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Biological components of Greek lagoonal ecosystems: an overview

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Abstract

The paper summarises the available information on the main biological components – phytoplankton, zooplankton, phytobenthos, zoobenthos and fish – of Greek lagoonal ecosystems. Meiobenthos was also studied in one of the lagoons. All components show great variability both in space and time, which is attributed to the variability of environmental conditions. The most important variable influencing species distribution and diversity is the degree of communication with the sea and the nutrient load introduced through fresh water inputs. Certain new methods, which have been applied for evaluation of the ecological quality state of the lagoons, are also presented.

Keywords: Lagoons; Benthos; Plankton; Fish; Pollution; Mediterranean.

Introduction

Coastal lagoons are transitional areas between land and sea, formed, in most cases, in river deltas (ZALIDIS & MANTZAVELAS, 1994). They are enclosed water bodies separated from the sea by depositional barriers with one or more narrow

openings allowing limited water exchange with the sea. Due to their formation, they are shallow areas, sheltered from strong waves and currents, with muddy or sandy bottoms often covered by macrophytes. Since there are no significant tides, the water circulation in the lagoons is mostly con-

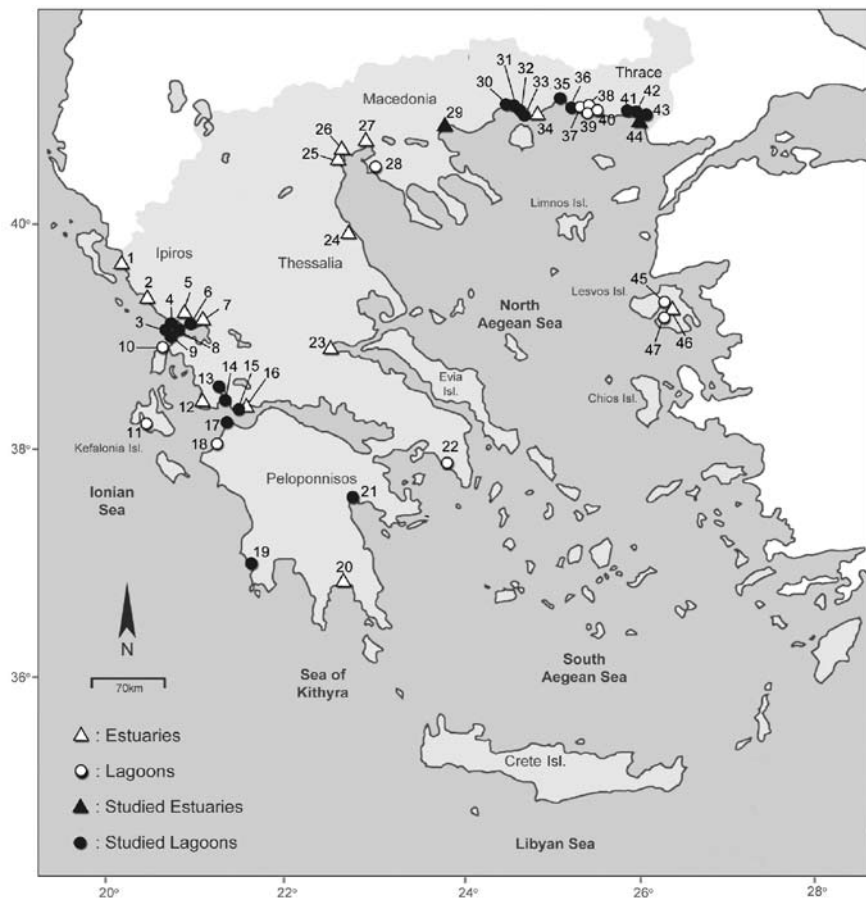


Fig. 1: Map of Greece showing main transitional coastal ecosystems (estuaries and lagoons). Dark symbols indicate ecosystems for which detailed information exists and are treated in this paper.

- | | | | |
|--------------------------|--------------------------|----------------------------------|----------------------------|
| 1: Kalamas Est. | 13: Aitoliko Lag. (●) | 25: Aliakmonas Est. | 37: Karatza Lag. |
| 2: Acherontas Est. | 14: Messolonghi Lag. (●) | 26: Axios Est. | 38: Alyki Lag. |
| 3: Mazoma Lag. (●) | 15: Kleisova Lag. (●) | 27: Gallikos Est. | 39: Ptelea Lag. |
| 4: Tsopeli Lag. (●) | 16: Evinos Est. | 28: Epanomi Lag. | 40: Elos Lag. |
| 5: Louros Est. | 17: Papas Lag. (●) | 29: Strymonas Est. | 41: Laki Lag. (●) |
| 6: Rodia Lag. (●) | 18: Kotychi Lag. | 30: Vassova Lag. (●) | 42: Drana Lag. (●) |
| 7: Arachthos Est. | 19: Gialova Lag. (●) | 31: Erateino Lag. (●) | 43: Monolimni Lag. (●) |
| 8: Logarou Lag. (●) | 20: Evrotas Est. | 32: Agiasma Lag. (●) | 44: Evros Est. (▲) |
| 9: Tsoukalio Lag. (●) | 21: Vivari Lag. (●) | 33: Keramoti Lag. (●) | 45: Alyki Kallonis Lag. |
| 10: Stenou Lefkadas Lag. | 22: Vouliagmeni Lag. | 34: Nestos Est. | 46: Vouvaris Est. |
| 11: Koutavos Lag. | 23: Spercheios Est. | 35: Porto Lagos Lag. | 47: Alyki Polychnitou Lag. |
| 12: Acheloos Est. | 24: Pineios Est. | 36: Fanari or Xsirolimi Lag. (●) | |

trolled by meteorological conditions, especially intensity and direction of the wind.

The most extensive lagoonal systems are lo-

cated in Western and Northern Greece (Fig. 1). The most important are protected under the Ramsar convention or are part of the Natura

2000 network (Table 1). Almost all are used for the extensive culture of fish. The Greek lagoons are not all equally explored scientifically. More attention has been paid to the lagoons of Amvrakikos Bay (NICOLAIDOU & KARLOU, 1983; NICOLAIDOU *et al.* 1985; NICOLAIDOU & KARAKIRI, 1989, REIZOPOULOU *et al.* 1998; CHRISTAKI & GOTSIS-SKRETAS, 1990; KORMAS *et al.* 2001, REIZOPOULOU & NICOLAIDOU, 2004, NICOLAIDOU *et al.* 2006) while the most comprehensive study was carried out in Gialova, on the Southwest Peloponnese (ARVANITIDIS *et al.* 1999; PETIHAKIS *et al.* 1999; KOUTSOUBAS *et al.* 2000a,b; McARTHUR *et al.* 2000, TRIANTAFYLLOU *et al.* 2000) (Table 2). Different aspects of the numerous eastern Macedonian and Thrace lagoons, such as phytobenthos (ORFANIDIS *et al.*, 2000, 2001a,b; MALEA *et al.*, 2003, 2004), zoobenthos (KEVREKIDIS, 1997, 2004a; GOUVIS & KOUKOURAS, 1993, GOUVIS *et al.*, 1997) and fishes (KOUTRAKIS & TSIKLIRAS, 2003) were also explored.

