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Macrobenthic community structure and disturbance assessment in Gialova Lagoon, Ionian Sea

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Gialova Lagoon, a coastal marine ecosystem in the Ionian Sea, suffered the impact of an oil spill incident in October 1993, leading to the extensive fish deaths when the oil tanker ''Iliad'' hit bottom in the entrance of the neighbouring Navarino Bay. A multidisciplinary study investigating the structure and functioning of Gialova Lagoon for the development of an integrated economic, social, and environmental management policy consistent with its conservation was carried out on a seasonal basis during 1995/1996. One of the research priorities was to investigate the structure and dynamics of the macrozoobenthic communities and assess whether these communities had recovered from the impact of the oil spill. The various methods applied (abundance/biomass comparison, distribution of species in geometric abundance and geometric size classes) revealed no detectable disturbance of the macrobenthic communities due to anthropogenic impact. However, it was proved that the lagoonal macrofauna suffered extreme natural disturbance due to a dystrophic crisis that occurred during autumn although they successfully recovered in subsequent seasons. Different sets of environmental factors were found to be highly correlated with the temporal and spatial distribution pattern of the macrobenthic communities and are discussed in detail. The coenocline observed in Gialova Lagoon appears to be strongly correlated with the degree of water exchange with adjacent marine and continental environments.

Key words: coastal lagoons, disturbance assessment, macrobenthic communities, population structure and dynamics, Ionian Sea.

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Introduction

Coastal lagoons may be defined as areas of relatively shallow water that have been partly or wholly sealed off from the sea by the formation of depositional barriers, usually of sand or shingle, built up above high-tide level by wave action (Bird, 1994). These areas are often of considerable interest as natural resources, largely because of visiting wintering and migrating birds and/or the flora and fauna of the shingle (Barnes, 1991), but they also provide significant food resources, and local fishing and mariculture constitute one of the oldest forms of coastal resource exploitation (Ardizzone *et al.*, 1988).

Depending on their geomorphological and hydrological status, these shallow coastal environments may be characterized by frequent fluctuations in environmental parameters on a daily and seasonal basis, which cause changes in the structure and distribution pattern of organisms. In this sense coastal lagoons can be considered as harsh and naturally stressed habitats (Barnes, 1980). In some cases, the change in the environmental parameters in lagoons is severe (Guelorget and Perthuisot, 1992) and leads to dystrophic crises (extremely high levels of temperature and salinity combined with low oxygen availability both in the water column and the surface sediments). Although this extreme natural disturbance often results in the instant destruction of great numbers of individuals, especially those entering the lagoon to feed, the ecosystem recovers quickly once the crisis is over (Guelorget and Perthuisot, 1992). However, various human activities in lagoons (harbour facilities, industrial and urbanized centres, repositories for wastes and drainage waters from rural land, etc.; Valleje, 1982) have a severe impact on the macrozoobenthic community structure, and it has been questioned whether these drastic changes are reversible (Barnes, 1991; Lardicci *et al*., 1997).

Gialova Lagoon is one of the ten major lagoons of Greece (Ananiadis, 1984). It has an important fisheries value (Buonfiglio and Rucci, 1986) and, being one of the important bird areas in Europe (Grimlet and Jones, 1989), is also of great interest as a natural resource. However, large-scale reclamation during the early 1960s, along with other technical interventions in the 1970s and 1980s (reduction of freshwater input because of rural use and periodical closure of the communication channel with the sea), resulted in severe changes in environmental parameters. Subsequently, frequent dystrophic crises have been reported from the area. In addition, Gialova Lagoon recently suffered an oil spill impact in October 1993, leading to the extensive mortality of fish, when the oil tanker "Iliad" hit bottom in the entrance of the neighbouring Navarino Bay (Yando, 1993).

