35.90	35.50	36.60	33.90	36.60	36.60		36.40
NH_4-N (µg at. l^{-1})	0.26	0.66	0.31	0.55	0.20	0.31	0.43	0.26	0.60	1.83
NO_2-N	0.04	0.07	0.06	0.18	0.24	0.27	0.60	0.57	0.96	1.02
NO_3-N	0.11	0.18	0.23	4.51	0.32	0.51	0.80	0.80	1.44	1.52
SiO_4-Si	1.41	1.24	1.41	6.83	1.41	1.92	2.68	2.93	3.10	3.44
PO_4-P	0.58	0.67	0.10	0.75	0.18	0.42	0.34	0.50	0.63	1.03
Chl *a* (µg l^{-1})	1.64	2.14	6.60	5.04	3.24	7.12	7.54	6.45	8.22	8.70
May 1985										
Temperature (°C)[a]	19.30	20.20	22.50	21.90	20.20	22.40	21.90	23.30	22.90	22.20
Salinity[a]	37.90	38.20	34.20	31.60	34.70	33.90	32.70	34.40	34.20	34.90
NH_4-N (µg at. l^{-1})	1.79	2.23	1.53	0.95	2.89	4.09	1.27	1.42	0.49	2.93
NO_2-N	0.23	0.06	0.06	0.05	0.09	0.18	0.15	0.06	0.06	0.12
NO_3-N	0.67	0.44	0.66	0.61	1.24	0.44	4.11	0.10	0.07	0.36
SiO_4-Si	0.80	1.41	0.90	9.54	1.66	4.29	5.81	0.73	0.39	0.56
PO_4-P	1.11	3.29	1.59	0.67	3.53	1.19	3.71	0.34	0.18	0.91
Chl *a* (µg l^{-1})	0.15	0.13	4.78	14.90	0.27	6.10	1.75	4.42	3.03	8.20
September 1985										
Temperature (°C)[a]	25.50	25.80	25.60	25.60	25.10	25.40	24.60	24.70	24.60	24.80
Salinity[a]	36.70	36.60	35.80	36.30	36.60		36.90	37.00	37.00	37.10
NH_4-N (µg at. l^{-1})	0.29	0.20	0.15	0.39	0.67	0.15	0.15	0.15	0.06	0.20
NO_2-N	0.01	0.06	0.03	0.26	0.20	0.04	0.11	0.09	0.13	0.11
NO_3-N	0.24	0.11	0.14	0.56	0.67	0.13	1.00	0.22	0.24	0.17
SiO_4-Si	0.59	0.86	4.50	2.88	1.69	0.77	1.50	1.05	1.60	0.95
PO_4-P	0.18	0.14	0.16	0.18	0.26	0.14	0.26	0.24	0.24	0.25
Chl *a* (µg l^{-1})	0.11	0.12	0.83	0.79	0.15	0.18	0.63	0.45	2.51	1.05

[a] Balopoulus in press

Table 2. Relative frequency (%) of different zooplankton groups and total abundance (ind. m^{-3})

