Differentiation of zooplankton communities in two neighbouring shallow areas

Ioanna Siokou-Frangou[1], George Verriopoulos[2], Constantin Yannopoulos[2] & Maria Moraitou-Apostolopoulou[2]
1. *National Centre for Marine Research, GR-16604 Hellenikon, Athens, Greece*
2. *Zoological Laboratory, University of Athens, GR-15874 Athens, Greece*

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Abstract

The annual cycle of zooplankton species composition was studied during two years in two shallow areas of Saronikos Gulf (Greece). Elefsis Bay is a semi-enclosed area receiving a large volume of domestic and industrial effluents. The Metopi area is located in the centre of Saronikos Gulf far away from the pollution sources. In Elefsis Bay the annual cycle was characterized by the extreme dominance of *Acartia clausi* during the January–May period of both years, while changes occurred during the summer–autumn period as four assemblages were distinguished according to the hierarchical clustering. In the Metopi area species composition was different from that in Elefsis Bay: the winter assemblage was characterized by *Clausocalanus pergens, Ctenocalanus vanus*, the summer one by *Penilia avirostris, Temora stylifera, Clausocalanus furcatus*, the autumn by *Oncaea media, Oithona plumifera* and *Paracalanus parvus*, while during spring three assemblages were distinguished. Correspondence analysis revealed that the seasonal evolution of the community in the Metopi area can be related to temperature as well as to the influence of the open sea, while the above influences were not obvious in the Elefsis Bay community. Rank-frequency diagrams and diversity index values showed a well-structured community in the Metopi area and a disturbed community in Elefsis Bay. Differences of these two communities could be attributed to pollution impact affecting them differently, coupled with the topography of the area.

Keywords: zooplankton, shallow, species assemblages, Eastern Mediterranean.

Introduction

The morphology of Saronikos Gulf (islands and peninsulas) results in the distinction of four major sectors: the inner gulf with a mean depth of 80 m, the outer one with a mean depth of 150 m, the western basin with depths varying between 80 and 400 m and Elefsis Bay with maximum depth of 30 m. Elefsis Bay is a semi-enclosed area, communicating through a western channel, 8 m deep, with the western basin and through an eastern channel, 12 m deep, with the inner gulf. According to Yannopoulos & Yannopoulos (1973) and Hopkins & Coachman (1975), Saronikos Gulf is differentiated hydrologically. Four different water masses have been distinguished, corresponding to the sectors mentioned above. Elefsis Bay water mass has a renewal time of about seven months while the time scale in the inner gulf is of the order of one month and about two months or longer for the upper layer of the western basin (Hopkins & Coachman 1975). The outer Saronikos Gulf communicates with the Aegean Sea which provides source water to Saronikos Gulf. During the winter period, the vertical mixing of the water column and the low differences of water density in the horizontal scale, facilitate the movement of the gulf water masses as a result of the influence of the wind or the general circulation of the Aegean Sea (Christianidis 1991).

Elefsis Bay receives industrial pollution along its northern shore and domestic wastes through the eastern channel from the metropolitan Athens sewage effluent. As a result, high levels of nutrients are detected in the bay (Friligos 1981), leading to phytoplankton blooms (Ignatiades 1983). In the western basin of Saronikos Gulf a shallow area (17 m) exists between the Aegina and Metopi Islands (Figure 1). The level of nutrients and chlorophyll-*a* values in the area indicate an oligotrophic character (Ignatiades 1983). Seasonal changes of temperature and salinity depth integrated values at both areas are presented in Figure 2. The annual cycle and the structure of zooplankton were studied in these two areas in order to assess differences and/or similarities.

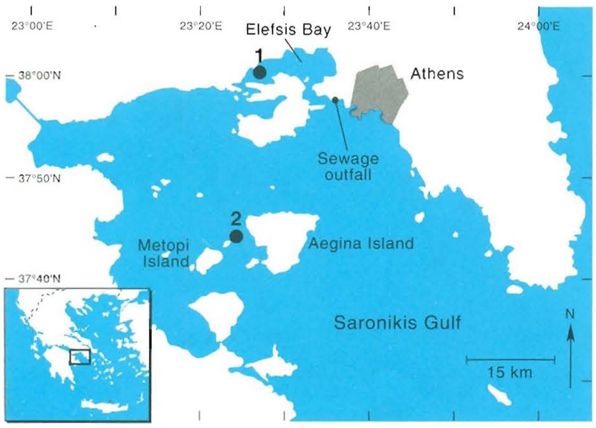

Figure 1.
Positioning of sampling stations.

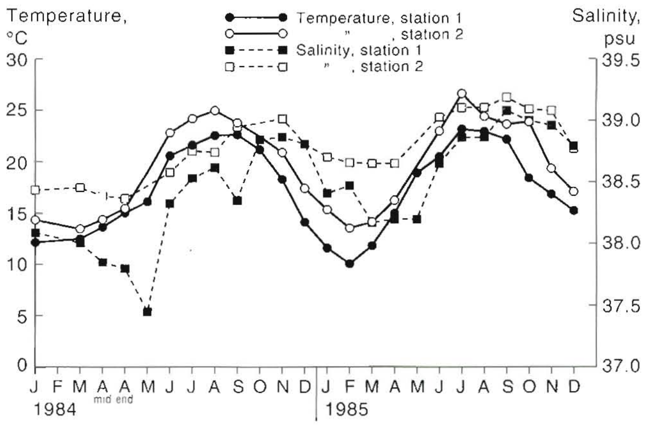

Figure 2.
Variations of temperature and salinity depth integrated values at station 1 and station 2 (data from Barbetseas 1986).

Materials and methods

Zooplankton samples were collected monthly from January 1984 to December 1985 at two stations, one in Elefsis Bay (station 1) and the other one in the Metopi area (station 2). Samples were not collected in February 1984 at both stations nor in May 1984, October 1984 and in May 1985 at the Metopi station. Sampling was performed by oblique hauls in the 0-20-m layer at the Elefsis station and in the 0-15-m layer at the Metopi station, using a WP-2 net (200 µm mesh size). The average volume of the filtered water was 60 m^3 at the Elefsis Bay and 54 m^3 at the Metopi station. Species identification concerned copepods, cladocerans and appendicularians and specimen counts were made in aliquots varying from $\frac{1}{10}$ to $\frac{1}{2}$ of each sample. In order to study the annual cycle of zooplankton, correspondence analysis was performed on the samples · species data matrix of each station (Benzecri *et al.* 1973). Ascending hierarchical clustering based on the x^2 distance was used (Laurec 1979) for the discrimination of species assemblages. In order to assess faunal similarities between areas, non-metric multi-dimensional scaling (MDS) was employed according to Field *et al.* (1982) and classification of samples was performed (Clarke & Green 1988). The raw data, expressed as number of individuals per m^3 were transformed: $y_{ij} = sq\,(x_{ij})$. The average-linkage clustering technique was used based on the Bray-Curtis similarity matrix. The species diversity of the community was estimated according to the Shannon-Wiener diversity index (Shannon & Weaver 1963) and dominance was calculated according to the formula described by Hulburt (1963). The evolution of zooplankton community structure was studied using the rank-frequency diagrams (Frontier 1985).

Results

The total zooplankton abundance fluctuated temporally and these fluctuations varied between areas (Figure 3). Maximum densities were recorded in Elefsis Bay in January 1984 (7460 ind. · m^{-3}) and in the period February (19 090 ind. · m^{-3}) to April 1985. Exceptional high abundances were also recorded during September 1984 (8021 ind. · m^{-3}). Lower values were registered during summer and autumn. In the Metopi area lower density values were found in the autumn–winter period and higher valves during spring (3228 ind. · m^{-3} in March 1985) and summer (3819 ind. · m^{-3} in July 1985). The mean density value in the Metopi area was lower (1053 ind. · m^{-3}) than in Elefsis Bay (3061 ind. · m^{-3}).

