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Benthic diversity of coastal brackish-water lagoons in western Greece

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ABSTRACT

1. Benthic community parameters were studied in six coastal brackish-water lagoons located in western Greece (Ionian Sea). Five of the lagoons studied are around the coast of the Amvrakikos Gulf under the influence of the Rivers Louros and Arachthos and one lagoon is situated in northwest Peloponissos.
2. All the lagoons experienced a wide range of temperatures, salinities and dissolved oxygen due to their high degree of confinement and shallow depths. Confinement and sediment composition were the major factors affecting number of species and biodiversity of benthic communities.
3. The Shannon diversity index does not appear to be efficient in discriminating between natural stress and anthropogenic disturbance in lagoonal ecosystems.

KEY WORDS: lagoons; benthic diversity; organic enrichment; ecological status

INTRODUCTION

Coastal lagoons located between land and sea are influenced by both the marine and the terrestrial environments. Coastal lagoons are naturally enriched areas with very unstable environmental conditions due to their confinement from the open sea and to their shallowness. In this sense they are considered as naturally stressed environments. Furthermore, being close to land, they are vulnerable to human disturbance (Bellan, 1972; Stora and Arnoux, 1983).

Coastal lagoons typically show low benthic diversity, caused by the natural instability of the environment, which discourages the settlement of many organisms (Gray, 1974). Low values of diversity, low numbers of species and strong dominance of a few species have been found often in lagoonal ecosystems (Guelorget and Michel, 1979; Nicolaidou *et al*., 1985; Arias and Drake, 1994; Reizopoulou *et al*., 1996).

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Seasonal patterns of benthic diversity have been recorded in Mediterranean lagoons, with the highest values mostly occurring during spring and autumn, when environmental conditions are more favourable (Gravina *et al*., 1989). Diversity indices in lagoons are often affected by fluctuations of the abundance of the most dominant species (Gravina *et al*., 1985; Arias and Drake, 1994).

Guelorget and Perthuisot (1983) introduced the concept of paralic ecosystems and the confinement theory. The fauna inhabiting paralic environments are assigned to six well-defined zones along the sea–land gradient. The zonal organization of the paralic ecosystem ('Domaine Paralique') is related to the confinement concept, as an expression of the time of renewal of the components of marine origin; confinement is the main factor for the organization of communities in lagoons and, consequently, it is reflected on biodiversity (Guelorget and Perthuisot, 1983).

The areas under study are ecologically very important and are located in western Greece. The Amvrakikos Gulf is considered as one of the most important lagoonal systems in Greece, and is protected under the Ramsar Convention. Papas lagoon is included in the Natura 2000 network.

This study attempts to relate the benthic community diversity of the six lagoons located in western Greece to a number of environmental parameters, including the factor of confinement.

METHODS

Description of sampling sites

The lagoons studied are located in western Greece (Ionian Sea). The study areas (Figure 1) are relatively enclosed water bodies with wide ranges of temperatures and salinities (euryhaline and eurythermic) and separated from the sea by narrow barriers with openings allowing limited water exchange. Temporal