Group	Stations									
	A	B	C	D	E	F	G	H	I	J
December 1984										
Copepoda	63.3	49.5	40.4	26.0	70.2	82.9	81.8	87.4	72.6	43.8
Cladocera	15.3	30.1	32.8	43.3	11.3	11.1	3.9	8.9	11.6	30.7
Siphonophora	0.6	0.1	–	–	0.2	0.1	0.1	–	0.3	0.1
Appendicularia	7.2	8.8	2.8	14.0	10.1	2.7	11.5	2.2	7.2	11.5
Doliolidae	3.1	2.0	3.0	1.6	0.3	0.1	0.1	–	–	–
Chaetognatha	6.5	3.0	12.5	1.5	2.3	–	0.1	0.1	0.3	0.1
Medusae	0.2	0.3	–	0.3	0.1	–	0.2	0.1	0.9	1.6
Mollusca larvae	1.1	0.9	3.2	1.6	2.4	1.0	1.1	0.8	3.6	3.8
Ichthyoplankton	0.6	0.3	0.4	–	–	–	–	–	–	–
Crustacea larvae	1.6	2.8	1.7	0.5	0.4	0.9	0.4	0.1	1.3	0.2
Polychaeta larvae	0.2	0.3	0.3	1.6	1.4	1.0	0.5	0.4	1.6	4.8
Echinodermata larvae	1.5	2.2	0.5	9.7	0.9	0.1	–	0.1	0.1	0.4
Ostracods	0.8	–	–	–	–	–	–	–	–	–
Total abundance	641	1209	441	838	2455	9345	16214	10153	12824	7542
May 1985										
Copepoda	69.1	71.0	58.2	55.6	64.8	60.7		48.4		42.1
Cladocera	22.4	26.5	26.8	17.5	27.7	16.4		25.2		26.6
Siphonophora	0.7	0.3	0.0	0.3	0.2	0.0		–		0.0
Appendicularia	0.7	0.3	0.4	0.3	0.2	0.2		0.1		0.3
Doliolidae	1.2	0.2	0.0	0.2	0.5	0.1		–		0.4
Chaetognatha	3.5	0.2	0.9	0.2	1.7	0.6		1.7		0.7
Medusae	–	–	–	–	–	–		0.1		0.2
Mollusca larvae	1.0	0.4	1.5	5.1	3.2	4.0		5.9		7.7
Ichthyoplankton	0.5	0.6	0.6	0.3	0.4	1.0		0.4		0.3
Crustacea larvae	0.6	0.2	2.1	11.0	1.0	15.2		3.5		3.3
Polychaeta larvae	0.1	–	0.2	1.0	0.1	0.4		3.1		4.8
Echinodermata larvae	0.1	–	–	1.4	–	0.2		5.9		4.3
Ostracods	–	–	–	–	–	–		–		0.3
Total abundance	772	1138	520	345	771	266		284		299
September 1985										
Copepoda	34.4	42.2	54.9	57.7	48.5	54.8	26.3	20.0	27.0	33.4
Cladocera	54.0	47.3	40.6	35.2	33.7	34.9	64.7	76.8	63.5	62.0
Siphonophora	0.1	–	–	–	0.6	0.1	0.0	1.3	0.1	–
Appendicularia	17.6	0.5	1.4	0.1	6.7	3.2	5.5	0.2	4.9	2.3
Doliolidae	0.9	2.0	–	0.2	7.4	0.1	0.1	–	0.1	–
Chaetognatha	1.4	0.7	0.1	1.1	1.3	0.4	0.1	–	0.5	0.1
Medusae	–	0.3	–	0.1	–	–	–	0.6	–	–
Mollusca larvae	0.6	0.9	0.7	0.2	0.6	2.8	0.1	–	0.3	0.0
Ichthyoplankton	0.2	–	0.0	–	–	–	0.1	–	–	0.0
Crustacea larvae	0.4	–	2.2	–	0.9	0.1	0.6	0.7	0.3	0.4
Polychaeta larvae	0.1	0.2	0.0	0.1	0.1	1.3	0.2	0.1	0.1	0.4
Echinodermata larvae	0.2	0.4	–	0.2	0.1	0.1	2.2	0.2	3.2	0.8
Ostracods	–	3.8	4.1	–	–	–	–	0.2	–	–
Total abundance	1405	2283	2175	829	404	2013	1427	2469	1400	3508

(Moraitou-Apostolopoulou 1972, Siokou et al. 1990) were found, such as *Clausocalanus pergens*, *C. jobei*, *Evadne spinifera*, *Oncaea media* and *Corycaeus giesbrechti* (Table 3). At the central and western stations (D, F) the dominant species were *A. clausi* followed by *Paracalanus parvus* and *Penilia avirostris*. Appendicularians were well represented interms of both in species and number of individuals in the southern and central part of the Gulf.

During May *Acartia clausi* was still the most abundant species in the Gulf but in lower numbers than in December. In the northern part *Podon polyphemoides* and *Oithona helgolandica* were also dominant species (Table 3). Their numbers however decreased towards the southern stations where other species, like *Centropages typicus* and *Evadne spinifera*, were abundant.

In comparison to the other sampling seasons, the species composition was totally different in September.

Table 3. Relative frequency (%) of dominant zooplankton species, with Shannon-Wiener diversity index H and Hurlburt dominance index δ