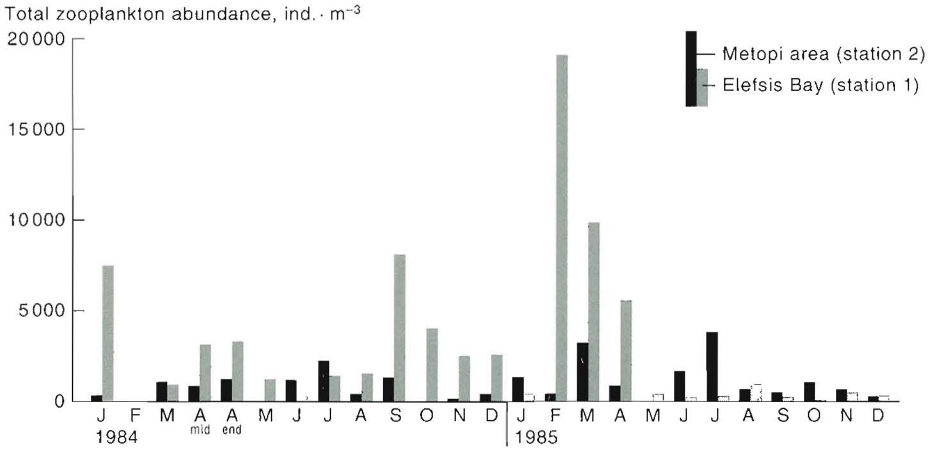

Figure 3.
Fluctuations of total zooplankton abundance in Elefsis Bay (st. 1) and the Metopi area (st. 2).

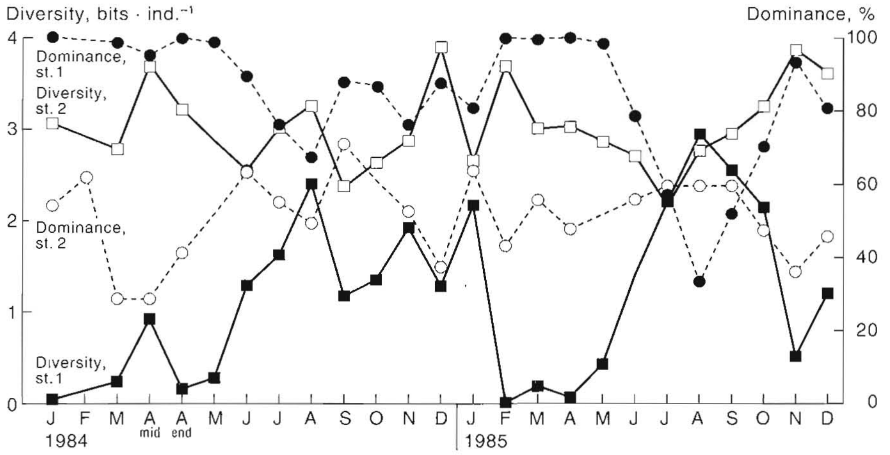

Figure 4.
Fluctuations of species diversity and dominance index at both stations.

A total of 59 species was found in Elefsis Bay; in many samples the relative abundance of the first species exceeded 50% of the total zooplankton numbers resulting in very low diversity values (0.045-2.94 bits · ind.$^{-1}$) and very high dominance values (33.49-99.79%), mainly during the winter–spring period (Figure 4). During the summer–autumn period, zooplankton was more diversified . This is also obvious from the rank-frequency diagrams (Figure 5): almost rectilinear in winter–spring and slightly curved during summer months. Dominant species abundace and relative

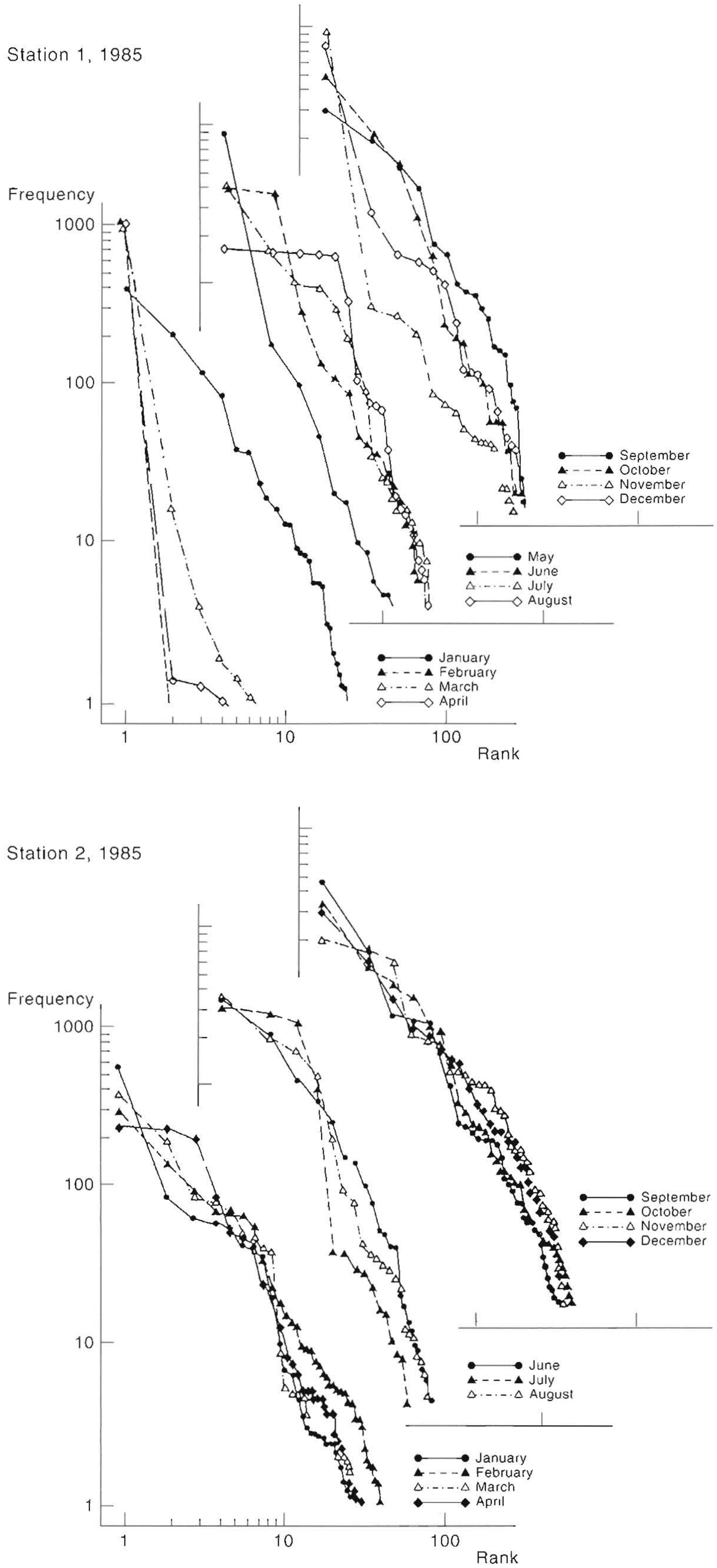

Figure 5.
Rank-frequency diagrams at both stations.

abundance fluctuations are given in Table 1. The copepod *Acartia clausi* dominated during the period January–May 1984 and February–May 1985: its density varied between 285 and 19 019 ind. · m^{-3} while this species represented more than 90% of the zooplankton. Among the other species the presence of the copepods *Oithona nana* and *Isias clavipes* and the cladoceran *Evadne nordmanni* was quite important.