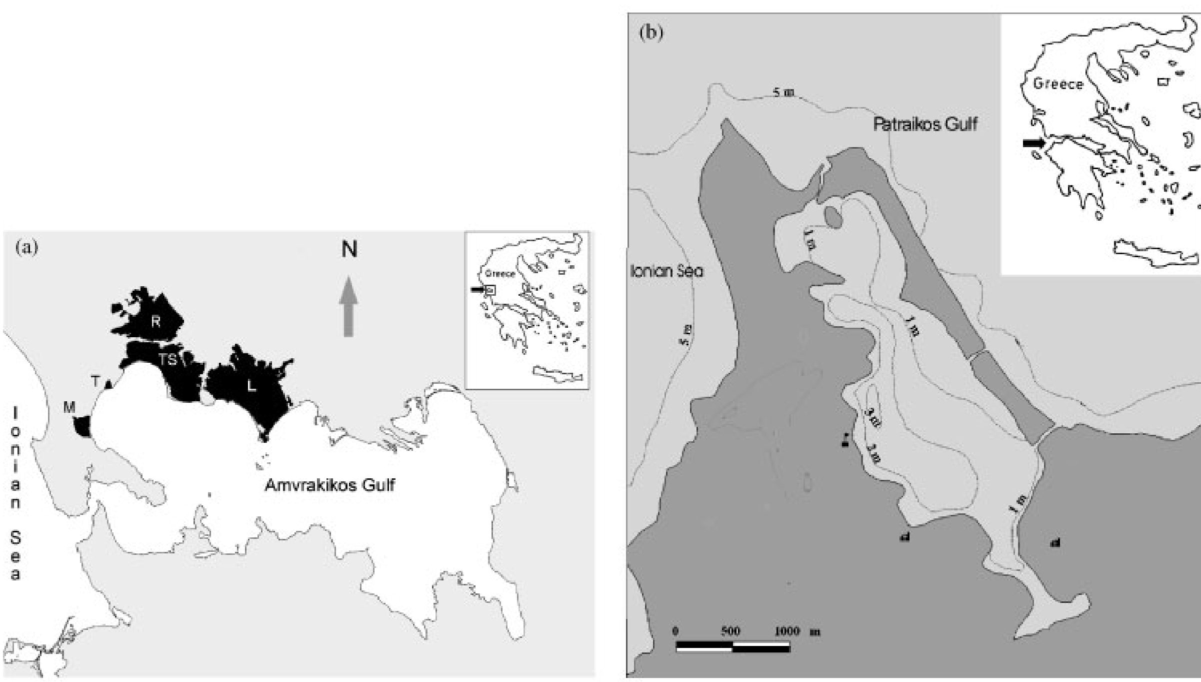

Figure 1. Maps of the lagoons studied. (a) Amvrakikos Gulf. M: Mazoma, T: Tsopeli, Ts: Tsoukalio, R: Rodia, L: Logarou. (b) Papas lagoon.

variations of abiotic parameters can be attributed mostly to climatic factors, including rainfall and wind, and to geomorphological characteristics, including depth and degree of communication with the sea. The hydrological balance is mostly controlled by meteorological conditions, since, owing to the absence of significant tides, the main factors controlling the water circulation in the lagoons are the intensity and the direction of the wind.

Five of the lagoons (Mazoma, Tsopeli, Tsoukalio, Rodia and Logarou) are situated in the Amvrakikos Gulf and are formed under the influence of the Rivers Louros and Arachthos. The input of fresh water is seasonal. No obvious source of stress was detected. Stratification of the water column is mostly noted during the summer months and early autumn, whereas during winter, spring and autumn the high levels of dissolved oxygen observed indicate a good mixing of the water. The oxygenation process is enhanced by the presence of the rooted angiosperms (*Zostera noltii*, *Ruppia maritima*, *Ruppia cirrhosa* and *Cymodocea nodosa*) on the bottom of the lagoons. Excessive growth of tolerant species of macroalgae, anoxic conditions and dystrophic crises were not observed in these lagoons. The lagoons are used for the extensive culture (sustainable use) of various species of mullet and eel. Small amounts of gilthead, bass and sole are also caught. Tsopeli is the most productive lagoon in the Amvrakikos Gulf.

Papas lagoon is situated in northwest Peloponnisos and is linked with the Patraikos Gulf and the Ionian Sea in the south. Evidence of eutrophication was visible during late spring and summer, where floating macroalgae (*Ulva rigida*) dominated the southern part of the lagoon. *Ulva* is considered an opportunistic genus (Lobban and Harrison, 1994; Coelho *et al*., 2000; Orfanidis *et al*., 2001) and constitutes the main component of benthic primary production in the southern part of the lagoon. The dystrophic crises coincided with the rapid decomposition of large beds of macroalgae and caused a severe adverse effect on the ecosystem and on fish production (NCMR, 2000).

The relative composition in tolerant algal flora and sensitive angiosperms serve as an indirect estimation of eutrophication, as increased levels of organic matter reduce eelgrasses and favour macroalgae-dominated communities (Orfanidis *et al*., 2001).

Sampling methods

Temperature, salinity and dissolved oxygen were measured just above the bottom, and sediment and benthic samples were collected using a Ponnar $0.05\,m^2$ grab.