Species	Station A	B	C	D	E	F	G	H	I	J
December 1984										
Acartia clausi	20.34	23.63	18.12	2.24	30.67	55.42	65.16	56.19	49.90	26.73
Acartia latisetosa	0.05	–	0.10	–	0.02	4.01	0.45	0.44	0.14	0.02
Centropages typicus	3.62	0.68	2.73	0.14	0.41	0.21	0.93	6.32	1.65	1.91
Clausocalanus furcatus	0.02	0.01	–	–	–	–	–	–	–	–
Clausocalanus jobei	1.63	0.06	1.00	0.35	0.02	–	–	0.02	–	–
Clausocalanus pergens	25.64	4.95	0.53	0.31	0.93	–	–	–	–	–
Corycaeus giesbrechti	1.58	0.93	2.40	0.21	0.39	0.01	–	0.10	0.10	0.01
Corycella rostrata	0.51	0.30	0.60	0.40	0.50	–	–	–	–	–
Oithona helgolandica	0.10	0.62	0.21	1.77	–	0.01	–	0.01	–	–
Oithona nana	–	0.25	0.10	6.23	–	10.45	11.23	20.63	15.78	12.52
Oithona plumifera	–	0.50	1.00	0.85	–	0.01	0.04	0.02	0.14	0.04
Oncaea media	1.32	0.41	0.50	1.34	1.43	0.24	0.27	0.31	–	0.02
Paracalanus parvus	5.24	14.85	6.33	5.12	32.34	4.37	3.59	1.52	4.55	3.48
Temora stylifera	1.22	2.23	4.22	0.92	0.17	0.12	0.01	0.02	–	0.02
Evadne spinifera	5.63	10.53	19.37	3.16	1.25	–	–	–	–	–
Evadne tergestina	0.16	0.68	0.23	0.74	0.02	0.16	–	0.06	0.23	0.51
Penilia avirostris	7.63	15.42	5.62	19.23	3.71	1.26	0.99	0.71	1.51	1.82
Podon polyphemoides	1.53	3.47	7.55	21.85	3.41	13.09	1.58	6.76	7.47	28.30
Oikopleura dioica	–	0.12	–	0.92	0.68	1.04	4.70	0.46	3.12	–
Fritillaria pellucida	0.20	0.93	0.32	3.54	–	0.01	–	–	–	–
Fritillaria haplostoma	0.61	2.85	–	5.46	0.72	–	–	0.01	–	–
H (bits ind.$^{-1}$)	3.38	1.61	3.21	3.24	2.51	1.84	1.42	1.59	2.73	2.09
δ (%)	45.9	39.1	37.3	41.1	62.3	68.5	76.4	76.8	65.7	55.3
May 1985										
Acartia clausi	15.02	20.34	32.23	13.56	20.45	30.73	–	23.42	–	22.17
Acartia latisetosa	0.03	–	–	–	–	–	–	–	–	–
Centropages typicus	37.23	12.37	6.53	20.27	37.14	25.63	–	4.39	–	3.19
Clausocalanus furcatus	0.32	0.15	0.07	0.12	0.02	–	–	–	–	–
Clausocalanus jobei	0.30	–	–	–	0.02	–	–	–	–	–
Clausocalanus pergens	–	–	–	–	–	–	–	–	–	–
Corycaeus giesbrechti	0.40	0.06	–	–	0.02	–	–	0.01	–	–
Corycella rostrata	0.06	–	–	–	0.02	–	–	–	–	–
Oithona helgolandica	3.55	0.64	14.70	8.42	4.23	6.15	–	26.34	–	22.47
Oithona nana	0.10	0.02	0.01	0.20	–	0.84	–	0.16	–	0.74
Oithona plumifera	3.04	1.05	3.20	1.15	1.12	1.17	–	1.92	–	0.65
Oncaea media	1.50	0.20	–	–	0.02	–	–	–	–	–
Paracalanus parvus	0.34	0.42	0.03	0.94	0.27	–	–	0.42	–	–
Temora stylifera	0.03	0.02	–	–	–	–	–	–	–	–
Evadne spinifera	23.65	26.37	14.70	12.18	26.57	8.26	–	0.56	–	0.22
Evadne tergestina	0.03	0.10	0.05	0.23	0.12	0.15	–	0.01	–	–
Penilia avirostris	–	–	–	–	–	–	–	0.01	–	–
Podon polyphemoides	–	0.02	12.05	4.53	0.92	6.24	–	21.00	–	24.36
Oikopleura dioica	–	–	–	–	–	–	–	–	–	–
Fritillaria pellucida	–	–	–	–	–	–	–	–	–	–
Fritillaria haplostoma	–	–	–	–	–	–	–	–	–	–
H (bits ind.$^{-1}$)	2.13	1.83	2.31	2.37	1.87	2.24	–	2.06	–	2.07
δ (%)	60.9	46.7	46.93	33.8	63.9	56.4	–	49.7	–	46.8
September 1985										
Acartia clausi	–	–	–	–	–	–	–	–	–	–
Acartia latisetosa	–	–	–	–	–	–	–	–	15.33	20.45
Centropages typicus	0.34	0.08	0.43	–	0.35	0.03	–	1.22	1.45	2.61
Clausocalanus furcatus	6.83	5.36	0.53	0.39	0.51	0.06	0.08	1.60	0.37	–
Clausocalanus jobei	–	–	–	–	–	–	–	–	–	–
Clausocalanus pergens	–	–	–	–	–	–	–	–	–	–
Corycaeus giesbrechti	1.40	0.30	1.20	1.10	1.40	0.50	–	0.44	–	–
Corycella rostrata	0.09	0.08	0.06	–	0.03	–	–	–	–	–
Oithona helgolandica	–	0.02	1.53	–	0.05	0.03	0.31	–	–	–