1984	January		March		Mid April		End April		May		June	
	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%
Acartia clausi	7413.8	99.38	852.1	96.43	2440.0	76.50	3216.7	97.10	1145.9	94.95	16.3	9.68
Acartia latisetosa	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Centropages ponticus	0.0	0.00	0.0	0.00	1.5	0.05	0.0	0.00	0.0	0.00	0.0	0.00
Oithona nana	0.0	0.00	0.8	0.09	313.2	9.82	2.7	0.08	0.6	0.05	7.1	4.25
Paracalanus parvus	0.0	0.00	0.1	0.01	0.0	0.00	4.7	0.14	3.9	0.33	1.7	1.00
Temora stylifera	0.0	0.00	0.0	0.00	0.5	0.02	0.0	0.00	0.0	0.00	1.1	0.65
Evadne tergestina	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.3	0.21
Penilia avirostris	0.0	0.00	0.0	0.00	0.6	0.02	0.0	0.00	0.0	0.00	125.4	74.68
Podon polyphemoides	13.0	0.17	0.0	0.00	11.3	0.35	0.0	0.00	17.3	1.44	0.3	0.17
Appendicularia sicula	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.1	0.06
Fritillaria haplostoma	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Oikopleura dioica	0.0	0.00	0.4	0.05	11.8	0.37	0.0	0.00	1.1	0.09	1.2	0.69
Larv. Decapoda	5.6	0.08	5.4	0.61	5.5	0.17	9.5	0.29	19.1	1.58	7.8	4.66
Larv. Gastropoda	0.0	0.00	0.6	0.07	25.9	0.81	0.0	0.00	0.1	0.01	1.0	0.62
Larv. Lamellibranchia	0.7	0.01	0.0	0.00	11.2	0.35	2.3	0.07	0.4	0.04	0.2	0.12
Larv. Polychaeta	6.3	0.08	1.8	0.21	216.5	6.79	16.2	0.49	0.3	0.03	0.0	0.00

1984	July		August		September		October		November		December	
	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%
Acartia clausi	483.8	34.52	219.5	15.15	861.7	10.74	357.2	9.03	180.8	7.36	288.5	11.21
Acartia latisetosa	0.0	0.00	12.0	0.83	100.2	1.25	109.2	2.76	23.9	0.97	1.4	0.06
Centropages ponticus	0.0	0.00	34.5	2.38	115.9	1.44	1.5	0.04	5.3	0.22	0.6	0.02
Oithona nana	5.5	0.40	5.1	0.35	1.1	0.01	0.0	0.00	1.0	0.04	0.0	0.00
Paracalanus parvus	0.6	0.04	7.3	0.51	63.1	0.79	4.3	0.11	37.7	1.54	11.8	0.46
Temora stylifera	0.9	0.06	119.2	8.23	4.6	0.06	1.3	0.03	3.3	0.14	1.5	0.06
Evadne tergestina	322.3	22.99	435.4	30.06	678.6	8.46	638.6	16.14	295.0	12.01	9.5	0.37
Penilia avirostris	577.3	41.19	496.6	34.28	6174.1	76.97	2795.2	70.67	1394.4	56.77	1763.5	68.53
Podon polyphemoides	0.9	0.06	0.0	0.00	0.0	0.00	40.0	1.01	441.0	17.95	492.3	19.13
Appendicularia sicula	0.1	0.00	0.1	0.01	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Fritillaria haplostoma	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Oikopleura dioica	0.3	0.02	1.3	0.09	0.0	0.00	0.0	0.00	40.0	1.63	0.7	0.03
Larv. Decapoda	5.2	0.37	44.1	3.05	9.0	0.11	1.5	0.04	3.2	0.13	0.0	0.00
Larv. Gastropoda	1.0	0.07	1.2	0.08	6.1	0.08	0.0	0.00	3.7	0.15	0.0	0.00
Larv. Lamellibranchia	0.3	0.02	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Larv. Polychaeta	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00

1985	January		February		March		End April		May		June	
	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%
Acartia clausi	143.3	39.09	19019.6	99.63	9638.1	97.12	5491.1	99.15	285.4	89.92	45.8	37.65
Acartia latisetosa	2.7	0.74	3.4	0.02	2.5	0.03	0.0	0.00	0.0	0.00	0.0	0.00
Centropages ponticus	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Oithona nana	3.1	0.84	3.4	0.02	1.0	0.01	2.4	0.04	0.0	0.00	1.2	0.95
Paracalanus parvus	12.9	3.52	4.6	0.02	18.7	0.19	5.7	0.10	13.3	4.20	0.9	0.75
Temora stylifera	0.5	0.14	0.0	0.00	0.0	0.00	0.3	0.01	0.4	0.12	0.5	0.44
Evadne tergestina	0.0	0.01	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	2.5	2.08
Penilia avirostris	0.0	0.00	0.6	0.00	0.0	0.00	0.0	0.00	0.1	0.02	3.7	3.06
Podon polyphemoides	72.3	19.71	4.4	0.02	1.1	0.01	0.0	0.00	0.0	0.00	1.0	0.79
Appendicularia sicula	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Fritillaria haplostoma	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Oikopleura dioica	6.6	1.81	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.4	0.35
Larv. Decapoda	2.0	0.55	11.7	0.06	10.6	0.11	5.2	0.09	7.4	2.33	50.0	41.12
Larv. Gastropoda	8.1	2.22	0.4	0.00	0.6	0.01	1.0	0.02	0.2	0.07	8.3	6.81
Larv. Lamellibranchia	43.4	11.83	1.1	0.01	3.3	0.03	4.2	0.08	1.3	0.42	3.0	2.44
Larv. Polychaeta	30.1	8.21	15.9	0.08	38.4	0.39	2.0	0.04	0.4	0.14	0.7	0.60

1985	July		August		September		October		November		December	
	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%	Ab.	%
Acartia clausi	89.6	42.06	0.0	0.00	3.7	2.33	0.0	0.00	1.2	0.26	0.0	0.00
Acartia latisetosa	10.1	4.75	136.1	15.52	3.9	2.50	0.0	0.00	0.0	0.00	0.0	0.00
Centropages ponticus	21.0	9.86	69.0	7.88	50.7	32.29	2.8	5.72	2.0	0.43	0.0	0.00
Oithona nana	0.2	0.08	21.8	2.49	0.0	0.00	0.5	1.03	1.1	0.25	0.7	0.26
Paracalanus parvus	21.9	10.26	8.1	0.93	3.4	2.18	0.0	0.07	7.1	1.54	4.0	1.43
Temora stylifera	15.5	7.27	138.6	15.82	31.2	19.86	0.3	0.57	1.2	0.27	1.7	0.61
Evadne tergestina	1.2	0.56	140.7	16.06	1.6	1.00	0.0	0.09	1.1	0.25	0.2	0.08
Penilia avirostris	0.8	0.36	3.5	0.40	0.6	0.41	0.0	0.00	0.0	0.00	0.0	0.00
Podon polyphemoides	1.8	0.84	150.5	17.18	22.6	14.41	23.5	48.39	424.6	91.56	202.5	73.06
Appendicularia sicula	0.0	0.00	142.9	16.31	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Fritillaria haplostoma	0.0	0.00	0.0	0.00	0.0	0.00	10.6	21.74	8.0	1.73	0.0	0.00
Oikopleura dioica	0.2	0.08	0.2	0.03	0.0	0.00	0.2	0.34	1.8	0.39	0.0	0.00
Larv. Decapoda	33.4	15.69	15.1	1.72	15.8	10.05	0.7	1.37	2.3	0.49	6.7	2.42
Larv. Gastropoda	4.8	2.25	14.4	1.64	2.5	1.57	0.2	0.34	5.5	1.18	10.9	3.92
Larv. Lamellibranchia	0.1	0.03	0.0	0.00	0.0	0.00	0.0	0.00	0.7	0.14	9.7	3.5
Larv. Polychaeta	0.3	0.16	4.0	0.45	0.7	0.44	1.6	3.32	0.7	0.14	0.7	0.26

Table 1.
Fluctuations of dominant species and groups abundance, ind.· m^{-3} (Ab.) and relative abundance (%) at Elefsis Bay.