This paper gives an account of the available information on the main biological components of Greek lagoonal ecosystems in an effort to highlight the distribution of species and their variability in space and time. Certain new methods which have been applied for evaluation of the ecological quality state of the lagoons are also presented. A summary can also be found in SoHelME (2005).

Phytoplankton

In terms of species composition, phytoplankton in lagoons is poorer than neritic phytoplankton. It is frequently enriched by benthic diatoms, which, due to the small depth of the lagoons, are put to suspension by the wind. In addition, neritic species enter passively from the sea and remain in the lagoon for a period of time. Thus, in the most enclosed lagoons, for example in Rodia of Amvrakikos, cryptophytes, such as *Rhodomonas* sp. and *Cryptomonas* sp., are the most abundant genera, while, where

communication with the sea is greater, as in Logarou, the prevalent species are diatoms, such as *Rhizosolenia fragilissima* and *Nitzschia closterium* and the dinoflagellates *Scrippsiella trochoidea* and *Procentrum scutellum* (CHRISTAKI & GOTSIS-SKRETAS, 1990). In semi-enclosed lagoons, such as Gialova (DOUNAS & KOUTSOUBAS, 1996) the diatoms are rather few, restricted to the marine channels, while dinoflagellates (*Oxyrrhis marina*, *Goiniodoma sphaericum*, *Peridinium depressum* and *Gymnodinium heterostriatum*) are quite well represented especially in the innermost part of the lagoon.

The abundance of phytoplankton varies not only between lagoons and seasons but also between stations in the same lagoon. Maximum concentrations are observed at the end of winter, beginning of spring. Total phytoplankton abundance usually ranges between 3×10^4 to 2×10^6 cells/l but concentrations of up to 4.4×10^7 cells/l, belonging mostly to nanoplankton, have been reported under slightly polluted conditions. Such blooms tend to be monospecific and localised (GOTSIS-SKRETAS & SATSMADJIS, 1989/90).

Qualitative and quantitative variability in lagoonal phytoplankton is attributed to variability of environmental conditions, such as salinity and nutrient concentrations, which are related to freshwater inputs and mixing with seawater (GOTSIS-SKRETAS & SATSMADJIS, 1989/90).

Zooplankton

Spatial and temporal variability, both in terms of numbers of species and individuals, is also observed in the zooplankton community. In the mesozooplankton, density ranges from few individuals per m^3 to approximately 4500 indiv./ m^3 (SIOKOU-FRANGOU, 1986). Copepods are the dominant group. In the inner parts of lagoons the zooplankton consists of brackish water species, such as *Calanipeda aquaedulcis*, accompanied, or replaced depending on the season, by eury-

Table 1

Characteristics of lagoons and parameters studied.

(A=Actoliko, Ag=Agiasma, E=Eratino, F=Fanari, G=Gialova, K=Keramoti, L=Logarou, Ma= Mazoma, Me=Messolonghi, P=Papas, R=Rodia, T=Tsopeli, Ts=Tsoukhalio, Va=Yassova). (F=Fisheries, AE=Extensive aquaculture, ASJ=Semi-intensive aquaculture, DC=Dystrophic crisis, D=Drainage) (Sampling frequency: * =occasional, ** =seasonal, *** =seasonal, more than one year)

LAGOONS	Amvrakikos Gulf			Patraikos Gulf			Ionian Sea			Eastern Macedonia & Thrace			Evros Delta			
	Ma	T	Ts	R	L	Me	A	P	G	Va	E	Ag	Ke	F	F	
Size (km)	1.6	1	16.5	13.5	25.7	100	26	3	2.5	0.8	3.0	3.9	1.0	1.9		
Exploitation	AE, F	F, AE, ASI	F, AE, ASI	F, AE, ASI	F, AE, ASI	F, AE, ASI	F, AE	F, AE	F, AE	F, AE	F, AE	F, AE	F, AE	F, AE	F	F, AE
Conservation	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR	NATURA	NATURA	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR	RAMSAR
Human impact							DC	DC	DC						D	
Abiotic	*	***	***	***	***	***	***	***	***	*	*	*	*	*	***	***
Plankton			**				**	**	**							
Phyto-benthos	*	**	**	**	**	**	**	**	*	**	**	**	**	*	**	**
Zoo-benthos	*	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Fishfauna						*	*	*	*	*	*	*	*	*	**	**

Table 2

Environmental characteristics of Greek lagoons.

(A=Actoliko, E=Eratino, G=Gialova, K=Klissova, L=Logarou, Ma= Mazoma, Me=Messolonghi, P=Papas, R=Rodia, T=Tsopeli, Ts=Tsoukhalio, Va=Yassova).

Lagoons	Amvrakikos Gulf			Patraikos Gulf			Ionian Sea			Eastern Macedonia & Thrace			Evros Delta			
	Ma	T	Ts	R	L	K	Me	A	P	G	Va	E	F	F	F	
Depth (m)	1.0 - 2.0	0.2 - 1.5	1.6 - 5.2	2.9 - 5.2	0.7 - 1.0	0.2 - 2.0	0.20 - 2.0	0.3 - 30.0	0.2 - 1.5	0.3 - 1.2	0.2 - 4.0	0.2 - 3.0	0.2 - 0.4			
S (psu)	23.0 - 27.0	21.0 - 38.0	14.0 - 36.5	5.0 - 35.0	15.8 - 48.6	23.0 - 41.0	37.0 - 45.0	18.5 - 23.5	20.0 - 42.5	13.0 - 60.0	26.1 - 34.6	19.3 - 34.2	4.0 - 25.0			
T (°C)	9.0 - 13.0	8.0 - 29.0	8.6 - 30.0	8.9 - 29.1	9.1 - 28.1	20.5 - 21.6	24.5 - 27.9	15.5 - 25.3	10.0 - 32.0	14 - 31	2.0 - 31.5	2.0 - 31.5	12.6 - 24.5			
O2 (mg/l)	4.8 - 6.8	2.8 - 9.8	4.6 - 10.6	3.5 - 10.8	4.5 - 12.1	5.0 - 6.7	4.2 - 7.9	4.5 - 7.3	1.2 - 9.3	4.5 - 9.1	4.2 - 22.0	4.3 - 15.2				
Coarse %	-	6.7 - 66.3	8.3 - 79.0	12.0 - 77.5	6.4 - 32.0	19.9 - 35.6	2.0 - 76.8	9.1 - 11.1	23.0 - 98.0	14.5 - 94.7	-	-	147 - 208*			
Org. C %	-	1.1 - 5.3	1.3 - 5.1	1.2 - 5.0	2.2 - 3.5	1.6 - 3.6	0.9 - 5.1	2.4	2.9 - 5.6	0.2 - 5.0	2.2 - 7.8	3.2 - 6.1	0.4 - 1.3			