Table 3 (continued)

Species	Station A	B	C	D	E	F	G	H	I	J
September 1985 (continued)										
Oithona nana	–	0.24	0.04	–	–	–	–	–	–	–
Oithona plumifera	–	4.56	0.85	1.56	0.42	0.42	0.21	0.11	0.51	–
Oncaea media	0.10	0.21	0.09	–	0.90	0.10	0.08	–	–	–
Paracalanus parvus	25.12	25.37	38.42	35.67	15.23	27.45	17.63	13.37	5.62	2.38
Temora stylifera	11.24	7.36	6.42	2.36	16.32	10.32	7.38	0.28	3.31	–
Evadne spinifera	28.12	17.84	12.18	15.32	12.16	1.88	0.35	7.62	0.07	–
Evadne tergestina	19.24	8.03	8.14	9.93	1.39	26.73	59.54	61.01	40.49	51.62
Penilia avirostris	6.34	17.86	19.15	13.62	21.24	6.97	9.07	9.01	33.65	8.15
Podon polyphemoides	0.11	0.02	0.21	–	0.65	0.09	0.26	0.72	2.93	0.72
Oikopleura dioica	–	–	–	–	–	0.03	0.06	–	0.27	–
Fritillaria pellucida	–	–	–	–	–	–	–	–	–	–
Fritillaria haplostoma	–	–	–	–	–	–	–	–	–	–
H (bits ind.$^{-1}$)	2.64	2.65	2.51	2.09	2.26	2.18	1.52	1.82	2.27	1.52
δ (%)	53.2	43.2	57.5	50.9	37.5	54.1	77.1	74.3	74.6	72.0

The cladoceran *Evadne tergestina* dominated in the northern part of the Gulf and *Paracalanus parvus*, *P. avirostris* and *Acartia latisetosa* were found in lower numbers (Table 3). In the central and southern part the abundance of *P. parvus* increased, followed by *Evadne spinifera*, *P. avirostris* and *Temora stylifera*. At Stns A and B, *E. spinifera* was the dominant species followed by *Clausocalanus furcatus*. Other taxonomic groups were found in lower numbers which varied according to stations (Table 2).

There were few doliolids, siphonophores and chaetognaths either in the northern part of the Gulf or off the estuaries. In contrast, meroplanktonic groups such as crustacean and molluscan larvae seem to favour these waters, which are rich in nutrients. A greater abundance of these was observed during May (Table 2).

In December, greater densities of zooplankton were found at the northern stations (G, H, I, J) and off the river mouths (Stn F) (7540 to 16214 ind. m^{-3}) (Table 2). During this period there was a large difference in density between those stations and the southern part of the Gulf, as Stns A and C revealed 641 and 441 ind. m^{-3} respectively.

Two-way analysis of variance on log (x + 1) transformed abundances for all seasons revealed significant differences among the northern (Stns J, I, H and G), eastern (A, B and E) and central stations (C, D and F) at the 95 % level (F-ratio = 4.265, p = 0.0305). The least significant range test showed that the difference was clearly between the northern and the rest of the stations. Significant differences were also observed among months (F-ratio = 13.021, p = 0.0003). The least significant range test showed that the difference was accounted for by December at the 95 % level. Note that the northern stations in December were responsible for the significant differences observed (Fig. 2).

The diversity indices and the dominance indices for the sampling period clearly show the zooplankton distribution described above (Table 3). Differences among stations were more evident during December when lower diversity values were observed for the northern part and higher values for the southern and eastern parts. Dominance indices varied inversely to diversity. Differentiation between stations was also evident by the graphical descriptors (k-dominance curves) (Fig. 3). During December and September southern stations (A,