The sampling frequency, number of stations and total sample size in each lagoon are shown in Table 1. The samples were sieved through a 1 mm mesh sieve and stained with Rose Bengal. Samples were preserved in 4% formalin. In the laboratory, the macrofauna was sorted, identified to species level where possible and counted. A small amount of sediment was kept for granulometry and analysis of organic carbon. Grain size analysis of the sediment was carried out according to the methods described by Buchanan (1984). Samples with high sand content were dry sieved, and the rest were analysed using the pipette method.

Table 1. Sampling frequency, number of stations and total sample size in every lagoon

Lagoon	Sampling frequency	No. of stations	Total sample size
Mazoma	2 occasions (1981 and 1990)	5	0.15
Tsopeli	5 occasions (1990–1991)	6	0.15
Tsoukalio	3 occasions (1993–1995)	4	0.25
Rodia	2 occasions (1994–1995)	3	0.25
Logarou	2 occasions (1994)	4	0.15
Papas	5 occasions (1998–1999)	3	0.15

Mathematical methods

Univariate and multivariate methods were applied for the statistical analyses of the data. For the macrofauna, univariate measures included number of taxa, abundance, Shannon–Wiener diversity H' ($\log_2$ basis) and Pielou's evenness J. The zones of confinement were established according to Guelorget and Perthuisot (1983). To obtain a quantitative estimation of confinement for use in statistical analyses, each lagoon station studied (Mazoma, Tsopeli, Tsoukalio, Rodia, Logarou and Papas) was assigned to a zone according to Guelorget and Perthuisot (1983), with intermediate stations being ordered between the respective zones (zone I = 1, zone I–II = 2, zone II = 3, ..., zone V = 9). Then, a number was given to each rank. Spearman's rank correlation coefficient (Zar, 1974) was employed in order to investigate the possible correlation between biotic and abiotic parameters. Community structure is described by multidimensional scaling (MDS), based on a similarity matrix constructed using the Bray–Curtis similarity index. The data were first transformed by $Y = \log(x + 1)$. The MDS was performed using the PRIMER v5 software package.

RESULTS

The ranges of environmental parameters (depth, salinity, temperature, dissolved oxygen, percentages of coarse particles, clay and silt, and percentage of organic carbon in the sediment) of each lagoon are shown in Table 2.

All the lagoons experienced a wide range of temperatures and salinities due to their high degree of confinement and shallowness. Temperature and salinity showed the expected seasonal patterns. Salinity showed lower values in the winter months, with a minimum of 5 psu in Rodia, and higher values during summer, with maximum of 48.6 psu in Logarou. The largest variations in salinity were recorded in Logarou (32.8 psu), the shallowest lagoon. Temperature showed a minimum during the winter months (8.0°C in Tsopeli) and a maximum during summer (32.0°C in Papas lagoon). The minimum value of dissolved oxygen was found ($1.2\,\mathrm{mg\,L^{-1}}$) during summer in Papas lagoon, which often experiences dystrophic crises due to the decomposition of enormous amounts of macroalgal (*U. rigida*) biomass.

Lagoonal sediments were muddy, with a high clay and silt content (Table 2), often mixed with bivalve shells (e.g. Tsopeli, Tsoukalio, Rodia in the Amvrakikos Gulf) or agglomerations of calcareous tubes of serpulid polychaetes (e.g. Papas lagoon).

The variations of percentage of organic carbon in the sediment in each lagoon are shown in Table 2. Lower values were recorded in undisturbed lagoons, such as Tsopeli (1.1%), and maxima occurred in organically enriched areas such as Papas (5.6%). Figure 2 shows the mean values of organic carbon in the sediment of the lagoons.

Ecological indices of benthic communities — total number of species, and ranges of number of species diversity H', evenness J, and abundance N (ind.m^{-2}) — in each lagoon are shown in Table 3. The total