In the period June–December 1984 the cladoceran *Penilia avirostris* was the most abundant species (125-6174 ind. · m^{-3} and 41.19-76.97%). It was accompanied by the cladoceran *Evadne tergestina* (max. 30% in August), the copepod *A. clausi*, the cladoceran *Podon polyphemoides* (max. 19% in December) and small numbers of the copepods *Temora stylifera, Paracalanus parvus, Centropages ponticus* and *Clausocalanus furcatus*. In January 1985 *A. clausi* and the cladoceran *P. polyphemoides* were abundant, while the presence of meroplanktonic larvae was important (lamellibranchs 11.83% and polychaetes 8.21%). The abundance of *A. clausi* was lower in June and July 1985 than the previous months and zooplankton was also dominated by the copepods *Acartia latisetosa, P. parvus, T. stylifera, C. ponticus* and decapod and gastropod larvae. In August and September 1985 copepod species (*T. stylifera, C. ponticus, A. latisetosa*), cladocerans (*P. polyphemoides, E. tergestina*) and the appendicularian *Appendicularia sicula* were abundant. During the last three months of 1985 the zooplankton was dominated by the cladoceran *P. polyphemoides* (max. 424 ind. · m^{-3} and

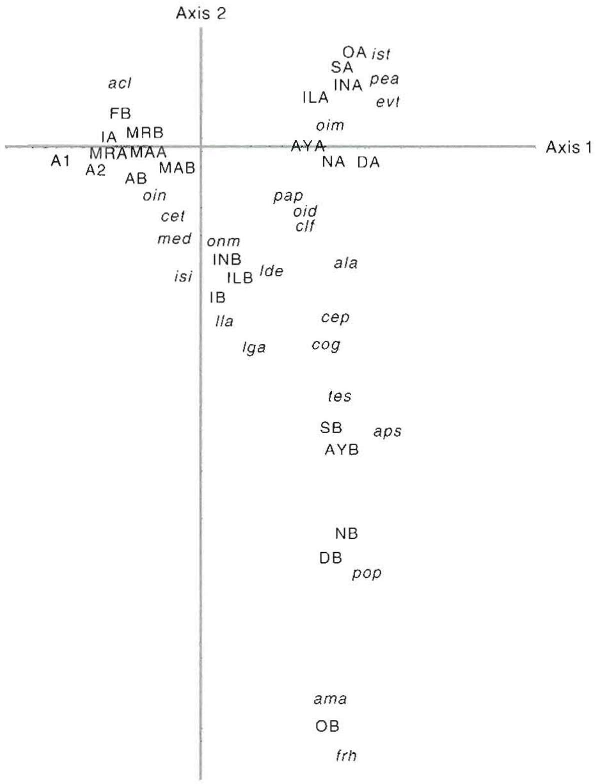

Figure 6.
Correspondence analysis (1 · 2 plane) of data collected in Elefsis Bay (st. 1).
IA = January 1984;
IB = January 1985;
FB = February 1985;
MA = March 1984;
MB = March 1985;
A1 = mid April 1984;
A2 = end April 1984;
AB = April 1985;
MAA = May 1984;
MAB = May 1985;
INA = June 1984;
INB = June 1985;
ILA = July 1984;
ILB = July 1985;
AYA = August 1984;
AYB = August 1985;
SA = September 1984;
SB = September 1985;
OA = October 1984;
OB = October 1985;
NA = November 1984;
NB = November 1985;
DA = December 1984;
DB = December 1985.
acl = *A. clausi;*
ala = *A. latisetosa;*
ama = *A. margalefi;*
ane = *A. negligens;*
aps = *A. sicula;*
cap = *C. pavo;*
cav = *C. pavoninus;*
cet = *C. typicus;*
cep = *C. ponticus;*
cha = chaetognaths;
che = *C. helgolandicus;*
cla = *C. arcuicornis;*
clf = *C. furcatus;*
clj = *C. jobei;*
clp = *C. pergens;*
cog = *C. giesbrechti;*
ctv = *C. vanus;*
dol = doliolids;
evn = *E. nordmanni;*
evs = *E. spinifera;*
evt = *E. tergestina;*
far = *F. rostrata;*
frh = *F. haplostoma;*
frp = *F. pellucida;*
isi = *I. clavipes;*
ist = *I. tenuis;*
lde = L. decapods;
lga = L. gastropods;
lla = L. lamellibranchs;
lpo = L. polychaetes;
mte = *M. tenuicornis;*
med = medusae;
nmi = *N. minor;*
oid = *O. dioica;*
oil = *O. longicauda;*
oim = *O. mediterranea;*
oin = *O. nana;*
ois = *O. similis;*
oip = *O. plumifera;*
onm = *O. media;*
pap = *P. parvus;*
pea = *P. avirostris;*
poi = *P. intermedius;*
pop = *P. polyphemoides;*
pte = pteropods;
sal = salps;
sip = siphonophores;
tes = *T. stylifera.*

91% in November) and among the other species the presence of the copepods *Acartia margalefi, P. parvus* and *C. ponticus* and of the appendicularian *Fritillaria haplostoma* was important.

The above fluctuations of species composition in Elefsis Bay are also obvious in the first two axes plane of the correspondence analysis, which accounted for 35.6 and 19% of the total variance (Figure 6). Samples of the January–May 1984 period and of February–May 1985 are projected very closely and are also in close vicinity to *A. clausi* indicating similar zooplankton composition during this period. This species characterizes the winter–spring assemblage in both years, accompanied by the species *E. nordmanni, Mesocalanus tenuicornis, Clausocalanus pergens, Euterpina acutifrons* and *Podon intermedius*. The distance observed between the May and June 1984 samples indicates a great change in zooplankton composition due to the appearance of *P. avirostris*, found in high abundance values. This species characterizes the assemblage of summer–autumn 1984, accompanied by *Evadne tergestina, Ischnocalanus tenuis, Oikopleura mediterranea* and *Oikopleura dioica*. Samples of the period June–December 1984 are projected closely to each other, suggesting small changes in composition, while a greater difference occurred in January 1985 due to the reappearance of *A. clausi* and the abundance of meroplanktonic larvae (bivalves and polychaetes) and medusae (*Aurelia aurita* ephyrae). June and July 1985 samples are projected close to January 1985 due to the similarity in community composition (*A. clausi* and meroplanktonic larvae) creating a new assemblage. Another assemblage is distinguished for August–September 1985, characterized by *C. ponticus* and *T. stylifera* which are accompanied by the copepods *A. latisetosa, Corycaeus giesbrechti* and the appendicularian *Appendicularia sicula*. Finally the appearance in abundance of *P. polyphemoides* in October 1985 differentiates the zooplankton assemblage composed by this species together with the copepod *Acartia margalefi* and the