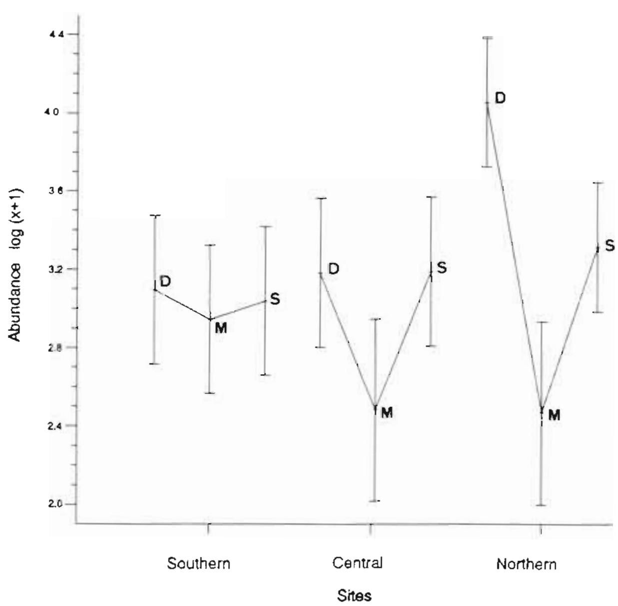
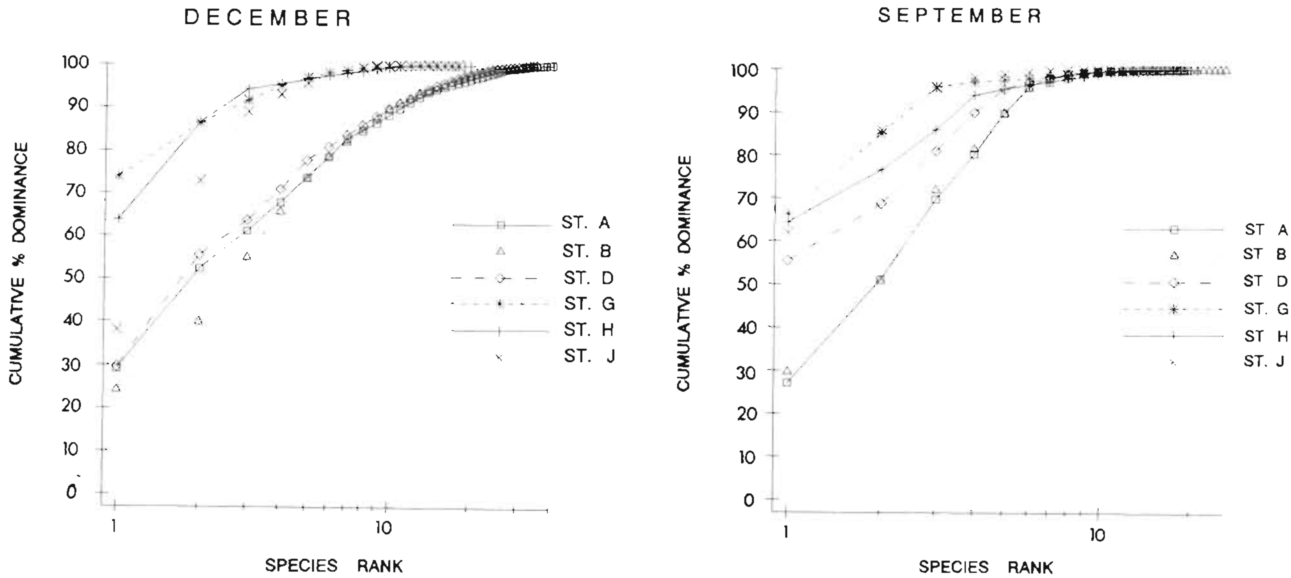


Fig. 2. Plots of means and 95 % confidence intervals for month by site interactions



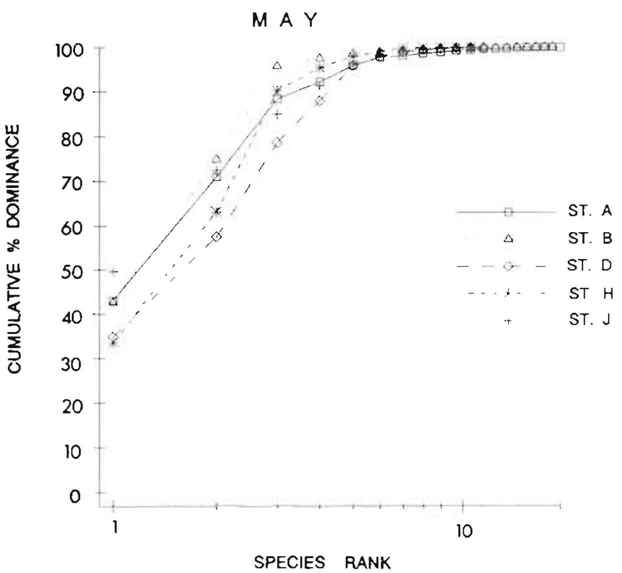


Fig. 3. Plots of the *k*-dominance curves during the sampling period

B) revealed more diversified and less dominated communities than the northern stations (G, J), with Stn D having an intermediate position. On the other hand the *k*-dominance curves did not exhibit any major difference among stations during May.