* =Median diameter (φ)

Basic sources: Amvrakikos Gulf: REIZOPOULOU & NICOLAIDOU, 2004; NICOLAIDOU *et al.*, 2006; Patraikos Gulf: BOGDANOS & DIAPOLILIS 1984; Ionian Sea: KOUTSOBAS *et al.*, 2000b, Evros Delta: GOUVIS *et al.*, 1997; KEVREKIDIS, 1997; KEVREKIDIS, 2004a; MOGIAS & KEVREKIDIS, 2005; MOGIAS 2005.

haline species such as *Acartia latisetosa*, *A. clausi* and *Centropages kroyeri* and invertebrate larvae of barnacles, molluscs, decapods and polychaetes. In the outer parts euryhaline species including *Acartia latisetosa*, *A. clausi*, *A. discaudata* and *Oithona nana* are dominant. These copepods are often accompanied by meroplanktonic larvae and benthic amphipods. Close to the sea, typically marine species, such as *Temora stylifera*, *Oithona plumifera*, *Paracalanus parvus* and *Clausocalanus furcatus* enter the lagoons with currents.

Micro-zooplankton in coastal lagoons is represented mostly by ciliates such as *Strombidium* spp., *Lohmaniella oviformis* and *Tintinopsis* spp. Densities vary considerably and range from 0.1 to 50 X 10⁶ indiv./m³, depending on the prevailing environmental conditions, season and distance from the point of communication with the sea (DOUNAS & KOUTSOUBAS, 1996).

Phytobenthos

Benthic vegetation in lagoons consists of a small number of species and associations. The dominant phytobenthic species are shown in Table 3. The following five associations (*sensu* the "Zürich-Montpellier School") are considered most important:

1. Association with *Ruppia cirrhosa* and/or *Ruppia maritima*
2. Association with *Zostera noltii*
3. Association with *Cymodocea nodosa*
4. Association with *Cystoseira barbata*, *Gracilaria* spp., *Cladophora* spp. and *Ulva* spp.
5. Association with *Lamprothamnion papulosum*
6. Association with *Zannichellia palustris*

Seaweeds

The four main classes of seaweeds (15 Chlorophyceae, 1 Charophyceae, 4 Phaeophyceae, 24 Rodophyceae) are recorded in the Greek lagoons (Table 3). Characteristic Rodophyceae are species of the genus *Gracilaria*,

of which the most abundant is *G. bursa-pastoris*. Other abundant Rodophyceae are *Chondria tenuissima* and *Polysiphonia elongata*. During summer and autumn the species of tropical affinity *Hypnea musciformis* and *Acanthophora najadiformis* are recorded. Characteristic Chlorophyceae are species of the genera *Ulva*, *Chaetomorpha* and *Cladophora*. The most characteristic of Phaeophyceae is the species *Cystoseira barbata*.

The Charophyceae, regarded as a class of the Chlorophyta, despite their highly distinctive thallus and reproductive organs, are represented by the genus *Lamprothamnion* recorded in the Amvrakikos Gulf.

The diversity varies seasonally and is higher during summer and autumn due to the growth of tropical affinity species in the Vassova lagoon, Nestos Delta (ORFANIDIS *et al.*, 2001b). By contrast, biomass values are higher during winter (max. dry biomass 1276 g/m²) possibly due to higher loads of nutrients during this period.

Angiosperms

The angiosperms, annual or perennial rooted flowering plants, recorded in Greek transitional waters, belong mainly to the genera *Ruppia*, *Zostera*, *Cymodocea* and *Zannichellia* (Table 3).

Ruppia is a cosmopolitan genus, characteristic of many coastal brackish waters and inland salt-water habitats. Its tolerance to salinity fluctuations (total range ca. 3 to 101psu) is enormous (VERHOEVEN, 1979). Two different species of *Ruppia* were recorded in the Greek lagoons: *R. cirrhosa* and *R. maritima*. They form dense submerged meadows in many lagoons, especially in Macedonia and Thrace. The growth of *R. maritima* meadows in Evros Delta is regulated by temperature, being maximum during the warm period of the year (MALEA *et al.*, 2004).

Zostera noltii is the only species of this genus inhabiting Greek lagoons. It has a relatively restricted distribution, found mainly in the lagoons of the Amvrakikos Gulf.

Cymodocea nodosa is a characteristic

Table 3

Presence of common benthic macrophytes at each lagoon.
 (A=Aetoliko, Ag=Agasma, D=Drana, E=Eratino, F=Fanari, Ke=Keramoti, L=Logarou, La=Laki, Ma=Mazoma, Me=Messolonghi, Mo=Monolimni, P=Papas, R=Rodia, T=Isopeli, Ts=Tsoukalio, Va=Vassova).

* dominant species, (absence of a mark does not indicate absence of the species)

Species	Lagoons			Amvrakikos Gulf					Patraikos Gulf					Eastern Macedonia & Thrace					Evros Delta		
	Ma	T	Ts	R	L	Me	A	P	Va	E	Ag	Ke	F	La	Mo	D	La	Mo	D		
Phaeophyceae																					
<i>Cystoseira barbata</i> C. Agardh									*	*	*										
<i>Ectocarpus siliolosus</i> (Dillwyn) Kjellman																				*	
<i>Ectocarpus</i> sp.																				*	
<i>Feldmaniasp.</i>																				*	
Rhodophyceae																					
<i>Acanthophora najadiiformis</i> (Delile) Papenfuss									*												
<i>Ceramium flaccidum</i> (Kützting) Ardissone									*												
<i>Ceramium rubrum</i> (Hudson) C. Agardh																				*	
<i>Ceramium circinatum</i> (Kützting) J. Agardh																				*	
<i>Ceramium diaphanum</i> (Lightfoot) Roth																				*	
<i>Ceramium</i> spp.																			*	*	
<i>Sylonema alsidii</i> (Zanardini) Drew																				*	
<i>Sylonema cornu-cevri</i> Reinsch																				*	
<i>Gelidium pusillum</i> (Stackhouse) Le Jolis																				*	
<i>Bangia</i> sp.																				*	
<i>Erythrotrichia carnea</i> (Dillwyn) J. Agardh																				*	
<i>Chondria tenuissima</i> (Goodenough & Woodward) C. Agardh								*	*	*	*	*	*							*	
<i>Chondria dasiphyllo</i> (Woodward) C. Agardh																				*	
<i>Gracilaria armata</i> (C. Agardh) J. Agardh																				*	
<i>Gracilaria bursa-pastoris</i> (Gmelin) Silva					*			*	*	*	*	*	*							*	
<i>Gracilaria verrucosa</i> (Hudson) Papenfuss																				*	
<i>Herposiphonia secunda</i> f. <i>tenella</i> (C. Agardh) Wynne								*	*	*	*	*	*							*	
<i>Nitophyllum</i> sp.																				*	
<i>Hypnea musciformis</i> (Wulfen) Lamouroux									*	*	*	*	*							*	
<i>Laurencia obtusa</i> (Hudson) Lamouroux								*												*	
<i>Laurencia</i> sp.																				*	