We describe the structure and dynamics of the macrobenthic community in Gialova Lagoon, with the aim to assess the level of disturbance in the ecosystem and to provide a basis for the development of an integrated economic, social, and environmental management policy for the lagoon and the surrounding wetlands consistent with their conservation.

Materials and methods

Study area

Gialova Lagoon is a poly-hypersaline basin in SW Greece and lies between Navarino Bay and the Voidokilia embayment adjacent to the Ionian Sea (Eastern Mediterranean) (Fig. 1). It covers an area of 2.5 km^2, with a maximum depth of one metre and is connected with the adjoining Navarino Bay *via* a small channel (100 m long, 10 m wide, and 1.2 m deep). Fluvial input occurs by two small inlets to the eastern part of the lagoon. Generally the sediment is muddy-sand, covered in most areas with green algae and the eel grass *Cymodocea nodosa.* Locally, mud is mixed with dead shells of the bivalve *Cerastoderma glaucum*. The lagoon is used for the extensive culture of various species of mullet (*Liza saliens, L. aurata, L. ramada*) and sea bream (*Sparus aurata*). Small amounts of sea bass (*Dicentrarchus labrax*), eel (*Anguilla anguilla*), and other commercial species are also caught. The mean annual fish production during 1986–1996 was 10 t, with the exception of 1993 and 1994 when production did not exceed 3.5 t owing to the oil spill incident.

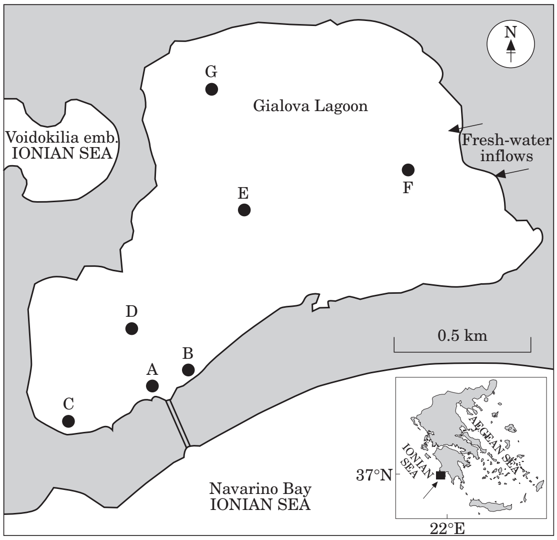

Figure 1. Map of Gialova Lagoon with indication of sampling stations for macrofaunal analysis (A–F).

Sampling

Seven stations were sampled that covered the entire lagoon (Fig. 1). Five replicate samples (total surface area of 0.25 m^2) were taken for macrofauna analysis at each station in June 1995, September 1995, December 1995, and March 1996 with the use of a hand-operated van Veen grab. The samples were sieved through a 0.5 mm mesh and preserved in 5% neutralized formalin. Additional sediment (by means of a sediment corer) and water samples were taken at each station for analysis of abiotic parameters: temperature, redox potential, sediment particulate organic carbon (POC), chlorophyll *a*, phaeopigments, mean particle size of sediment, silt-clay percentage, salinity, dissolved oxygen, pH, ammonia, nitrates, nitrites, phosphates, and silicates. Samples of POC, Chl *a*, phaeopigments, and nutrients were frozen at -20°C until analysis. Also, sediment and biological (fish and bivalve) samples for analysis of hydrocarbons were taken and stored in hexane-cleaned glass bottles or aluminium foil and kept deep-frozen until analysis, while sediment samples for analysis of heavy metals were frozen at -20°C.