	Jan. 84 Ab.	%	Mar. 84 Ab.	%	Mid Apr. 84 Ab.	%	End Apr. 84 Ab.	%	June 84 Ab.	%	July 84 Ab.	%	Aug. 84 Ab.	%
Nannocalanus minor	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.6	0.02	0.4	0.14
Calocalanus pavoninus	0.0	0.00	0.5	0.05	4.0	0.51	11.8	1.00	0.4	0.03	0.8	0.04	0.3	0.08
Centropages typicus	7.8	2.95	57.6	5.23	125.2	15.75	130.1	11.00	16.1	1.42	0.2	0.01	0.0	0.00
Clausocalanus furcatus	2.6	0.97	0.0	0.00	0.0	0.00	1.3	0.11	99.1	8.75	316.1	14.27	21.0	6.65
Clausocalanus jobei	0.0	0.00	4.3	0.39	1.0	0.12	0.0	0.00	0.1	0.01	0.0	0.00	8.1	2.58
Clausocalanus pergens	97.2	36.85	75.9	6.89	55.6	7.00	48.9	4.14	0.0	0.00	0.0	0.00	0.0	0.00
Ctenocalanus vanus	33.2	12.60	78.9	7.16	85.7	10.78	200.3	16.93	0.1	0.01	0.0	0.00	0.3	0.10
Oithona similis	2.5	0.96	2.4	0.22	91.6	11.52	8.8	0.74	2.6	0.23	5.2	0.23	1.7	0.53
Oithona plumifera	40.9	15.50	8.9	0.81	6.9	0.86	11.1	0.94	37.4	3.30	30.8	1.39	19.5	6.19
Oncaea media	0.8	0.30	25.5	2.31	10.6	1.33	13.7	1.16	11.0	0.97	38.9	1.76	2.2	0.70
Paracalanus parvus	14.5	5.49	19.2	1.74	70.8	8.91	219.8	18.58	5.4	0.48	55.0	2.48	0.7	0.23
Temora stylifera	5.5	2.08	11.9	1.08	1.1	0.13	5.0	0.42	78.5	6.93	522.6	23.60	78.8	24.96
Evadne nordmanni	0.4	0.16	547.6	49.69	54.5	6.86	133.0	11.25	0.0	0.00	0.0	0.00	0.0	0.00
Evadne spinifera	0.7	0.28	5.7	0.52	47.9	6.02	246.1	20.80	88.9	7.85	27.4	1.24	61.6	19.50
Evadne tergestina	1.3	0.51	1.5	0.14	0.0	0.00	0.0	0.00	2.7	0.24	57.4	2.59	3.5	1.10
Penilia avirostris	0.0	0.02	0.7	0.06	0.0	0.00	1.4	0.12	577.1	50.94	636.3	28.73	31.8	10.09
Fritillaria pellucida	9.2	3.48	33.5	3.04	0.0	0.00	0.3	0.03	0.0	0.00	0.0	0.00	0.0	0.00
Oikopleura longicauda	0.0	0.00	1.2	0.11	1.7	0.21	3.1	0.26	67.9	6.00	164.2	7.41	28.4	9.00
Doliolidae	0.9	0.36	30.0	2.72	4.8	0.60	0.0	0.00	47.9	4.23	33.7	1.52	11.6	3.67

	Sep. 84 Ab.	%	Nov. 84 Ab.	%	Dec. 84 Ab.	%	Jan. 85 Ab.	%	Feb. 85 Ab.	%	Mar. 85 Ab.	%	Apr. 85 Ab.	%
Nannocalanus minor	4.4	0.36	2.8	5.89	6.9	1.87	3.9	0.28	7.7	1.77	0.0	0.00	10.2	1.32
Calocalanus pavoninus	0.5	0.04	0.0	0.00	4.8	1.30	9.1	0.66	4.0	0.93	0.7	0.02	1.0	0.13
Centropages typicus	0.3	0.02	0.1	0.21	0.2	0.06	6.4	0.46	14.6	3.35	113.0	3.50	176.2	22.70
Clausocalanus furcatus	505.3	41.59	16.1	34.41	80.8	21.84	47.4	3.42	2.3	0.52	0.0	0.00	0.5	0.06
Clausocalanus jobei	4.8	0.39	0.7	1.43	18.6	5.01	56.2	4.06	9.9	2.28	9.1	0.28	18.0	2.32
Clausocalanus pergens	0.0	0.00	0.1	0.14	0.0	0.00	77.5	5.60	121.2	27.83	151.8	4.70	0.7	0.09
Ctenocalanus vanus	0.2	0.02	0.1	0.24	33.8	9.12	83.6	6.04	23.7	5.45	239.7	7.42	58.8	7.58
Oithona similis	0.0	0.00	0.0	0.00	4.6	1.24	72.8	5.26	57.8	13.27	1150.7	35.64	38.5	4.97
Oithona plumifera	2.0	0.16	6.9	14.68	27.7	7.48	26.8	1.94	27.3	6.27	148.0	4.58	38.8	4.99
Oncaea media	102.6	8.44	7.1	15.05	23.7	6.40	51.7	3.74	28.2	6.47	211.2	6.54	3.7	0.47
Paracalanus parvus	4.0	0.33	3.8	8.17	43.4	11.73	755.6	54.58	38.7	8.89	590.3	18.28	148.7	19.17
Temora stylifera	68.0	5.60	0.3	0.62	5.3	1.42	9.4	0.68	2.4	0.56	6.5	0.20	3.8	0.48
Evadne nordmanni	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	6.8	0.21	176.9	22.80
Evadne spinifera	273.0	22.47	0.1	0.17	0.0	0.00	0.0	0.00	0.0	0.00	0.7	0.02	0.0	0.00
Evadne tergestina	28.1	2.32	0.0	0.00	0.3	0.07	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Penilia avirostris	1.1	0.09	4.2	8.99	2.2	0.59	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Fritillaria pellucida	0.0	0.00	0.0	0.02	3.6	0.96	0.1	0.00	4.2	0.97	2.9	0.09	0.0	0.00
Oikopleura longicauda	66.7	5.49	0.0	0.00	13.7	3.70	2.0	0.14	0.8	0.19	7.7	0.24	0.0	0.00
Doliolidae	39.4	3.25	0.0	0.00	11.8	3.19	0.7	0.05	1.0	0.23	2.3	0.07	1.1	0.14