Table 2. Range of abiotic parameters in each lagoon

Lagoon	Depth (m)	S (psu)	T (°C)	O_2 ($\mathrm{mg\,L^{-1}}$)	Coarse material (%)	Clay (%)	Silt (%)	Organic C (%)
Mazoma	1.0–2.0	23.0–27.0	9.0–13.0	4.8–6.8	–	–	–	–
Tsopeli	0.2–1.5	21.0–38.0	8.0–29.0	2.8–9.8	6.7–66.3	5.6–45.6	42.1–75.7	1.1–5.3
Tsoukalio	1.6–5.2	14–36.5	8.6–30.0	4.6–10.6	8.3–79.0	1.9–13.9	17.2–81.0	1.3–5.1
Rodia	2.9–5.2	5.0–35.0	8.9–29.1	3.5–10.8	12.0–77.5	3.4–9.0	19.0–80.0	1.2–5.0
Logarou	0.7–1.0	15.8–48.6	9.1–28.1	4.5–12.1	6.4–32.0	9.5–53.5	25.3–80.8	2.3–3.5
Papas	0.2–1.5	20.0–42.5	10.0–32.0	1.2–9.3	23.0–98.0	4.4–58.0	3.2–15.0	2.9–5.6

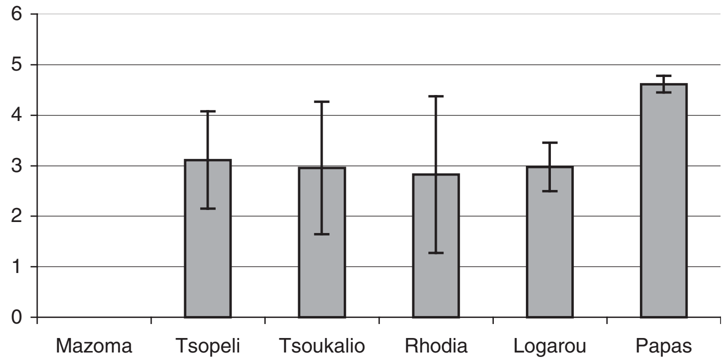

Figure 2. Percentage of organic carbon in the sediment (mean values plus/minus standard deviation).

Table 3. Biotic indices: total number of species and variations of number of species *S*, diversity *H′*, evenness *J* and abundance *N* (ind.m^{-2}) of each lagoon

Lagoon	Total no. of species *S*	Variations of no. of species *S*	Diversity *H′*	Evenness *J*	Abundance *N*
Mazoma	59	8–39	2.1–3.5	0.61–0.83	776–16 400
Tsopeli	84	5–45	1.3–3.7	0.48–0.89	508–5827
Tsoukalio	47	6–29	1.9–3.3	0.48–0.86	96–6260
Rodia	26	3–16	0.8–3.0	0.34–0.92	184–16 744
Logarou	49	11–31	0.4–3.3	0.10–0.86	168–15 533
Papas	76	0–44	1.7–3.7	0.45–0.79	0–44 108

number of species recorded in each lagoon ranged from 26 in Rodia to 84 in Tsopeli. The highest number of species (45) collected at any one time was found in Tsopeli in late spring, and the lowest (only three) was found in Rodia during the summer. In the inner south part of Papas lagoon, azoic zones were noted during summer due to the decomposition of large beds of *U. rigida*.

In the lagoons studied, various zones of confinement were evident. Confinement based on species composition ranged from zone III to zone V. The confinement was highest in Tsopeli (IV–V), which had only one channel of communication with Amvrakikos and the water circulation was further obstructed by a number of radiating dykes. The most common and abundant species was the lagoonal species *Abra ovata*. Other bivalves with a wide distribution were *Cerastoderma glaucum* (Tsopeli, Tsoukalio, Logarou, Papas), *Mytilaster minimus* (Mazoma, Tsopeli, Tsoukalio, Rodia), *Loripes lacteus* (Tsoukalio, Rodia, Papas) and *Cyclope neritea* (Tsoukalio, Rodia, Logarou). The lagoonal isopod *Idotea baltica* and amphipods of the genera *Corophium* and *Microdeutopus* were common in the lagoons studied, reaching very high numbers in Papas lagoon. The polychaetes *Nephtys hombergi* and *Hediste diversicolor* were dominant in the lagoons of the Amvrakikos Gulf, whereas in Papas lagoon the serpulid *Hydroides dianthus* was very abundant, reaching extremely high numbers at some stations. Occasionally, opportunistic species such as *Capitella capitata* and *Heteromastus filiformis* were found in very high numbers in Papas lagoon. Other lagoonal organisms such as chironomids and *Hydrobia* sp., able to withstand sporadic anoxic conditions, were very common in the restricted parts of the lagoons.