In the laboratory, the macrofauna were sorted, identified to species level where possible, counted, and weighed after being dried at 80°C for 48 h. POC, Chl *a*, phaeopigment, and nutrient concentrations were obtained according to standard procedures outlined by Yentsch and Menzel (1963), Strickland and Parsons (1972), Grasshoff *et al*. (1983), and Parsons *et al*. (1984). Sediment particle size analysis used wet sieving through a 63 μm mesh to separate coarse and fine fractions, and % silt-clay was determined by pipette analysis (Buchanan, 1984. Hydrocarbon analyses followed standard procedures detailed in UNEP (1992). After extraction of the samples and separation with column chromatography, the fractions were analysed by gas chromatography with flame ionization detection (GC-FID). Quantitative analysis of heavy metals (Cu, Zn, Cr, Pb, Cd) in the sediment was performed with atomic absorption spectrophotometry with graphite furnace (GFAAS) after digestion of the samples with HNO_3 65% and H_2O_2 32%. The methodology was checked with standard reference material (BCSS-1 and PACS-1).

Data analysis

Macrobenthic community structure and dynamics were analysed in terms of total number of species (s), average density (D; mean number of individuals m^{-2}), Shannon-Wiener diversity (H′, log2 basis) and Margalef's species richness (d) indices. These measures were also used to compare Gialova Lagoon with other Mediterranean lagoons for which similar kinds of data sets exist.

Biological data (mean of the five replicates from each sampling station) were analysed by multivariate analyses after average densities by species and station had been transformed to the fourth root. Faunal similarities among the stations sampled were investigated using cluster analysis (group average) and non-metric multi-dimensional scaling (MDS; Kruskall and Wish, 1978) based on the Bray-Curtis similarity index of species composition between stations (Clarke and Green, 1988). Species contributing mostly to the dissimilarity among station groups were investigated using the SIMPER percentages procedure (Clarke, 1993). Environmental variables best correlated with the multivariate pattern of the macrobenthic community were identified by means of harmonic Spearman coefficient (BIO-ENV analyses) as proposed by Clarke and Ainsworth (1993). The degree of disturbance was assessed by means of the abundance/biomass comparison (ABC; Warwick, 1986; Warwick and Clarke, 1994). Other techniques employed included the distribution of species in geometric abundance and geometric size classes. The percentage of species was plotted against the density per species in geometric abundance classes and against mean biomass (mg m^{-2}) per species in geometric size classes. These techniques have been described in detail by Pearson and Rosenberg (1978), Gray and Mirza (1979), Pearson *et al.* (1983), and Warwick *et al.* (1986). The PRIMER package developed at Plymouth Marine Laboratory was used.

Results

Abiotic data

Temperature ranged between 14 and 31°C in the water column and between 14 and 25°C in the sediment.

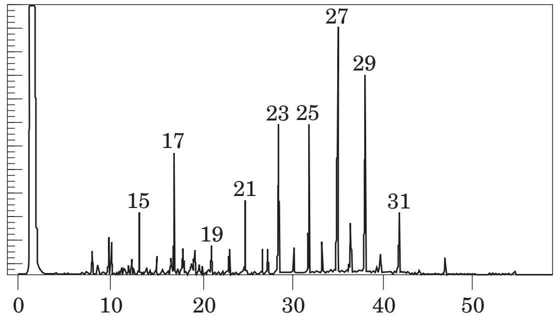

Figure 2. Chromatogram showing the distribution of n-alkanes in surface sediments from Gialova Lagoon.

Salinity ranged from 13 to 60 but exceeded 44 during most of the year. Therefore, the lagoon can be characterized as a hypersaline basin. Oxygen concentration in the water column was relatively low in all periods (4.5–7 mg l^{-1}) except during winter (7–9.1 mg l^{-1}). Redox potential values in the surface sediment (0–2 cm) were positive at all sampling sites (33–398 mV) throughout the year, except in early autumn when anoxic conditions (−32 to −150 mV) prevailed over most of the lagoon (stns C, D, E, and G). Maximum pH values (8.3–8.7) were obtained during spring, indicating increased photosynthetic activity. Large ranges of values were recorded for POC (1–8.2 mg l^{-1} and 1.5–50.3 mg g^{-1}), and chloroplastic pigments (Chl *a* 0.2–18.5 μg l^{-1} and 1–62.4 μg g^{-1}; phaeopigments 0.2–17.6 μg l^{-1} and 1–77 μg g^{-1}) in the water column and the sediment, respectively. Phosphate concentrations were extremely low (0.005–1.365 μM) on all stations, indicating possible phosphorus limitation. Nitrates (0.3–7.49 μM), nitrites (0.04–0.64 μM), and ammonia (0.18–9.45 μM) concentrations exhibited significant temporal fluctuations. With the exception of dissolved oxygen, the highest values in the environmental variables mentioned above were observed at the innermost sampling sites (D, E, F, and G) and the lowest ones at the sites located closer to the communication channel with the sea (A, B, and C).