(Continued)

Table 3 (continued)

Presence of common benthic macrophytes at each lagoon. (A=Aetoliko, Ag=Agiasma, D=Drana, E=Eratino, F=Fanari, Ke=Keramoti, L=Logarou, La=Laki, Ma=Mazoma, Me=Messolonghi, Mo=Monolimni, P=Papas, R=Rodia, T=Tsopeli, Ts=Tsoukalio, Va=Vassova).
* dominant species, (absence of a mark does not indicate absence of the species)

Species	Lagoons			Amvrakikos Gulf			Patraikos Gulf			Eastern Macedonia & Thrace			Evros Delta			
	Ma	T	Ts	R	L	Me	A	P	Va	E	Ag	Ke	F	La	Mo	D
<i>Lophosiphonia</i> spp.									*	*	*	*	*	*	*	*
<i>Polysiphonia elongata</i> (Hudson) Sprengel									*	*	*	*	*	*	*	*
<i>Polysiphonia</i> sp.									*	*	*	*	*	*	*	*
Chlorophyceae																
<i>Acetabularia acetabulum</i> (Linnaeus) Silva					*	*										
<i>Chaetomorpha aerea</i> (Dillwyn) Kützting								*	*	*	*	*	*	*	*	*
<i>Chaetomorpha mediterranea</i> (Kützting) Kützting									*	*	*	*	*	*	*	*
<i>Chaetomorpha linum</i> (O.F. Möller) Kützting														*		
<i>Chaetomorpha</i> sp.							*									
<i>Cladophora liniformis</i> Kützting									*			*	*	*	*	*
<i>Cladophora rupestris</i> (Linnaeus) Kützting														*	*	*
<i>Cladophora prolifera</i> (Roth) Kützting								*	*	*	*	*	*	*	*	*
<i>Cladophora</i> spp.								*	*	*	*	*	*	*	*	*
<i>Enteromorpha flexuosa</i> (Wulfen ex Roth) J. Agardh														*	*	*
<i>Enteromorpha compressa</i> (Linnaeus) Greville														*	*	*
<i>Enteromorpha prolifera</i> (O.F. Möller) J. Agardh														*	*	*
<i>Enteromorpha linza</i> (Linnaeus) J. Agardh														*	*	*
<i>Enteromorpha</i> spp.		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<i>Ulva</i> spp.					*	*	*	*	*	*	*	*	*	*	*	*
Charophyceae																
<i>Lamprothamnion</i> sp.			*	*	*	*										
Potamogetonales																
<i>Cymodocea nodosa</i> (Ucria) Aschers					*	*	*	*	*	*	*	*	*	*	*	*
<i>Ruppia cirrhosa</i> (Petagna) Grande					*	*	*	*	*	*	*	*	*	*	*	*
<i>Ruppia maritima</i> Linnaeus			*	*	*	*	*	*	*	*	*	*	*	*	*	*
<i>Zostera noltii</i> Hornem		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<i>Zamichellia palustris</i> Linnaeus																*

* (see also HAYDEN *et al.*, 2003). Basic sources: Amvrakikos Gulf (LAZARIDOU *et al.*, 2002), Patraikos Gulf (BOGDANOS & DIAPOULIS, 1984), Evros Delta (MALEA *et al.*, 2003; 2004), Eastern Macedonia & Thrace ORFANIDIS *et al.*, 2001)

angiosperm of several Greek coasts forming extensive meadows from the sea surface down to 10 m depths. A recent attempt to limit freshwater inflow in the lagoons, as a measure against eutrophication, increased their water salinity and may have favored the growth of this species (ORFANIDIS *et al.* 2001a).

The freshwater genus *Zannichellia* has been found in the Evros Delta.

Meiofauna

Meiofauna has only been studied in Gialova lagoon, where 18 meiofaunal taxa were found (McARTHUR *et al.*, 2000). These are: foraminiferans, ciliates, cnidarians, turbellarians, gnathostomulids, gastrotrichs, nematodes, nemertines, rotifers, gastropod and bivalve molluscs, annelids, amphipods, harpacticoid copepods, dipteran larvae, bryozoans, holothuroids and ascidians. Densities ranged from 17 to over 2.000 individuals per 10 cm², with nematodes and copepods being the most abundant taxa. The distribution pattern of the meiofaunal community varied both across the lagoon and over the seasons. On the basis of the spatial differences a meiofaunal coenocline, correlated with the degree of isolation, was observed, composed of mainly two zones: one comprising the area close to the marine channel and the other the more isolated area in the inner lagoon. Meiofaunal distribution pattern, however, was not clearly correlated to a single environmental variable: apart from purely physical and chemical characteristics it was also associated with food supply.

Zoobenthos

Macrozoobenthos is the ecosystem component most studied in Greek lagoons (e.g. NICOLAIDOU *et al.*, 1983, 1985, 2006; DOUNAS *et al.*, 1998; ARVANITIDIS *et al.*, 1999; KOUTSOUBAS *et al.*, 2000a; GOUVIS & KOUKOURAS, 1993; KEVREKIDIS 1997, 2004a; KEVREKIDIS *et al.*, 2000; REIZOPOULOU & NICOLAIDOU, 2004;

MOGIAS & KEVREKIDIS, 2005). The most abundant species in each lagoon are shown in Table 4.