The dominant species often accounted for approximately 90% of the individuals of the community, thus controlling the temporal fluctuations of diversity.

Figure 3 shows the grouping of the lagoons according to their faunal similarities (stress level 0.14). Tsopeli and Papas lagoons are grouped into two distinct clusters; both lagoons present the most diverse of populations, with high numbers of species and large numbers of crustaceans. The fauna of Tsopeli is distinguished from the other lagoons of Amvrakikos by the presence of dense angiosperm vegetation on the bottom of the lagoon. In contrast, the stations at Tsoukalio and Rodia, which were indistinguishable from each other, are characterized by great paucity of species. Mazoma and Logarou generally ordinate in the central cluster of stations.

Diversity H' values range from 0.4 in Logarou to 3.7 in Tsopeli and Papas lagoons. Benthic diversity peaked mainly in autumn and spring, when the marine influence and water renewal were stronger. The study sites with the greatest marine influence supported the highest numbers of species and diversity H'; the restricted sites farthest from the open sea were species-poor, with low diversity and high densities.

Evenness J ranges from 0.10 in Logarou to 0.92 in Rodia, and abundance ranges from 96 m^{-2} in Tsoukalio to 44 108 m^{-2} in Papas, the most eutrophic lagoon.

Table 4 presents the statistically significant correlations between biotic parameters and degree of confinement, percentage of coarse material and percentage of organic carbon in the sediment. Number of species S and benthic diversity H' decreased with increased degree of confinement within the lagoons ($p=0.002$ and $p=0.0001$ respectively). Moreover, it can be seen that the number of species and diversity increase as the amount of fines in the sediment decreases ($p=0.002$ in both correlations; Table 4).

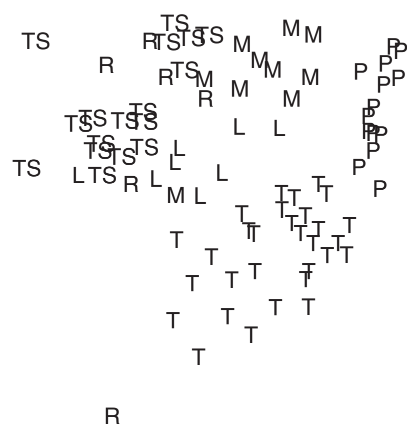

Figure 3. MDS plot of the sampling sites. M: Mazoma, T: Tsopeli, Ts: Tsoukalio, R: Rodia, L: Logarou, P: Papas.

Table 4. Statistically significant correlation coefficients between abiotic and biotic parameters

	S	H'	N (ind.m^{-2})
Confinement	–0.344 $p=0.002$ $n=80$	–0.454 $p=0.0001$ $n=80$	–
Coarse (%) Material	0.385 $p=0.002$ $n=70$	0.371 $p=0.002$ $n=70$	–
Organic C (%)	–	–	0.262 $p=0.03$ $n=70$

Data on vegetation were available only for Tsopeli, Mazoma and Papas. In Tsopeli and Mazoma, where angiosperms dominated, there was a positive, although weak, correlation between number of species and plant biomass. On the contrary, in Papas lagoon, which experienced excessive growth of opportunistic macroalgae, the number of species decreased with increasing algae biomass ($p = 0.02$).

Correlation between benthic diversity and organic carbon in the sediment was weak, but a strong relationship was observed between number of individuals and the percentage of organic carbon in the sediment ($p = 0.03$). Correlations between other environmental parameters (salinity, temperature, dissolved oxygen) and benthic community parameters (number of species S, community diversity H', evenness J, abundance N) were all weak.

The number of species and community diversity within the lagoons decrease with increasing confinement (Figures 4 and 5). Increasing organic enrichment in the lagoons studied is accompanied by an increase in the number of individuals, but it is not related to community diversity. However, in the eutrophicated lagoon (Papas), benthic communities, as in other organically polluted areas, showed occasionally high numbers of individuals and seasonal peaks of opportunistic species (*C. capitata* and *H. filiformis*). During the summer in 1998 the decomposition of large beds of *U. rigida* caused a severe dystrophic crisis in the southern part of the lagoon. The impact of dystrophic phenomena on benthic communities depends on the capacity of adaptation of the various organisms; in November, when the environmental conditions within the lagoon were more favourable, there was a rapid reaction of benthic communities to recolonize the areas affected by summer anoxic conditions. The short period of recovery of the lagoon is due to the high resilience of those systems.