The stations were also differentiated by the ordination technique (Fig. 4), which gave a satisfactory presentation of the stations' positions due to the low stress in 2 dimensions, calculated at 0.048, 0.005 and 0.053 for December, May and September respectively. In December 2 groups of stations can be distinguished on the MDS plots: the first group comprises Stns I, G, H, F and J in the northern part and at the estuary mouth, and the second the stations A, B, C, D and E. The pattern of stations is complicated during May when 3 groups of stations can be distinguished; the first group is constituted by the inner stations (J, H), the second by stations influenced by the rivers (D, F), and the third by Stns A, B, C, E (southeastern). It can also be seen that Stns F and D were positioned between the inner stations and the southeastern ones. Finally, during September the ordination plot revealed an even differentiation of stations in agreement with their geographical distribution.

In order to investigate relationships between zooplankton and environmental parameters, an attempt was made to superimpose temperature, salinity, nutrients and chlorophyll *a* measurements (taken from Gotsis-Skretas & Friligos 1990) on the MDS plots derived from the faunistic multivariate analysis. Of the above parameters only the chlorophyll *a* distribution seems to be correlated to zooplankton with regard to the position of stations on the plots (Fig. 5). From the principal components analysis on the environmental data (Fig. 6), the northern stations can be distinguished from the others in all sampling periods.

DISCUSSION

Spatial differentiation was revealed in the zooplankton of the Gulf of Thermaikos. This could be the result of the pollution which influences this area (Friligos 1977, Samanidou et al. 1987, Ganoulis et al. 1988), and was shown from the PCA analysis of environmental data, since there is no clear influence of salinity distinguishing estuarine and marine communities. The differentiation of total zooplankton density varied according