	June 85 Ab.	%	July 85 Ab.	%	Aug. 85 Ab.	%	Sep. 85 Ab.	%	Oct. 85 Ab.	%	Nov. 85 Ab.	%	Dec. 85 Ab.	%
Nannocalanus minor	5.6	0.35	0.3	0.01	0.3	0.05	6.1	1.34	60.2	6.22	17.3	2.85	3.9	1.22
Calocalanus pavoninus	0.3	0.02	0.0	0.00	0.0	0.00	10.8	2.40	51.7	5.34	15.5	2.54	11.0	3.49
Centropages typicus	20.1	1.25	0.2	0.00	0.0	0.00	0.3	0.08	1.6	0.16	0.5	0.09	1.3	0.40
Clausocalanus furcatus	130.5	8.13	1205.5	31.57	124.1	20.02	194.7	43.16	325.1	33.62	102.6	16.86	46.6	14.77
Clausocalanus jobei	15.9	0.99	0.0	0.00	0.4	0.07	2.0	0.45	32.0	3.31	27.7	4.56	4.1	1.29
Clausocalanus pergens	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.4	0.04	0.1	0.02	1.6	0.51
Ctenocalanus vanus	1.0	0.06	0.0	0.00	0.0	0.00	0.1	0.03	12.1	1.25	26.7	4.38	15.8	5.02
Oithona similis	0.2	0.01	1.8	0.05	0.1	0.02	5.0	1.10	6.4	0.66	15.1	2.47	13.8	4.38
Oithona plumifera	54.1	3.37	14.0	0.37	1.2	0.20	73.3	16.25	130.8	13.53	30.3	4.98	28.4	8.99
Oncaea media	15.6	0.97	9.4	0.25	0.9	0.15	3.8	0.85	8.1	0.84	13.8	2.26	18.0	5.69
Paracalanus parvus	178.9	11.15	1081.3	28.32	70.9	11.44	27.5	6.10	85.0	8.79	115.9	19.05	97.9	31.00
Temora stylifera	347.7	21.67	365.1	9.56	225.5	36.37	27.3	6.05	2.4	0.25	6.0	0.99	2.4	0.76
Evadne nordmanni	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Evadne spinifera	40.3	2.51	26.3	0.69	102.1	16.46	2.8	0.63	2.3	0.24	5.8	0.95	0.0	0.01
Evadne tergestina	8.1	0.51	2.8	0.07	29.1	4.70	29.2	6.47	13.1	1.36	18.1	2.97	0.4	0.13
Penilia avirostris	544.5	33.94	950.1	24.88	1.6	0.27	17.4	3.87	12.9	1.34	10.8	1.77	0.4	0.12
Fritillaria pellucida	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	6.9	0.71	86.0	14.13	0.0	0.01
Oikopleura longicauda	30.9	1.93	20.4	0.54	4.9	0.79	2.0	0.45	16.3	1.68	5.2	0.85	1.2	0.38
Doliolidae	96.0	5.98	33.3	0.87	13.7	2.21	5.3	1.18	100.8	10.43	15.1	2.47	1.0	0.31

Table 2. Fluctuations of dominant species and group abundance, ind · m^{-3} (Ab.) and relative abundance (%) at the Metopi area..

appendicularian *Fritillaria haplostoma*. This assemblage is observed also during November and December 1985. The evolution of the annual cycle of zooplankton composition was similar for both years only during the winter–spring period.

Winter–spring samples of both years and *A. clausi* have negative values on the first axis, versus the summer–autumn 1984-samples and *P. avirostris* which all have positive values. As these species contribute noticeably to the formation of this axis (26.5 and 51.3%, respectively), we can conclude that their antithetical presence creates the first axis. As for the second axis, it should be created by the species *P. polyphemoides* as it contributes to its formation by 44.2%.

Zooplankton composition was very different in the Metopi area as 97 species were enumerated. Diversity index values (Figure 4) were higher than in Elefsis Bay (min. 2.16 bits · ind.$^{-1}$ in July 1985, max. 3.87 bits · ind.$^{-1}$ in December 1984 and November 1985) and dominance values were respectively lower (min. 27.27% in mid April 1984, max. 64% in September 1984). Rank-frequency diagrams (Figure 5) were almost curved as zooplankton was rich in species. In only a few months, mainly during summer, a part of the diagram was rectilinear due to the predominance of one or two species.

As shown in Table 2, during January 1984 the copepods *Clausocalanus pergens* (mainly copepodites), *Oithona plumifera* and *Ctenocalanus vanus* were abundant. High abundance (548 ind. · m^{-3}) of the cladoceran *Evadne nordmanni* was observed in March representing 49.7% of zooplankton while the presence of *C. vanus, C. pergens, Centropages typicus* and the cladoceran *Podon intermedius* was important. The abundance of *E. nordmanni* decreased significantly in mid April while *C. typicus* was the most important species (15.75%), followed by *Oithona similis, C. vanus* and the appendicularian *Oikopleura fusiformis*. By the end of this month the cladoceran *Evadne spinifera* was dominant (20.80%) accompanied by *Paracalanus parvus, C. vanus* and *E. nordmanni*. In June, the period of *P. avirostris* dominance began varying between 10% and 50.94%. This species was accompanied by *C. furcatus, T. stylifera, E. spinifera* and the appendicularian *Oikopleura longicauda* whose abundance fluctuated temporally. *C. furcatus* dominated from September to December fluctuating between 21.84 and 41.59%. The presence of the copepods *Oncaea media, O. plumifera* and *P. parvus* was also important.

In January 1985 *P. parvus* was abundant (755 ind. · m^{-3}, 54.58%) while its presence decreased in February. During this month *C. pergens* dominated (27.83%) accompanied by *O. similis, O. plumifera* and *A. clausi*. The abundance of *O. similis* increased considerably in March (1150 ind. · m^{-3}, 35.64%) and the presence of *Calanus helgolandicus* was important. In April 1985 *C. typicus* and *E. nordmanni* reappeared as dominant species and were accompanied by *P. parvus, C. vanus* and *O. similis*. In June–July 1985, *P. avirostris* dominated the community and the presence of *T. stylifera, C. furcatus, P. parvus* and *E. spinifera* was important, while in August *T. stylifera* was the most abundant among the above species. A predominance of *C. furcatus* was observed in September–October (43 and 33.6%, respectively) and it was accompanied by *O. plumifera* and *P. parvus*. The latter was mainly abundant in November–December while the abundance of *C. furcatus* decreased and numbers of *O. plumifera, O. media,* and *Calocalanus pavoninus* increased.

The evolution of the annual cycle in the Metopi area is obvious on the first two axes plane of the correspondence analysis (Figure 7A) which accounted for 27 and 18% of the total variance. Changes in zooplankton composition were important and abrupt in the January–April period, while between June and December changes were insignificant. The evolution was quite similar in both years with the exception of samples collected during March. These two samples with the corresponding species (*E. nordmanni* for 1984 and *O. similis* for 1985) are opposite along the second