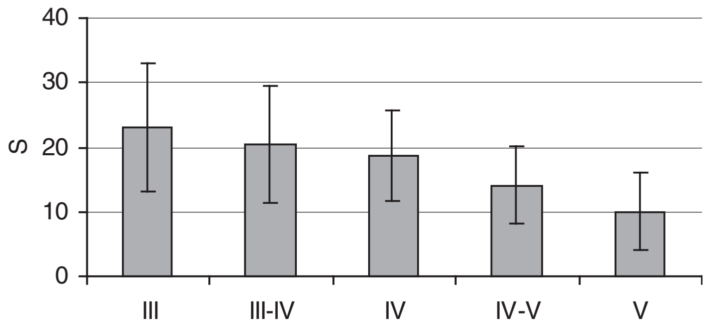

Figure 4. Number of species S against confinement (means in each confinement zone plus/minus standard deviation).

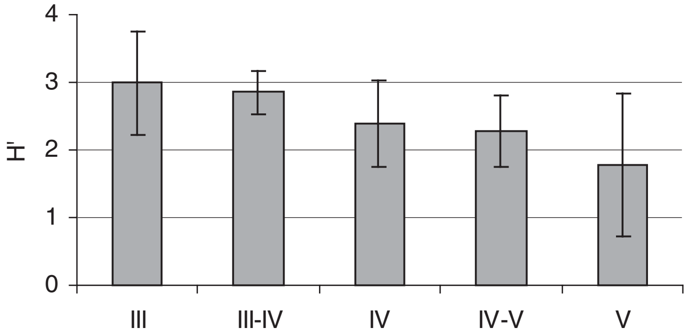

Figure 5. Biodiversity H' against confinement (mean values of diversity in each confinement zone plus/minus standard deviation).

DISCUSSION

The salinity of the lagoons was lower during the winter months in accordance with higher precipitation, and elevated in the summer due to high evaporation rates and low fresh water inputs from the land. The importance of rainfall in the lagoonal ecosystem was investigated in three of the lagoons studied (Tsoukalio, Rodia, Logarou) and a negative relationship of rainfall with salinity was observed (Kormas *et al*., 2001). Rodia and Logarou showed the highest variations of salinity, with the lowest salinity overall recorded in Rodia and the highest in Logarou. In Rodia, some fresh water may seep in from an underground karstic network (Guelorget *et al*., 1986). Kormas *et al*. (2001) attributed the variations in physicochemical parameters in Tsoukalio, Rodia and Logarou to climatic factors (including rainfall and wind) and to the geomorphological characteristics of the lagoons (including depth and communication with the sea). Moreover, the terrestrial input of nitrates, mainly as land runoff, was enhanced by winter precipitation, which, at the same time, lowered the salinity (Kormas *et al*., 2001).

Data on the composition and distribution of benthic macrofauna of the lagoons are limited (Nicolaidou and Karlou, 1983; Nicolaidou *et al*., 1983, 1985; Guelorget *et al*., 1986; Reizopoulou *et al*., 1996; NCMR, 2000).

MDS, based on faunal similarities, showed that Tsopeli and Papas lagoons were characterized by the most diversified benthic populations. The dominant species forming the major part of the communities in the lagoons studied were characteristic of brackish-water lagoons (e.g. *A. ovata*, *C. glaucum*, *I. baltica*, etc.) or characteristic of organically enriched areas (e.g. *C. capitata*, *H. filiformis*).

Spearman rank correlations (Table 4) between biotic and abiotic parameters showed that sediment characteristics and the degree of confinement were the major factors in controlling the biological organization of the lagoons studied.

Biodiversity and confinement

Diversity in the lagoons studied was comparable to that of other Mediterranean lagoons (Amanieu *et al*., 1977; Gravina *et al*., 1989; Dounas *et al*., 1998; Koutsoubas *et al*., 2000). Low diversity is a result of the very variable environmental conditions in the lagoons, which are due to their shallowness and their restricted communication with the marine environment. Natural stress levels increase with increase in confinement, which results in a decrease in the variety of species and an increase in the abundance/number density of individuals of a few species (Guelorget and Perthuisot, 1983, 1992).