Four main groups of benthic invertebrates are found in coastal brackish water lagoons, depending on their hydrologic and trophic status: i) fresh water species, ii) euryhaline brackish water species iii) marine species preferring shallow sheltered areas, and iv) opportunistic species. The first group is represented by chironomid larvae and oligochaetes and it is found in areas isolated from the sea with increased fresh water input. The typically euryhaline brackish water species include the molluscs *Cyclope neritea*, *Abra segmentum*, *Mytilaster minimus*, and *Cerastoderma glaucum*, the polychaete *Hediste diversicolor*, and the crustacean *Gammarus aequicauda*. They are the most widely distributed and highly abundant species. Characteristic marine species of shallow areas are the mollusc *Loripes lacteus*, the polychaete *Nephtys hombergii* and the amphipod *Corophium insidiosum*. Finally the opportunistic species, commonly found in abundance in organically enriched areas, include the polychaete species *Capitella capitata*, *Heteromastus filiformis*, *Polydora ciliata* and *Hydroides dianthus*. Apart from the hydrological and trophic status of the lagoon, the relative importance of each group of species varies according to season and the life cycle of the dominant species.

Some of the dominant species have received special attention in relation to their life-cycle and population dynamics. They are the polychaete *Streblospio shrubsolii* (KEVREKIDIS, 2005), the bivalve molluscs *Abra segmentum* (NICOLAIDOU & KOSTAKI-APOSTOLOPOULOU, 1988; KEVREKIDIS & KOUKOURAS, 1992; GONTIKAKI *et al.*, 2003), *Mytilaster minimus* (NICOLAIDOU & ANAGNOSTAKI, 1983) and the amphipods *Gammarus aequicauda* (KEVREKIDIS & LAZARIDOU-DIMITRIADOU 1988, KEVREKIDIS & KOUKOURAS, 1988-89, 1989), *G. insensibilis*, *Dexamine spinosa*, *Microdeutopus*

Table 4

Dominant benthic animal species at each lagoon.

(A= Aetoliko, C=Coast, D=Drana, G=Gialova, I=Isolated shallows, K=Klissova, La=Laki, L=Logarou, Ma= Mazoma, Me=Messolonghi, Mo=Monolimni, P=Papas, R=Rodia, T=Tsopei, Ts=Tsoukalio, V=Vivari). * dominant species, + locally or occasionally important species (absence of a mark does not indicate absence of the species)

Species	Lagoons					Amvrakikos Gulf					Patraikos Gulf		Ionian Sea	Aegean Sea		Evros Delta				
	Ma	T	Ts	R	L	K	Me	A	P	G	V	C	La	Mo	D	I				
Mollusca																				
<i>Abra alba</i>						+	+													
<i>Abra segmentum</i>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
<i>Bittium reticulatum</i>										+										
<i>Cerastoderma glaucum</i>		+	*		*	*	*	*	+	*										
<i>Cerithium vulgatum</i>										*										
<i>Cyclope neritea</i>			*	+	+					+										
<i>Haminoea hydatis</i>					*															
<i>Hydrobia acuta</i>										*										
<i>Hydrobia ulvae</i>									+											
<i>Hydrobia ventrosa</i>		+			+															
<i>Ventrosia maritima</i>												*	*	*	*	*				
<i>Loripes lacteus</i>				*	*				+											
<i>Mytilaster minimus</i>	*	+	*	*		*	*													
<i>Mytilus galloprovincialis</i>									*											
<i>Pirenella conica</i>										*										
<i>Tapes decussatus</i>										+										
Polychaeta																				
<i>Arandia cirrosa</i>							*	+	*											
<i>Capitella capitata</i>						+	+	+	*			*								
<i>Chaetozone</i> sp.											*									
<i>Exogone hebes</i>								+												
<i>Exogone verrugera</i>											+									
<i>Harmothoe spinifera</i>			+																	
<i>Hediste diversicolor</i>					+	*	*		+	*	*	*	*	*	*	*				
<i>Heteromastus filiformis</i>		*			+				+	+	*									
<i>Hydroides dianthus</i>										*										
<i>Lumbrineris latreilli</i>						+	+													
<i>Malacoceros fuliginosus</i>						*	*			+										
<i>Microspio mecnikowianus</i>			+		+															
<i>Nainereis laevigata</i>	*		+	+																
<i>Neanthes caudata</i>						+	*													
<i>Neodexiospira pseudocorrugata</i>										*										
<i>Nephtys hombergi</i>	*	+	*	+	*															
<i>Notomastus latericeus</i>							*	+												
<i>Ophiodromus pallidus</i>								*												
<i>Owenia fusiformis</i>		+																		
<i>Perinereis cultifera</i>										*										
<i>Platynereis dumerilii</i>			+																	

(continued)

Table 4. (continued)

Lagoons	Amvrakikos Gulf				Patraikos Gulf				Ionian Sea	Aegean Sea	Evros Delta					
	Ma	T	Ts	R	L	K	Me	A	P	G	V	C	La	Mo	D	I
<i>Phyllodoce</i> sp.			+													
<i>Polydora ciliata</i>					+											
<i>Polyophthalmus pictus</i>						+										
<i>Protoaricia oerstedii</i>				+			*									
<i>Streblospio shrubsolii</i>							+						*	*		
<i>Syllis prolifera</i>								*								
Crustacea																
Cirripedia																*
<i>Corophium acherusicum</i>						+										
<i>Corophium insidiosum</i>										*						+
<i>Corophium orientale</i>													*	*	*	
<i>Erichthonius brasiliensis</i>					+											
<i>Erichthonius difformis</i>				*												
<i>Gammarus aequicauda</i>										+			*	*	*	
<i>Gammarus crinicornis</i>										+						
<i>Gammarus insensibilis</i>			*						+	+						
<i>Gammarus subtypicus</i>										+						
<i>Idotea baltica</i>		*	+	+	*					*						
<i>Iphinoe serrata</i>				*		*	*									
<i>Leptochelia savignyi</i>				+				+								
<i>Melita palmata</i>								+								
<i>Microdeutopus anomalus</i>							+	*								
<i>Microdeutopus gryllotalpa</i>		+			+				*	*		+				
<i>Microdeutopus</i> sp.			+	+												
<i>Phtisica marina</i>								+								
<i>Sphaeroma ghigii</i>			*		+											
<i>Sphaeroma serratum</i>									*							
<i>Tanais cavolinii</i>		*														
<i>Upogebia litoralis</i>										+						
Miscellanea																
<i>Amphipholis squamata</i>									*							
Actinaria				*	+	+		+	+	+		+				
Chironomidae	+	*		*	+				+	*					*	
Nematoda									+	+						
Nemertea		+	+							+						
Oligochaeta							*	*	+	*				*		
Ophiuroidea								+								
<i>Phoronis muelleri</i>		+														

Basic sources: Amvrakikos Gulf: REIZOPOULOU *et al.*, 1996; REIZOPOULOU & NICOLAIDOU, 2004; NICOLAIDOU *et al.*, 2006; Patraikos Gulf: BOGDANOS & DIAPOULIS, 1984; NICOLAIDOU *et al.*, 1983; Ionian Sea: KOUTSOUBAS *et al.*, 2000b; Evros Delta: GOUVIS *et al.*, 1997; KEVREKIDIS, 1997; KEVREKIDIS *et al.*, 2000; KEVREKIDIS, 2004a; MOGIAS & KEVREKIDIS, 2005.