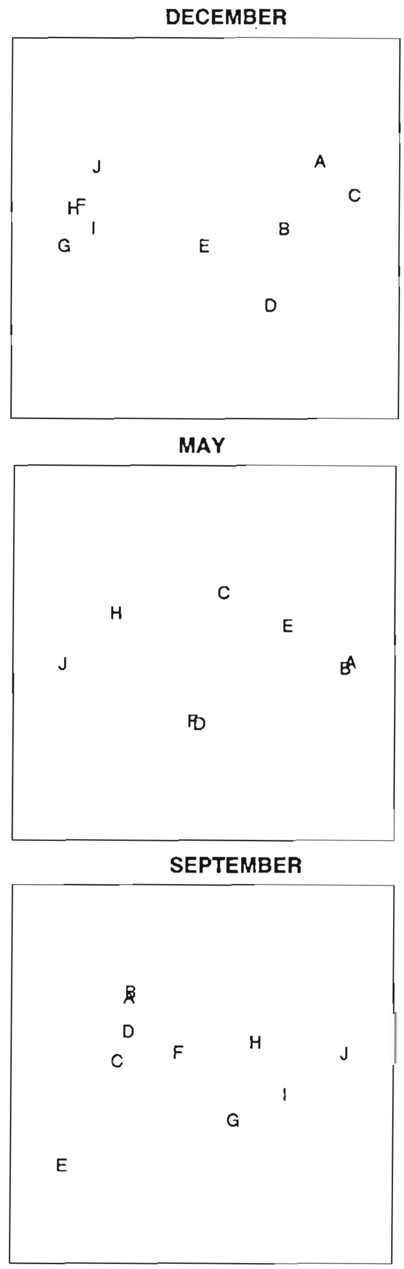


Fig. 4. MDS plots resulting from the analysis of the zooplankton data

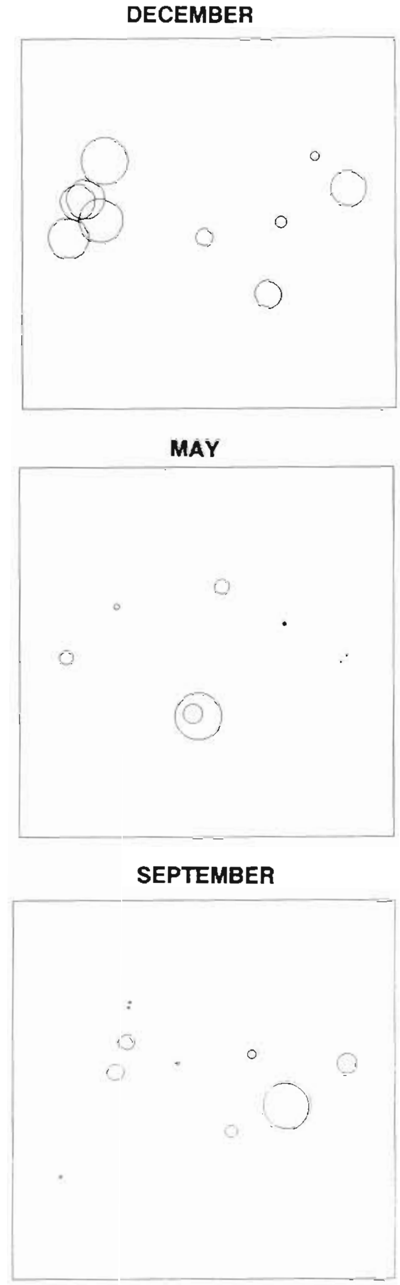


Fig. 5. MDS plot with the values of chlorophyll *a* superimposed on the zooplankton data

to the sampling period. During December the northern part of the Gulf was characterized by extremely high values of total zooplankton abundance (up to 16 000 ind. m^{-3}), suggesting a disturbance of the zooplankton population as a result of the eutrophication simulataneously detected by chlorophyll *a* concentrations (Gotsis-Skretas & Friligos 1990). Nutrient values observed during the same cruise did not show clear differentiation among stations, but it should be taken into account that maximum nutrient values occurred during November (Ganoulis et al. 1988). Comparable studies in the Gulf of Fos, France, revealed that high abundance values were the result of domestic, industrial and river discharges (Benon et al. 1977). Similarly high values of zooplankton abundance were found in Elefsis Bay, Greece, which is considered to be polluted by industrial and domestic wastes (Moraitou-Apostolopoulou & Ignatiades 1980, Siokou-Frangou & Anagnostaki 1985). However high zooplankton abundances have been found in larger areas in the Mediterranean, such as the

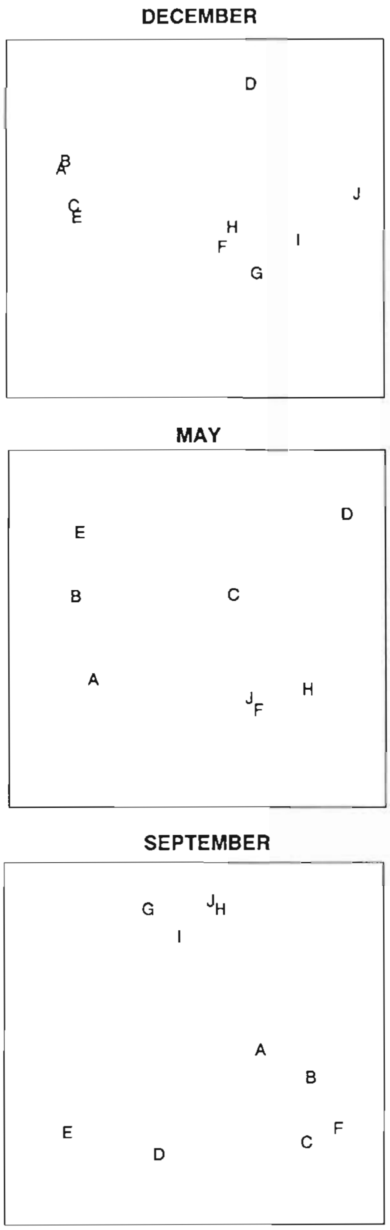


Fig. 6. PCA plot resulting from the analysis of the environmental data

Gulf of Trieste and the northern Adriatic Sea (Specchi et al. 1981).

In the southeastern part of the Gulf of Thermaikos zooplankton abundance was generally low and resembled that observed just outside of the Gulf of Fos (Benon et al. 1977), in the Gulf of Naples (Carrada et al. 1980) and in the outer Gulf of Saronikos, Greece (Moraitou-Apostolopoulou & Ignatiades 1980). Intermediate values were recorded for the central part of the study area. Similar spatial differentiation in zooplankton abundances and biomass has also been observed in the Gulf of Thermaikos by Papadimitriou (1979) and Yannopoulos (1979).

During May and September this spatial pattern of the total zooplankton density in the Gulf had disappeared. During May silicates and chlorophyll *a* concentrations were high at Stns D and F, affected by the river outflows (Gotsis-Skretas & Friligos 1990); in September, however, differences among stations were less marked. The discordance between nutrients, phytoplankton and zooplankton data could be due to the time lag in the development of different levels of the trophic chain.