The sediment at most stations was muddy-sand. Stns C, E, F, and G had the highest silt-clay percentages, followed by D. Stns A and B consistently had the lowest percentages. Hydrocarbon concentrations in surface sediments ranged from 7.9 to 20 μg g^{-1} for the n-alkanes and from 60 to 250 ng g^{-1} for the polynuclear aromatic hydrocarbons, with lower values obtained from the innermost stations (D, E, F, and G). The analysis confirms the predominance of n-alkanes with odd-numbered carbon atoms (Fig. 2) and indicates that a large percentage of the hydrocarbons have a natural source (organisms indigenous to the sediments or detritus of terrestrial plants), rather than stemming from oil pollution. Also, no oil-originating hydrocarbons were detected in any samples taken from biota (the

Table 1. Seasonal changes in macrofaunal diversity and density in Gialova Lagoon.

	s	D	d	H′
Summer	68	25 600	4.58	3.37
Autumn	22	2870	1.83	1.90
Winter	28	5220	2.19	2.69
Spring	44	1600	3.07	3.00

s, Number of species; D, average density; d, richness; H′, Shannon–Wiener diversity.

bivalve species *C. glaucum, Tapes decussatus*, and the fish *L. aurata*). Heavy-metal concentrations were low at all sites (Cu: 0.28–14.1 μg g^{-1}; Zn: 3.6–18.5 μg g^{-1}; Cr: 16.1–27.3 μg g^{-1}; Pb: 0.1–0.4 μg g^{-1}; Cd: 10.6–18.7 μg g^{-1}). With the exception of cadmium, the higher values were observed at the innermost stations. Dounas and Koutsoubas (1996) provide detailed information on the various environmental parameters.

Faunal composition

Overall, 87 species were collected during the four sampling periods. Annelids, crustaceans, and molluscs were the most abundant taxa and accounted for 39%, 28%, and 26% of the total number of species, respectively. Mean density was 12 580 individuals m^{-2}, while dry biomass was 0.37 g m^{-2}. The number of species ranged from 1 in stn G (September) to 62 in stn A (June). June yielded the highest and September the lowest number of species and density (Table 1). Some 15 species (representing 17.2% of the total number of species and 72% of the overall density) were present throughout the year. Following Barnes (1994), these species can be divided into three groups: freshwater species such as larvae of *Chironomus* sp.; typical lagoonal species of marine ancestry such as the gastropods *Hydrobia acuta* and *Pirenella conica*, and the polychaete *Armandia cirrhosa*; and marine/estuarine species such as the gastropods *Bittium reticulatum, Cerithium vulgatum*, and *Cyclope neritea*, the bivalve *Abra ovata*, the polychaetes *Perinereis cultrifera, Capitella capitata*, and *Heteromastus filiformis*, the oligochaete *Limnodriloides maslinicensis*, the amphipods *Dexamine spinosa* and *Microdeutopus gryllotalpa*, and the decapod *Diogenes pugilator*.