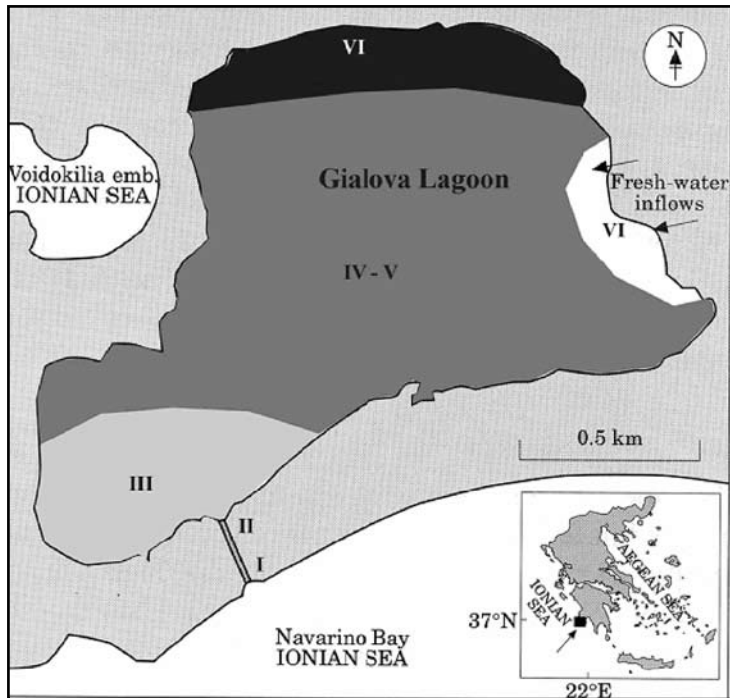


Fig. 2: Biological Zonation in Gialova lagoon, according to the scheme proposed by GUELORGET & PERTHUISOT (1992) for Mediterranean lagoons.

gryllotalpa (KARAKIRI & NICOLAIDOU, 1987), *Corophium insidiosum* (KARAKIRI & NICOLAIDOU, 1987; KEVREKIDIS, 2004b) and *Corophium orientale* (KEVREKIDIS *et al.*, 2004; KEVREKIDIS in press).

It is worth mentioning the dominance of the mudsnail *Ventrosia maritima*, a typical lagoonal species, found mainly in isolated areas of Evros Delta. This mud-snail was only known from the Black Sea. However, utilizing DNA sequencing and phylogenetic analyses, the occurrence of this species was recently ascertained in the Evros Delta. The first detailed data concerning the ecology and distribution of *Ventrosia maritima* in a lagoon system, its life cycle, population dynamics and productivity, were given by KEVREKIDIS *et al.* (2005) and KEVREKIDIS & WILKE (2005).

The most important variable shaping species composition and macrobenthic community structure is the degree of communica-

tion with the sea, or *confinement*, described by GUELORGET & PERTHUISOT (1992) as the time required for a lagoon to renew its marine elements. Six zones, as described in the model, have been found in Greek lagoons: Zone I, which is a continuation of the sea, with strictly marine species, Zone II, where the more stenohaline marine species are lost, Zone III, with mixed species, Zone IV, with strictly brackish water species, Zone V with only vagile fauna and freshwater (hypohaline) or evaporitic (hyperhaline) species and finally, Zone VI, which shows almost total colonisation of substratum by Cyanobacteria. Some or all of the zones are present in each lagoon, as shown in Figure 2 for the lagoon Gialova. The limits of the zones may show seasonal shifts indicating the dynamic character of the lagoonal environment (KOUTSOUBAS *et al.*, 2000b).

The degree of confinement affects community diversity (REIZOPOULOU & NICO-

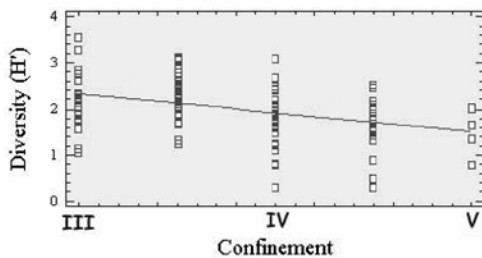


Fig. 3: Regression of diversity against confinement (based on data from the lagoons of Amvrakikos, Messolonghi, Papas, Vivari, and Gialova).

LAIDOU, 2004). There is a negative correlation ($p=0.0001$) between confinement and diversity (Fig. 3). Lowest diversity is observed in enclosed lagoons, most isolated from the marine environment, while in lagoons with an important marine element and good water circulation, diversity is high. Such differences in diversity may be observed in the same lagoon where the inner parts show the lowest diversity and the canals of communication with the sea the highest.

Fishfauna

More than 30 fish species have been recorded from the Greek lagoonal systems under consideration (Table 5). They could be divided in three different categories: i) *typical lagoonal species*, which complete their whole life-cycle in lagoons such as *Aphanius fasciatus* and *Atherina boyeri* ii) *migratory marine/estuarine species* which reproduce in the sea, but which spend a period of their life in brackish waters, for example *Sparus aurata*, *Dicentrarchus labrax*, *Anguilla anguilla*, *Mugil cephalus*, *Chelon labrosus*, *Liza saliens*, *L. aurata*, *L. ramada*, *Diplodus sargus* and *Solea solea* and iii) *marine species* which are normally distributed in the sea and are occasionally or accidentally found in the lagoons e.g. *Gobius* spp., *Blennius* spp., *Diplodus annularis*, *D. puntazzo*, *Lithognathus mormyrus*, and *Salpa salpa*. The marine species extend in a narrow zone, influenced by the sea, while the permanent species occupy the innermost

part of the lagoonal systems where salinity, temperature, dissolved oxygen as well as other environmental variables present strong fluctuations. The migratory marine/estuarine species are also found in the inner parts of the lagoons but only during the most stable period, from spring to autumn.

In accordance with other biotic components of the lagoonal system, fish fauna is characterized by spatial and temporal variability, both in terms of numbers of species and individuals. Although temporal patterns vary significantly from lagoon to lagoon or even in the same lagoon inter-annually, there is a general tendency to have the most rich fish fauna, both in terms of species numbers and density, from spring to autumn, while during winter very few species and low densities are observed.