The differentiation in the Gulf is reinforced by the taxonomic composition found in the study using graphical descriptors and multivariate statistics. The classification and ordination techniques always discriminated between the southern and the northern parts of the Gulf, which accounts for the differences observed between species. Thus, at the northern stations opportunistic species like *Acartia clausi, Evadne tergestina, Podon polyphemoides, Oithona nana, Penilia avirostris, Acartia latisetosa* and *Oithona helgolandica* were found. The abundance of these species is generally high in disturbed areas (Blanc et al. 1975, Benon et al. 1977, Moraitou-Apostolopoulou & Ignatiades 1980, Arfi et al. 1981, Specchi et al. 1981, Rodriguez & Vives 1984, Regner 1987, Siokou-Frangou et al. 1990a).

In their studies in the Gulf of Fos, Benon et al. (1977) and Patriti (1984) found that Acartiidae and Oithonidae dominated ports and semi-enclosed areas. They also reported that under certain conditions cladocerans became dominant. In the Gulf of Thermaikos the low number of species, resulting in low diversity index values, as well as the absence of carnivorous species (Corycaidae, Oncaeidae, chaetognaths) reflects the perturbation of the zooplankton communities in this area. Comparable results have been found in other areas affected by pollution (Specchi et al. 1981).

Furthermore, *k*-dominance curves seemed to strengthen the argument that pollution affects the structure of the zooplankton communities in the northern part of the Gulf, since diversity was significantly lower at the northern stations during December and September. Stations located off the river mouths indicated intermediate diversity, depending on the sampling period, while the southern stations was definitely more diverse than the others. An interesting feature during May was that all the examined stations showed generally the same species diversity, independent of geographical position.

At stations located seaward of the estuaries (F, D) the zooplankton community was composed by the above opportunistic species. In addition, less tolerant species and/or groups, like *Paracalanus parvus, Centropages* *typicus*, *Temora stylifera* and *Evadne spinifera*, appendicularians, siphonophores and chaetognaths, could be found. These less tolerant species have been found also elsewhere in similar situations (EPOPEM 1979, Arfi et al. 1981). In addition the environmental regime of mixed fresh and saline waters favours the presence of crustacean larvae, especially during May, as these are probably reproduction grounds. Results of the multivariate techniques showed that Stn F was always associated to the northern part and this is probably related to its position in the exit of the Gulf of Thessaloniki and off the river estuaries. In contrast, Stn D was associated either to the southern stations (December, September) or to Stn F with lower similarity to the northern stations (May). Based on the graphical descriptors the communities at that station were quite diversified. Ordination results consistently showed a gradient from the nothern stations to the southern stations, with the x-axis representing the pollution gradient based on nutrient and dissolved oxygen values presented by Ganoulis et al. (1988) Salinity, on the other hand, did not vary significantly between northern and southern stations. The behaviour and community composition of the central stations should very much depend on the hydrology and water circulation, which is responsible for the dispersion of pollutants.

Results also showed that the zooplankton communities at the southern stations were quite different from those in the north. The observed higher diversity index values and the k-dominance curves reflect a well-diversified population where many neritic species like *Clausocalanus furcatus*, *C. jobei*, *C. pergens*, *Oncaea media*, *Corycella rostrata* and *Corycaeus giesbrechti* are present. The presence of these species in the north Aegean Sea (Moraitou-Apostolopoulou 1972, Siokou-Frangou & Akepsimaides 1986, Siokou-Frangou et al. 1990b, Siokou-Frangou et al. in press) suggests an influence of the north Aegean Sea on the environment of the Gulf of Thermaikos. This influence extends northwards along the eastern coast of the Gulf, as the zooplankton composition of Stn E was similar to that of southern stations and, should be attributed to the water circulation in the area (Balopoulos 1985). The latter does not permit the diffusion of pollutants into this area, and these are therefore restricted to the northern stations. The influence of water circulation upon the impact of pollution on zooplanktonic communities has been previously reported for the Saronikos Gulf; this receives a similar load of waste discharges but the zooplankton communities are not disturbed to any great extent, due to the diffusion of pollutants by the intense water circulation (Siokou-Frangou et al. 1990a).

Similar spatial discrimination was revealed when studying the benthic communities of the Gulf of Thermaikos, which were differentiated according to organic enrichment (Zarkanellas & Katoulas 1982).

Thus, it is evident that the impact of pollution upon the zooplankton distribution and composition depends on the combination of several environmental factors in the study area including the morphology, the hydrology and the river effluents. The simultaneous use of univariate and multivariate techniques permitted the interpretation and confirmation of the results.

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