Structural analysis

Total number of species (s), mean density (D), species richness (d), and diversity (H′) for the entire lagoon by sampling periods (Table 1) show the same seasonal pattern: an abrupt decline from summer to autumn followed by a gradual increase during winter and spring. Regarding the spatial pattern, higher values of H′ and d

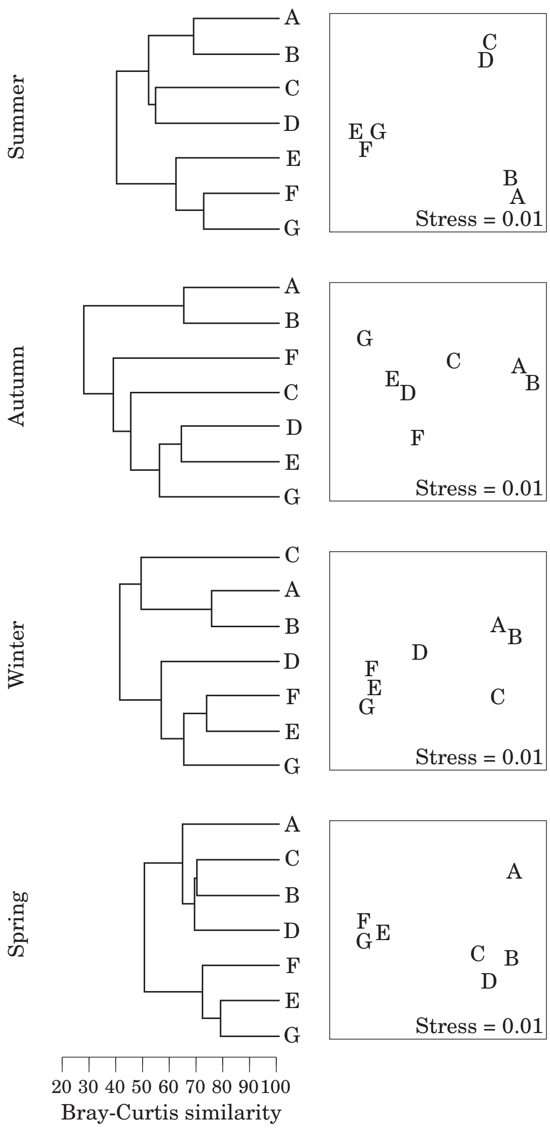

Figure 3. Similarity dendrograms and MDS ordination plots of stations in Gialova Lagoon by sampling season.

were obtained at stations near the inlet (A, B, C) and lower values at the innermost stations (E, F, G). For station D, diversity indices varied markedly; during summer they were close to those obtained for stations near the sea inlet, in autumn and winter they were close to those of the innermost stations, and during spring they were intermediate.

MDS ordinations and Bray-Curtis cluster analysis of the stations applied to each sampling period are shown in Figure 3. In summer, there are three distinct groups: one comprising stations A and B, a second comprising C and D, and a third formed by the innermost stations E, F, and G. In autumn, only two groups can be distinguished, one including A and B, and a second group

Table 2. Summary of environmental variables best correlated with macrobenthic community structure by sampling period in Gialova Lagoon.

	Dist.	T	S	Redox	pH	POC	Chl a	Phae	NO_3	SiO_4	ρ_w
Summer		+							+		0.92
Autumn			+				+				0.71
Winter	+		+	+	+	+		+		+	0.63
Spring	+		+		+				+	+	0.89

Dist, distance from channel; T, temperature; S, salinity, Phae, phaeopigments; σ_w, weighed Spearman rank coefficient.

including the remainder. During winter, the same pattern is maintained, with C transferred to the first group. Finally, during spring, D is also clustered withing the first group. With the exception of the group of inner stations in autumn, the similarity level among stations within these groups was more than 50%. ANOSIM tests showed that the groups distinguished are significantly different (global R superior to 0.8 at a significance level <5%).