Most lagoons in Greece are used for the extensive culture of various fish species the majority of which belong to the migratory marine/estuarine species. Mean annual production varies significantly depending on the size of the lagoon while differences are also observed in the fish catch composition 10t in Gialova lagoon during 1986 to 2003 - mostly various species of grey mullet (*Liza saliens*, *L. aurata*, *L. ramada*), sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*); 45t in Papas lagoon during 1996 to 2000 - mostly the species referred above for Gialova and additionally eel (*Anguilla anguilla*) ZOU LIAS, 2003; over 200t in Messolonghi lagoon during 1988 to 1996 - mostly the aforementioned species and additionally *Chelon labrosus* and *Mugil cephalus*) (DIMITRIOU *et al.*, 1997).

Modelling

The simulation of lagoon ecosystem dynamics has an increased level of complexity compared with the simulation of open sea systems. Therefore, application of ecological models is required. Such an approach has been performed in Gialova lagoon where the European Regional Seas Ecosystem Model

Table 5. Fish species found in Greek Transitional Ecosystems.
(A=Aetoliko, Amv= Amvrakikos, D=Drana, G=Gialova, La=Laki, Me= Messolonghi, Nest=Western Macedonia and Thrace, P=Papas)

Species	Category	Common name (Greek/English)	Transitional Ecosystem	Com.
<i>Alburnus alburnus</i> (Linnaeus, 1758)	Freshwater	Sirko/Bleak	D	
<i>Anguilla anguilla</i> Linnaeus, 1758	Marine/Estuarine	Cheli/Eel	La, Nest, P, G, Me, A, Amv	+
<i>Aphanius fasciatus</i> Nardo, 1827	Lagoonal	Kounoupoposaro/Killifish	G, Me, A, La, D	
<i>Atherina boyeri</i> Risso, 1810	Lagoonal	Atherina/Big-scale sand smelt	P, G, La, D	
<i>Blennius</i> sp.	Marine	Saliara/Blenny	P	
<i>Carassius auratus</i> (Linnaeus, 1758)	Freshwater	Italiko/Goldfish	La, D	
<i>Chelon labrosus</i> Risso, 1826	Marine/Estuarine	Velanissa/ Thicklip grey mullet	Nest, P, G, Me, A, Amv	+
<i>Dicentrarchus labrax</i> Linnaeus, 1758	Marine/Estuarine	Lavraki/Sea bass	Nest, P, G, Me, A, Amv	+
<i>Diplodus annularis</i> Linnaeus, 1758	Marine	Sparos/Annular seabream	La, P, G, Me, A, Amv	+
<i>Diplodus puntazzo</i> Cetti, 1777	Marine	Mytaki/Sharpnose seabream	P, G, Me, A, Amv	+
<i>Diplodus sargus</i> Linnaeus, 1758	Marine/Estuarine	Sargos/White seabream	P, G, Me, A, Amv	+
<i>Diplodus vulgaris</i> Linnaeus, 1758	Marine	Sargopapas/Common two-banded seabream	P, Me, A, Amv	+
<i>Epinephelus aeneus</i> (Geofroy, 1817)	Marine	Sfirida/White grouper	P	+
<i>Gaidropsarus mediterraneus</i> (Linnaeus, 1758)	Marine	Shore rockling	La	
<i>Gambusia affinis</i> (Baird & Girard, 1853)	Freshwater	Kounoupoposaro/Mosquitofish	La	
<i>Gobius geniporus</i> Valenciennes, 1837	Marine	Govios/Slender gobby	G	
<i>Gobius</i> sp.	Marine	Govios/Gobby	P, Me, A	
<i>Knipowitschia caucasica</i> (Kawrajsky in Berg, 1916)	Lagoonal	Pontogovios/ Gobby	La, D	
<i>Lepomis gibbosus</i> (Linnaeus, 1758)	Freshwater	Eliopsaro/Pumpkinseed	D	
<i>Lithognathus mormyrus</i> Linnaeus, 1758	Marine	Mourmoura/Striped seabream	P, Me, A	+
<i>Liza aurata</i> Risso, 1826	Marine/Estuarine	Mixsinari/ Golden grey mullet	La, Nest, P, G, Me, A, Amv	+
<i>Liza ramada</i> Risso, 1826	Marine/Estuarine	Mavraki/ Thinlip mullet	Nest, P, G, Me, A, Amv	+
<i>Liza saliens</i> Risso, 1810	Marine/Estuarine	Gastros/Leaping mullet	La, Nest, P, G, Me, A, Amv	+
<i>Mugil cephalus</i> Linnaeus, 1758	Marine/Estuarine	Kefalos/Flathead grey mullet	Nest, P, G Me, A, Amv	+
<i>Mullus barbatus</i> Linnaeus, 1758	Marine	Koutsomoura/Red mullet	P, Me, A	+
<i>Mullus surmuletus</i> Linnaeus, 1758	Marine	Barbouni/Striped red mullet	P, G	+
<i>Oedechilus laleo</i> (Cuvier, 1829)	Marine/Estuarine	Grentzos/ Boxlip mullet	P, G	+
<i>Parablennius sanguinolentus</i> (Pallas, 1811)	Marine	Rusty blenny	La	
<i>Pomatoschistus marmoratus</i> (Risso, 1810)	Marine/Estuarine	Govios/Marbled goby	La, D	
<i>Salpa salpa</i> Linnaeus, 1758	Marine/Estuarine	Salpa/Salema	P, Me, A	+
<i>Solea vulgaris</i> Quensel, 1806	Marine	Glossa/Common sole	P, Me, A, Amv	+
<i>Sparus aurata</i> Linnaeus, 1758	Marine/Estuarine	Tsipoura/Sea bream	Nest, P, G, Me, A, Amv	+
<i>Spondyliosoma cantharus</i> (Linnaeus, 1758)	Marine	Skathari/Black seabream	G	+
<i>Syngnathus acus</i> Linnaeus, 1758	Marine/Estuarine	Greater pipefish	La	
<i>Zosterisessor ophiocephalus</i> (Pallas, 1811)	Marine/Estuarine	Grass goby	La	

Basic sources: ANANIADIS, 1984; DOUNAS & KOUTSOUBAS, 1996; DIMITRIOU *et al.*, 1997; KEVREKIDIS *et al.*, 1990; MOGIAS *et al.*, 2002; MOGIAS, 2005.