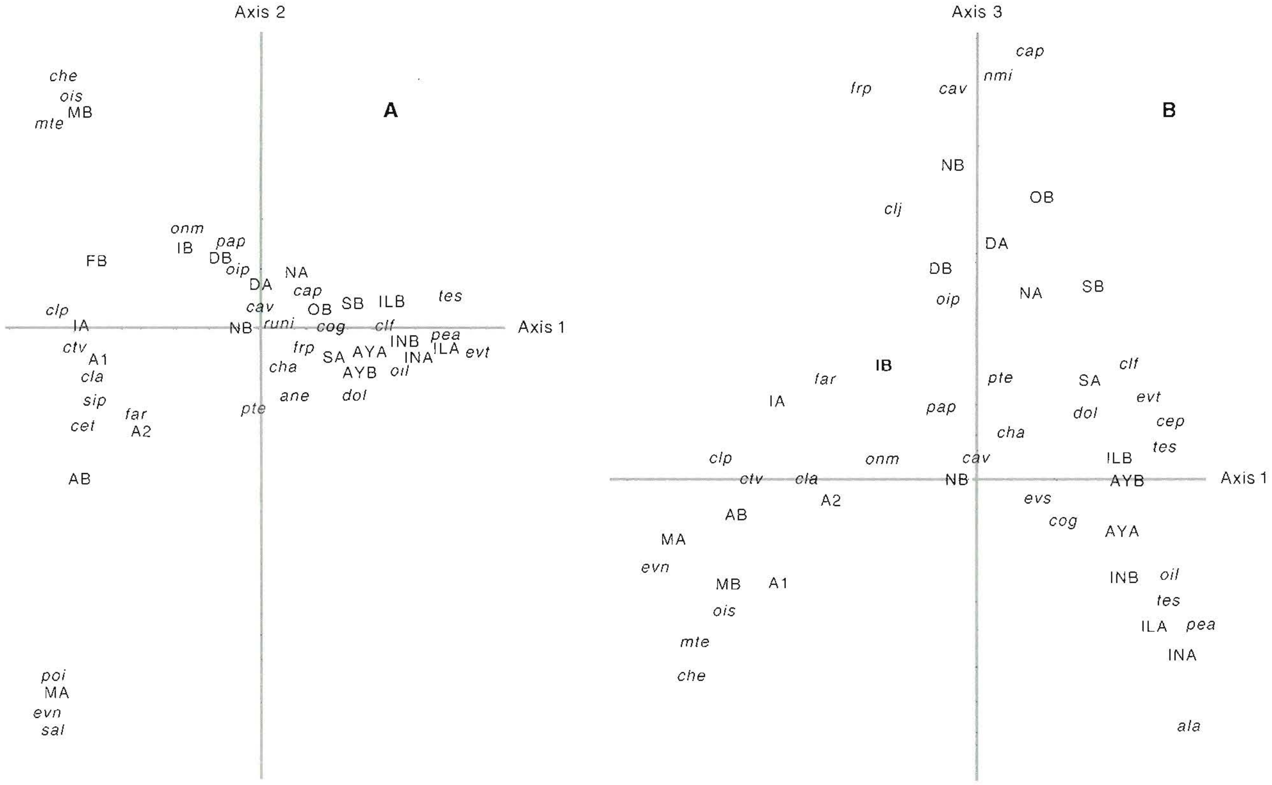

Figure 7.
A: correspondence analysis (1 · 2 plane) of data collected in Metopi area.
B: correspondence analysis (1 · 3 plane) of data collected in Metopi area.
Symbols as indicated in Figure 6.

axis, contributing significantly to its formation. As for the first axis, cold months (January–April) and the species *O. similis, E. nordmanni, C. pergens* and *C. vanus* are opposed to warm months (July–August) and the species *P. avirostris, T. stylifera* and *C. furcatus*, positioned along it. This axis should be related to the fluctuations in seawater temperature. The October, November and December samples, and the copepod species *C. furcatus, Nannocalanus minor, C. pavoninus, O. plumifera, Clausocalanus jobei* are opposed to the March, June, July samples and the species *P. avirostris, E. nordmanni, O. similis* and *T. stylifera* along the third axis (Figure 7B). In this case the axis should express the influence of the open sea since during autumn the influence of the open sea (N. Aegean Sea) is more intense in the Saronikos Gulf. As a result species having a mixed coastal-pelagic character (*C. furcatus, O. plumifera, N. minor, C. jobei, C. pavoninus*) are abundant.

According to the hierarchical clustering based on the x^2 distance, six assemblages of species are distinguished. The first is observed during January–February and is characterized by *C. pergens* and *C. vanus* which are accompanied by *A. clausi, C. arcuicornis, Candacia armata*. Three assemblages are distinguished in spring: one in March 1984 characterized by *E. nordmanni* accompanied by *Podon intermedius, C. pergens* and salps, the second in April of both years composed of the copepods *C. typicus, Farranula rostrata, Ischnocalanus tenuis* and siphonophores and the third in March 1985 with the copepods *O. similis, C. helgolandicus, Mesocalanus tenuicornis* and *Eucalanus crassus*. The summer assemblage is characterized by *P. avirostris, T. stylifera, C. furcatus* which are accompanied by *E. tergestina, C. ponticus, E. spinifera, A. latisetosa, O. longicauda*, doliolids and chaetognaths. *O. plumifera, P. parvus* and *O. media* are characteristic species of the autumn assemblage and they are accompanied by the copepods *Nannocalanus minor, Calocalanus pavo, Calocalanus pavoninus, Mecynocera clausi, Clausocalanus jobei*, the appendicularian *Fritillaria pellucida* and pteropods.

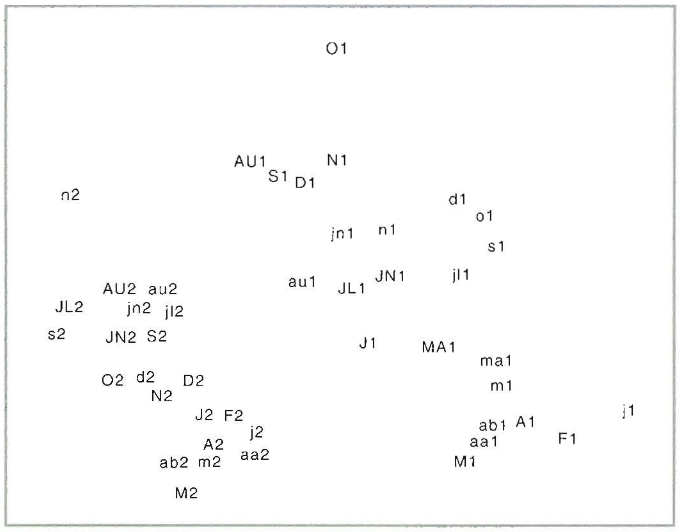

Figure 8.
MDS plot in two dimensions issued from both stations data analysis.
j = January;
f = February;
m = March;
aa = mid April 1984;
ab = end April 1984;
A = April 1985;
ma = May;
jn = June;
jl = July;
au = August;
s = September;
o = October;
n = November;
d = December;
small letters = samples 1984;
capital letters = samples 1985;
1 = station 1;
2 = station 2.

In order to assess faunal similarities between these two areas, an hierarchical clustering and a non-metric multi-dimensional scaling, based on the Bray-Curtis similarity, were performed on the total data. Samples from station 1 were separated from those of station 2 at the level of 25% similarity. In the MDS two-dimensions plot (stress 0.183) a clear difference is obvious (Figure 8) and grouping of samples is based on the hierarchical clustering results. Samples collected in the Metopi area are positioned close to each other. A seasonal differentiation can be observed: winter–spring, autumn, summer. The November 1984 sample is more differentiated due to the extremely low abundance of all present taxa. Samples from the Elefsis area are scattered suggesting seasonal and even annual differentiation: winter–spring of both years, summer–autumn 1984, and summer–autumn 1985. MDS seems therefore to verify the seasonal and annual differentiation observed with the correspondence analysis in each area.

Discussion

Seasonal fluctuations in the coastal areas of the Mediterranean Sea are more pronounced than in the open sea (Scotto di Carlo & Ianora 1983). Furthermore zooplankton fluctuations are abrupt in shallow waters of the temperate zone (Daan 1989, Garcia-Soto *et al.* 1990). According to Grahame (1976) seasonal variations are more intense inside port areas than outside. In the studied areas, Elefsis Bay and Metopi area, zooplankton abundance fluctuated suddenly, but in different periods: mainly during winter in Elefsis Bay and also in early autumn 1984, while in the Metopi area variations were important during summer and also in spring 1985. This difference is related to the species composition in each area. The extreme high values of zooplankton density in Elefsis Bay are due to the abundance of *Acartia clausi* which occurred in January–February. These high values are due to the eutrophic character of the area where high values of nutrients and phytoplankton are detected (Ignatiades 1983, Gotsis 1986, Friligos 1989). Furthermore, mixing events in this shallow area could facilitate the resuspension and hatching of the *A. clausi* resting eggs, resulting in a large increase in the numbers of this species. Winter maxima of zooplankton density and *A. clausi* abundance were observed during previous studies (Yannopoulos 1977, 1978) as well as during the years 1989-1990 (Siokou-Frangou 1991).