At least two of these groups showed different species compositions. *B. reticulatum, C. vulgatum, C. neritea, P. cultrifera, Malacoceros fuliginosus, Amphiglena mediterranea, C. capitata*, and *Microdeutopus gryllotalpa* were the most abundant species on stations linked mainly with the sea inlet (A, B), while *Chironomus* sp., *A. ovata, P. conica*, and *C. glaucum* were the most abundant species on the innermost stations (E, F, G). In the transitional stations (C, D), the most abundant species belonged either to the first or second group.

The results of the BIO-ENV analysis are summarized in Table 2. Values of the harmonic Spearman rank coefficient were over 0.5, indicating positive relationships between the multivariate pattern of macrofaunal density and measured environmental variables. The best correlated variables during summer were temperature and nitrate concentration, salinity and Chl *a* concentration were important during autumn, while a wide range of environmental variables were highly correlated with density during winter and spring.

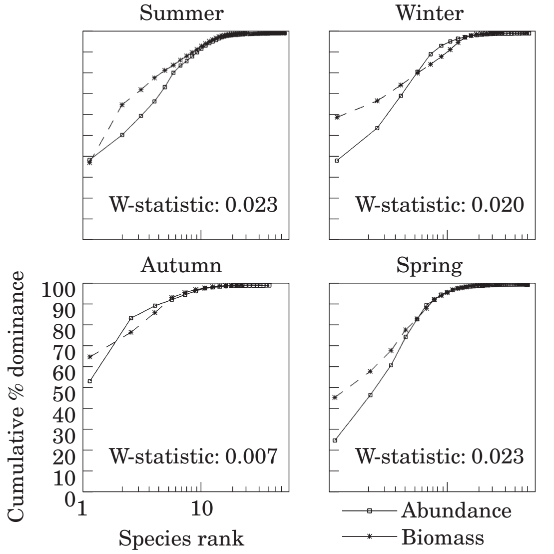

Figure 4. ABC curves along with W-statistic values for Gialova Lagoon by sampling season.

Disturbance assessment

ABC curves along with the W-statistic values are given in Figure 4 and the distribution of species in geometric abundance classes and in geometric size classes in Figure 5. The distribution of the number of geometric classes and the W-statistic values show a pattern similar to the density and diversity measures, i.e. an abrupt decrease from summer to autumn followed by a gradual increase during winter and spring. However, the decline from summer to autumn is not as abrupt as observed for the measures of density and diversity, and the values of the W-statistic are positive but close to zero. The abundance curve partially overlies the biomass curve during autumn and winter.

Discussion

The macrobenthic community in Gialova Lagoon can be characterized as typical of brackish water lagoons with euryhaline and eurythermic species distributed over the major parts (Pérès, 1967). Despite its small size and low average depth, Gialova is among the richest Mediterranean lagoons in terms of number of species, density, and diversity (Dounas *et al.*, 1998).

Based on the macrobenthic community pattern obtained by multivariate analyses, two main zones can be distinguished: a narrow zone near the inlet influenced mostly by the sea and dominated by marine/estuarine species, and the innermost part of the lagoon dominated by freshwater and typical lagoonal species. A third transitional zone becomes clearly apparent only during summer. The first zone can be assigned to "zone III" and the second to "zones IV–V" according to the