(ERSEM), initially designed for the open sea, has been usefully applied with minimum modifications. Model results depicting the seasonal variation of nutrients and Chl-a in the water column (PETIHAKIS *et al.*, 1999), as well as three benthic functional groups (suspension feeders, deposit feeders, and benthic carnivores), were validated with *in situ* data (TRIANAFYLLOU *et al.*, 2000). The modelled pelagic ecosystem exhibits a microbial foodweb, characterised by competition for nutrients between bacteria and phytoplankton, which was broadly in agreement with the observations made in the lagoon. The heterotrophic biomass was larger than the autotrophic biomass and there was a strong benthic-pelagic coupling in the model, as would be expected in a shallow system rich in detrital material. The seasonal variations in the benthic flux of nutrients were tightly coupled to the phytoplankton nutrient demand and hence the supply of detritus in the sediments. The likely effect of a technical intervention (river input) increasing the freshwater nutrient inputs on the lagoonal ecosystem functioning was also investigated. Model experiments indicated the shift of the ecosystem from nitrate limitation to predator control with external inputs. Model experiments also revealed a significant increase in the amount of carbon entering the benthic system through the activity of filter feeders when river inputs were implemented. The successful application of ERSEM to Gialova lagoon has highlighted the potential utility of a model as an operational tool to support environmental management decisions in such ecosystems.

Pollution

Lagoons are nutrient rich areas as a result of input of nutrients by rivers and recycling between sediment and water column facilitated by their shallowness. Nutrient excess and hydrological changes, often accelerated by human intervention, in the lagoons, result in a non-linear and self-accelerating chain

reaction, commonly called eutrophication (CLOERN, 2001). It starts with an increase in growth (organic production) and a shift in dominance of primary producers from angiosperms to opportunistic seaweeds, and culminates to a *dystrophic crisis* with extensive algal blooms, severe anoxia and mass killings of both fish and invertebrate fauna (SCHRAMM & NIENHUIS, 1996). Such events are not uncommon in some Greek lagoons. In Papas and Vassova the opportunistic seaweeds *Ulva* and *Gracilaria* have increased their dominance at the cost of angiosperms, in the last decades, due to nutrient excess in the water (KARYOTIS *et al.*, 2005). Some areas of Papas, Aetoliko and Gialova become completely defaunated, especially during summer or early autumn (REIZOPOULOU & NICOLAIDOU, 2004; KOUTSOUBAS *et al.*, 2000b). The sedentary infauna is more affected than vagile organisms, such as crustacea and fish, which are able to migrate. Recovery is generally rapid, as organisms soon recolonize the affected areas. Papas lagoon, for example, which was affected by summer dystrophic crisis with extensive mortality of fish and benthic invertebrates, recovered the same autumn. A similar trend has also been observed in Gialova lagoon.

The degree of pollution in Greek lagoons has been assessed by an array of methods, including Abundance Biomass Comparison (ABC) curves and plotting of Geometric Abundance Classes, which are widely used for pollution assessment in the fully marine environment (REIZOPOULOU *et al.*, 1996). However, due to the naturally stressed condition of the lagoons, these methods were ineffective as was Shannon diversity index. Conversely, the application of recently developed rapid biodiversity assessment techniques (WARWICK & CLARKE, 1998; CLARKE & WARWICK, 2001) in certain Greek lagoons was proved useful and efficient (ARVANITIDIS *et al.*, 2004). Furthermore, two new indices –the Ecological Evaluation Index, based on macrophytes, algae and angiosperms, and the Size Distribu-

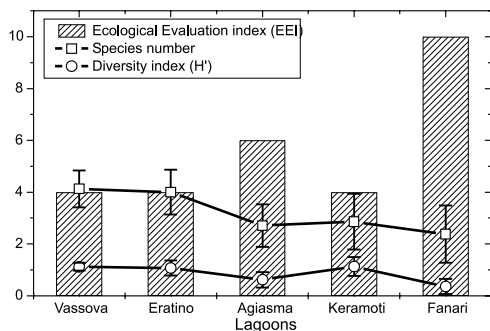


Fig. 4: Ecological Evaluation Index (EEI) in comparison to diversity indices in five Greek lagoons. Line bars indicate 95% confidence intervals.

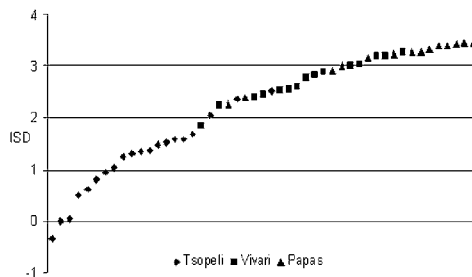


Fig. 5: Index of Size Distribution (ISD) in three Greek lagoons. Higher values correspond to the most disturbed lagoon, Papas, and low to the less affected, Tsopeli (REIZOPOULOU & NICOLAIDOU, in press).

tion Index, based on the size distribution of macrobenthic animals - have been proposed for the estimation of the ecological condition of lagoonal ecosystems.

Ecological Evaluation Index. (EEI) was designed to estimate the ecological status of transitional and coastal waters as shifts, due to anthropogenic stress, from the pristine state dominated by late successional species (EEI=10) to the degraded state dominated by opportunistic species (EEI=2) (ORFANIDIS *et al.*, 2001, 2003). Its application in five Greek lagoons and the comparison with diversity indices, considered inappropriate for ecological assessment, is shown in Figure 4.

Index of Size Distribution (ISD) is based on the observations that, with increasing organic load the community size structure changes (REIZOPOULOU & NICOLAIDOU, in press). Due to the dominance of small sized opportunistic species and the decline of large bodied specimens (mainly suspension-feeders and carnivores), smaller and fewer size classes are present, thus, size class distribution is skewed towards the smaller size classes. The value of skewness of the curve is used as a measure of environmental quality. It has the advantage of a good discrimination power and of not requiring a high taxonomic

expertise. An application of the ISD to three Greek lagoons is shown in Figure 5.

Conclusions

The research carried out so far in Greek lagoons confirms the variability of the environment, demonstrated also for other coastal lagoons in the Mediterranean. Differences exist not only among lagoons but also within the same lagoon, both in space and time. The degree of communication with the sea affects most of the other environmental variables, playing a prominent role in shaping the biological communities. Inflow of fresh water is also very important in the differentiation of biota. However, neither of the above has been directly quantified so far. The zonation of confinement is based on the end result- the species distribution- rather than the causative factor- the water circulation and exchange. An independent evaluation of confinement, based on physical predictors rather than on the fauna, might provide a better understanding of its role. The input of fresh water and the contributed organic matter and nutrients, would give a clearer picture of the terrestrial influence. Finally, it is demonstrated that variability between and within lagoons concerns mostly the dominance of species and not the pres-

ence of different sets of species. Changes in the dominance of species could be caused not only by variability in the physical environment, but also by biological interactions such as competition and predation, or they may be related to intrinsic characteristics of the species. Giving more emphasis to the autecology of the dominant species would give a better insight to the dynamics of the lagoonal communities.

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