The results of this investigation indicate that the confinement concept could also be extended to community diversity, which is a function of both species diversity and composition. Diversity indices decreased with increasing degree of confinement within the lagoons; the highest values were recorded adjacent to the canals of communication with the marine environment. This is similar to observations in other Mediterranean lagoons (Zaouali, 1982; Guelorget and Perthuisot, 1983, 1992; Dounas *et al*., 1998; Koutsoubas *et al*., 2000). The so-called 'thalassic' species were recorded in the areas of more marine influence; conversely, the so-called 'paralic' species were restricted to stations far from the open sea. The bivalve *A. ovata* was a very common and abundant species, and in many cases the variations of abundance of this bivalve reflected the degree of the confinement of the lagoons studied.

The highest values of species diversity were observed mostly in spring and autumn, as in other Mediterranean lagoons (Gravina *et al*., 1989). The seasonal variations of diversity H' reflected the seasonally high numerical abundance of a few dominant species, such as *A. ovata*, *C. glaucum*, and *H. diversicolor*, which often accounted for approximately 90% of the individuals.

Sediment particle size was also important in controlling diversity in the present study. However, the role of the sediment type is not easily distinguished from that of confinement, since they are both dependent on the water circulation of the lagoon. According to Frisoni *et al*. (1984), hydrological factors rather than hydrochemical or sedimentological factors are the most important in affecting the biological organization of Mediterranean lagoons. Inflow of fresh water and its contribution of nutrients are also very important for the fauna differentiation in some coastal lagoons in central Italy (Gravina *et al*., 1989).

The degree of confinement is directly linked to the level of biodiversity in brackish-water Mediterranean lagoons. Barnes (1994), in a critical appraisal of the application of the paralic ecosystem model, concluded that 'confinement' may be applicable to large and microtidal open lagoons, but it cannot describe the distribution of organisms in estuaries of macrotidal regions in Europe. An independent evaluation of the confinement model based on physical predictors (Millet and Guelorget, 1994), rather than on the fauna, might give a better insight on the role of confinement on benthic biodiversity of lagoons.

Is community diversity efficient enough in assessing the ecological status of the lagoons?

Organic enrichment, both natural and anthropogenic, is one of the most common forms of disturbance to the benthos. A positive correlation of macrofaunal densities with the organic carbon in the sediment was observed, but no clear relationship between diversity and organic enrichment was found.

The Shannon–Wiener index is probably the most commonly used tool in the assessment of pollution in the marine environment. However, the lagoonal environment, and the associated natural stresses, causes the disappearance of rare species and density increases of certain specific lagoonal species. In the lagoons studied, benthic diversity H' was not proved to be a sensitive enough tool for distinguishing polluted (Papas) from non-polluted lagoons (Tsopeli).

However, changes of community diversity were observed as a consequence of natural fluctuations of environmental parameters in all the lagoons studied. Elevated salinity fluctuations occurred in some lagoons due to decreased fluvial inputs (Tsoukalio, Rodia and Logarou) and to alterations in canal openings in Tsopeli. Other human activities, such as agricultural practices, caused dystrophic crises in Papas lagoon. In lagoonal ecosystems, which are very complex systems, hydrological, sedimentological and anthropogenic activities could have a synergistic effect on biodiversity. Consequently, the evaluation of the ecological status in lagoons is difficult because, in such an extreme natural environment, it is not easy to separate the effects of natural and 'man-induced' effects.

However, other methods based on the concept of indicator species (Reizopoulou and Nicolaidou, 2003), or on the distribution of the body size of benthic organisms (Reizopoulou *et al*., 1996), have been shown to be relatively sensitive in assessing pollution in lagoons.

Thus, the methodological approach for detecting disturbance in lagoons is essential in assessing the carrying capacity of the system, and the role of the confinement in limiting the managerial potential in such transitional zones should not be underestimated.

Further research in comparative studies of various lagoonal systems is needed to identify the spatial and temporal patterns in such complex ecosystems. This could be helpful, not only for a better understanding of lagoonal systems, but also to point out a general model governing lagoons, without excessive emphasis on local variability, thus focusing toward developing large-scale management and conservation policies.

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