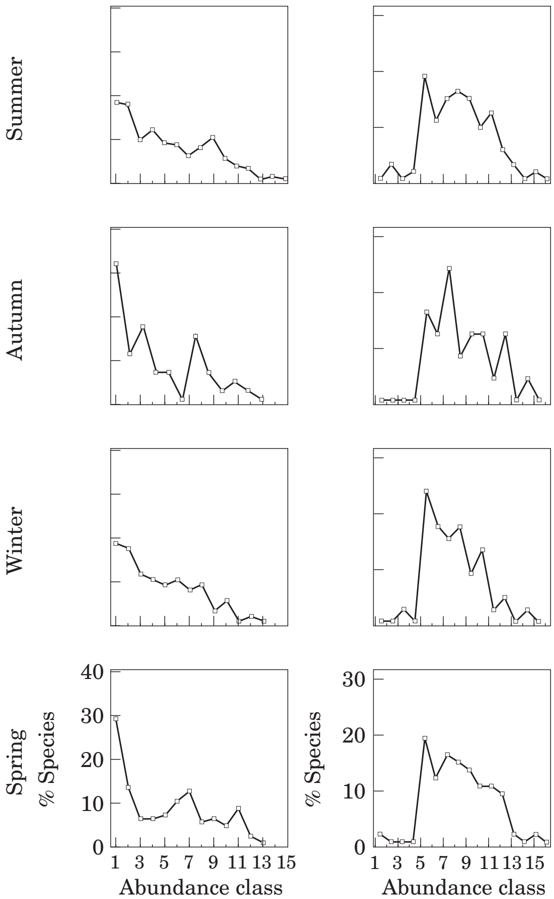

Figure 5. Distribution of species in geometric abundance (left) and geometric size classes (right) in Gialova Lagoon by sampling season.

confinement scale proposed by Guilorget and Perthuisot (1992). The third zone, dominated by a mixed macrobenthic fauna, can be considered as an extension of the first zone,, being in a distinct yet transitional state only during summer. The results indicate that the limits of the lagoonal zones may show seasonal shifts, a state consistent with the dynamic character of the habitat.

Both univariate and multivariate analyses reveal the same seasonal distribution pattern of the macrozoobenthic community as the lagoon passes from a rich (87 species) and well-structured state (three groups) during summer to an impoverished (22 species) and less structured (two groups) one during autumn. Similar seasonal patterns have been also observed in other Mediterranean lagoons (Carrada, 1973; Amanieu *et al.*, 1977; Gravina *et al.*, 1989; Arias and Drake, 1994; Lardicci *et al.*, 1997). In the subsequent seasons, Gialova Lagoon gradually approaches the previous summer levels. Consequently, the abrupt decline in diversity and density is interpreted as a dystrophic episode which may be considered as a natural reaction to the extreme environmental conditions (mainly anoxia) commonly occurring in the lagoonal habitat (Nicolaidou *et al.*, 1988; Cammete, 1992; Guelorget and Perthuisot, 1992).

In the literature, many environmental variables have been correlated with the temporal and spatial distribution pattern of the macrobenthic communities in lagoonal systems. These are either purely physical and chemical ones (temperature, salinity; Barnes, 1980) or associated with food supply (nutrients, organic material; Diaz, 1980; Gray, 1981; Nixon, 1982; Gravina *et al.*, 1989). Gialova Lagoon nicely illustrates the role of the confinement determined by the time of renewal with elements of marine origin at a given location, which according to Guelorget and Perthuisot (1983) primarily determines the biological zonation and species distribution in lagoonal ecosystems. Indeed, the innermost part of Gialova Lagoon always has a different faunal composition compared with the areas close to the sea inlet, indicating a biological zonation. This differentiation may be attributed to a variety of environmental variables depending on season, as revealed by the results of the BIO-ENV analysis. When the system is either well stratified and diverse or suffers a dystrophic crisis, only two environmental variables show positive correlation with the distribution pattern of the macrobenthic community. In contrast, when the system is recovering a greater number of variables seem to be involved. This indicates that the confinement (*sensu* Guelorget and Perthuisot, 1983) is expressed by a limited number of variables, the extreme values of which produce a strong gradient along the lagoon and presumably act as thresholds to species distribution. The effect of these critical variables dominates the effects of the other variables. When the community is in the recovery phase, the gradient is destroyed and the confinement is expressed by the synergistic effect of various environmental variables. Thus, our findings illustrate the role of confinement in the paralic domain (e.g. coastal lagoonal and estuarine ecosystems, salt marshes) as a function of a number of factors (Guelorget and Perthuisot, 1992) and also refer to the multiple limiting factor theory, which has been suggested for the sublittoral macrofauna in other coastal areas (Wildish, 1977).