In Elefsis Bay the *A. clausi* abundance decreased in spring and even more in summer–autumn. Yannopoulos (1978) attributed the decrease of zooplankton biomass and *A. clausi* abundance during the 1971-1973 summer period to oxygen depletion and high temperature values, and also to pollutant factors in the area. During the present study a large population of the scyphomedusa *Aurelia aurita* was observed in late spring and summer of both years, which was responsible for the decrease of copepods due to predation by medusae (Papathanassiou *et al.* 1987, Panayotidis *et al.* 1988). Medusae seem to be almost the sole predator of copepods and cladocerans in the area, as other carnivore groups (chaetognaths, siphonophores) are absent. Möller (1980) reported that medusae and ctenophores could seriously decrease the zooplankton biomass by predation, while Lindahl & Hernroth (1983) consider the abundance of medusae as having an important influence on the structure of coastal planktonic communities.

A second maximum of zooplankton density occurred in Elefsis Bay only during September 1984, and it was due to the massive presence of *Penilia avirostris*. This species, as all the cladocerans, creates dense populations when environmental conditions are favourable. As for *A. clausi*, the small depth of the area facilitate the resuspension of the *P. avirostris* resting eggs and favours an increase of the population. The abundance of *P. avirostris* presents interannual fluctuations in Elefsis Bay, as very few individuals were found during 1985 and the following years (Siokou-Frangou 1991). The observed maximum did not correspond to high chlorophyll-*a* values (Gotsis 1986), suggesting the nutrition of *P. avirostris* by other food sources, autotrophic or heterotrophic. According to Turner *et al.* (1988) *P. avirostris* is able to feed upon bacterioplankton and heterotrophic nanoplankton and dominates even in oligotrophic environments. A seasonal differentiation of the food chain is reported by Urban *et al.* (1992) who observed that there is a succession from a diatom-based food chain in the winter and spring to one based on the microbial loop in the summer and autumn.

These food relationships could also explain the observed zooplankton maximum density values in the Metopi area, consisting mainly of *P. avirostris*, during July 1984 and 1985. Although two zooplankton maxima are reported in the Mediterranean Sea, one in spring and the second in autumn (Gaudy 1985), summer maxima with high numbers of cladocerans are also observed in coastal areas receiving anthropogenic influence: the Gulf of Naples (Scotto di Carlo *et al.* 1985), the Gulf of Malaga (Rodriguez 1983), the Bay of Palma (Fernandez-de Puelles & Jansa 1990), and the Saronikos Gulf (Siokou-Frangou 1991). The maximum values detected in March 1984, and even more in March 1985, correspond to the spring maximum as stated previously.

In both areas changes in the zooplankton composition were observed to be important, but the periods differed: the warm period for the polluted and eutrophic Elefsis Bay, the cold period for the unpolluted and oligotrophic Metopi area. These changes were clear along the second axis of the correspondence analysis and the seasonal assemblages were distinguished. Interannual differences in abundance of the relevant dominant species (*P. avirostris* and *P. polyphemoides* in Elefsis Bay, *E. nordmanni* and *O. similis* in Metopi area) were so strong that they created the second axis which could express differences between the years 1984 and 1985. The results of this study in combination with the observations of Yannopoulos (1978), Moraitou-Apostolopoulou & Ignatiades (1980) and Siokou-Frangou (1991), suggest that there are interannual fluctuations of zooplankton species composition in Elefsis Bay during the summer–autumn period, while during winter–spring the high dominance of *A. clausi* constitutes a constant component of the zooplankton community. At the Metopi station, interannual fluctuations concerned only March, where phytoplankton maximum values occurred (Gotsis 1986) and warming of the surface layer had already started compared to the rest of Saronikos Gulf. These environmental factors could be the cause of the increased population of *O. similis* since Krause & Trahms (1982) and Krause & Radach (1989) reported a concentration of copepodite and nauplii stages of this species in the surface layer of the North Sea with the beginning of thermal stratification of the water column and the spring phytoplankton bloom.

Apart from this interannual variation observed in the Metopi area, species composition revealed the same annual cycle in both years. Species assemblages had a clear seasonal character (winter, spring, summer and autumn assemblages) and were observed each year. Their differentiation along the first axis of the correspondence analysis revealed the major role of temperature on the zooplankton community species composition. This differentiation was also obvious in the MDS plot, suggesting the importance of this factor. It is known that temperature fluctuations regulate the life history of all copepod species (Deevey 1960, Razouls 1972). According to Sullivan & McManus (1986) temperature is one of the most important regulating factors of the seasonal succession. The influence of temperature was also important in the species composition in Elefsis Bay as most of the species are known to be psychrophilic [*A. clausi* (Yannopoulos 1978)] or thermophilic species [*P. avirostris* (Fonda-Umani 1980), *P. polyphemoides* (Fonda-Umani 1980), *T. stylifera* (Moraitou-Apostolopoulou 1972)]. However, this influence was not so evident in the correspondence analysis due to the difference in abundance of *A. clausi, P. avirostris, P. polyphemoides*, which was very strong resulting in the formation of the first two axes.

A second factor for the differentiation of zooplankton composition in the Metopi station, was the influence of the open sea. In Saronikos Gulf the water column is mixed during autumn and winter and the influence of the Aegean Sea becomes more intense (Christianidis 1991). As a result species having a wide horizontal distribution (*O. plumifera, C. pavo, C. pavoninus, N. minor, M. clausi*) were abundant in the Metopi area, and some pelagic species occurred occasionally (*Lucicutia flavicornis, Pleuromamma gracilis, Scolecithricella dentata*). A similar influence is also reported in the Gulf of Naples by Scotto di Carlo *et al.* (1985) and in the Lebanese coastal waters by Lakkis (1990). The partial geographical isolation of Elefsis Bay from the whole Saronikos Gulf prevents the influence of the open sea on the zooplankton community of the area.

Species assemblages and generally species composition could be differentiated between the two areas. This was also obvious from the low similarity observed between the two stations samples and from the MDS analysis where samples of each area are clearly distinguished. Furthermore, species diversity was higher in the Metopi area than in Elefsis Bay, especially during the winter–spring period when the zooplankton community was almost monospecific in Elefsis Bay. The evolution of diversity and dominance indices, and also of the rank-frequency diagrams, suggest a different community structure in the studied areas. The almost linear shape of the diagrams in Elefsis Bay during winter indicate the disturbance of the zooplankton community by pollution. Simultaneously in the Metopi area the community is highly diversified and there is a trend towards realizing a mature stage (Frontier 1985). In Elefsis Bay the community attained higher diversity in summer but never reached the maximum value observed in the Metopi station. On the contrary, in the latter area the community revealed lower diversity during the summer period. All these data indicate the presence of two different zooplankton communities in the studied area.

At the Metopi station, positioned in the shallow 'plateau' in the middle of Saronikos Gulf, the zooplankton community revealed a well-diversified species composition and seasonal fluctuations similar to those observed in other coastal areas of the Mediterranean Sea (Scotto di Carlo & Ianora 1983, Gaudy 1985, Moraitou-Apostolopoulou 1985). The Elefsis Bay community is characterized by the extreme dominance of very few species, r-selected, which were accompanied by some rare neritic species. These characteristics combined with intense fluctuations of the total zooplankton density, the low diversity values and the linear-curved rank-frequency diagrams suggest a disturbed community. Disturbance is due to pollution of the area by many sources (domestic sewage, industrial and naval pollution). The influence of pollutants is accentuated by the morphology of the bay, a semi-enclosed and shallow area. Similar zooplankton communities have also been observed in the Gulf of Fos (Patriti 1984) and in the Bay of Thessaloniki (Siokou-Frangou & Papathanassiou 1991) both semi-enclosed and polluted areas.

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