Research on the biological effects of oil pollution on macrobenthic communities has revealed that, apart from the initial, acute impact, there may be a long-term effect, and the disturbance may persist for many years after the direct toxic effects of the oil have disappeared (Elmgren *et al.*, 1983; Clark, 1989). It is unfortunate that macrofaunal samples were not taken immediately after the oil spill incident to ascertain the initial effects of hydrocarbons on the structure and functioning of the ecosystem. However, taking into account anecdotal evidence from local fishermen that low mortality of invertebrates (shrimps and crabs only in the area close to the sea inlet) occurred after oil entered the lagoon, and meteorological data obtained for the area during summer and early autumn 1993, it is probable that, at the time of the incident, Gialova had already suffered a dystrophic crisis and that most animals had disappeared beforehand. Therefore, the effects of the oil spill may have been merely an extra stress in an already naturally stressed environment.

The n-alkanes values fall within the range of those reported from other non-polluted coastal areas of the Mediterranean (UNEP, 1988). The concentrations of polynuclear aromatic hydrocarbons in sediments as well as in biota were low in comparison with other regions (Mille *et al*., 1982; Elmgren *et al*., 1983), and their origin could not be attributed to the "Iliad" oil spill. In coastal zones, the conditions of nutrients, light, temperature, oxygen, and type of substrate lead to high rates of bacterial and photochemical biodegradation (Botello and Marco, 1982). Therefore, it seems likely that most of the petroleum hydrocarbons entering Gialova degraded very quickly and yet, even if there were acute effects, they did not last too long and were not severe enough to disrupt overall macrofaunal diversity.

In Gialova Lagoon, small and moderate geometric abundance classes dominate in all seasons. This means that large numbers of species are present in low numbers throughout the year, which is the opposite of the situation occurring in stressed systems, according to Gray and Pearson (1982). Pearson and Rosenberg (1978) suggested that the average size of the individual decreases in polluted areas; Warwick *et al*. (1986) assumed that large species are lost with increasing organic enrichment and mean species size declines. The plots of the number of species against size class show that moderate geometric size classes include representation by most species, that a few large species occur, and that small classes are almost entirely missing. This distribution cannot support the hypothesis of a polluted habitat. ABC curves and values of the W-statistic suggest that the lagoon is in a moderately stressed condition. The same approaches have been applied in other Mediterranean lagoons (Tsopeli, Vivari, Goro) by Reizopoulou *et al*. (1996), who found that methods based on size changes were more sensitive than those based on changes in relative abundance. According to disturbance level of the lagoons examined by these authors, the disturbance status of Gialova can be placed between Tsopeli (undisturbed) and Vivari (moderately disturbed). However, diversity (number of species, Shannon's index) values of Gialova Lagoon are beyond those calculated for all lagoons examined by Reizopoulou *et al*. (1996). In addition, no pronounced decrease of opportunistic species has been observed in Gialova Lagoon, as was the case in Orbetello Lagoon where it was interpreted as reflecting a reduced resilience capacity of the habitat (Lardicci *et al*., 1997).

According to the criteria described by Hiscock *et al*. (1998), Gialova Lagoon could be considered as an important area. It is not only of commercial interest because of the fisheries that it supports, but it is also a key element in the marine natural heritage and is essential for the support of the fauna of the fringe, especially the wintering and migrating birds that frequent the lagoon. For the development of a management plan of the lagoon and the surrounding wetlands consistent with their conservation, it is important to achieve a better regulation of the confinement along with successful protection measures. It is expected that soft and cheap technical interventions (increase of freshwater input by enlarging the existing fluvial inlets, re-opening of a second sea inlet channel, deployment of a floating barrier to avoid entrance of oil from potential future spills) in the framework of a LIFE-Nature project (LIFE B4-3200/97/244), planned to become operative at the end of 1999, will contribute to the sustainability of this coastal environment.

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