Mediterranean Marine Science

Vol 6, No 2 (2005)

## Biological components of Greek lagoonal ecosystems: an overview

A. NICOLAIDOU, S. REIZOPOULOU, D. KOUTSOUBAS, S. ORFANIDIS, T. KEVREKIDIS

doi: 10.12681/mms.184

*Mediterranean Marine Science*
Volume 6/2, 2005, 31-50

# Biological components of Greek lagoonal ecosystems: an overview

**A. NICOLAIDOU[1], S. REIZOPOULOU[2], D. KOUTSOUBAS[3], S. ORFANIDIS[4] and T. KEVREKIDIS[5]**

[1] University of Athens, Department of Zoology-Marine Biology, Panepistimiopolis, 15784 Athens, Greece

[2] Hellenic Centre for Marine Research, Institute of Oceanography, P.O.Box 712, 190 13 Anavissos, Greece

[3] University of the Aegean, Department of Marine Science, University Hill, 81100 Mytilini, Greece

[4] Fisheries Research Institute of Kavala, Nea Peramos, 64007 Kavala, Greece

[5] Democritus University of Thrace, Department of Education-Primary level, 68100 Alexandroupoli, Greece

e-mail: anikol@biol.uoa.gr

**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-

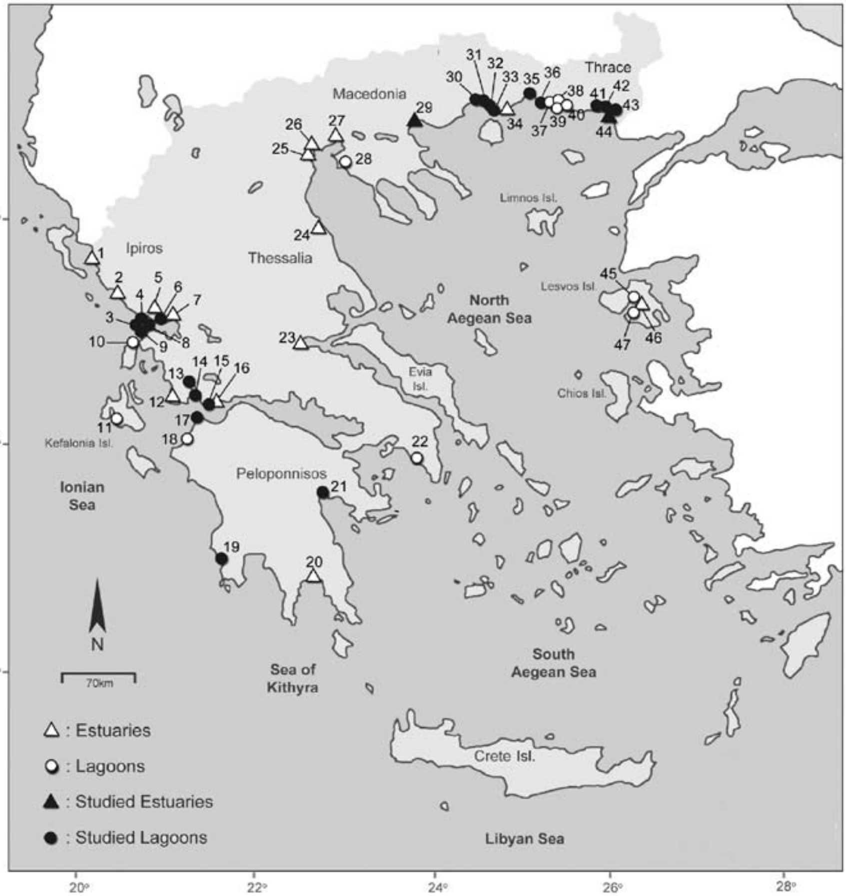


*Fig. 1:* Map of Greece showing main transitional coastal ecosystems (estuaries and lagoons). Dark symbols indicate ecosystems for which detailed information exists and are treated in this paper.

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

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

The most extensive lagoonal systems are located 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 *Nitzchia 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 $3x10^4$ to $2x10^6$cells/l but concentrations of up to $4.4x10^7$ cells/l, belonging mostly to nannoplankton, 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=Aetoliko, Ag=Agiasma, E=Eratino, F=Fanari, G=Gialova, Ke=Keramoti, L=Logarou, Ma= Mazoma, Me=Messolonghi, P=Papas, R=Rodia, T=Tsopeli, Ts=Tsoukalio, Va=Vassova). (F=Fisheries, AE=Extensive aquaculture, ASI=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 | |
| 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 | 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 |
| Human impact | | | | | | | | DC | DC | DC | | | | | | D |
| Parameters studied | Abiotic | * | *** | *** | *** | *** | *** | *** | *** | *** | * | * | * | * | | *** |
| | Plankton | | | | ** | | | | | ** | | | | | | |
| | Phyto-benthos | * | ** | ** | ** | ** | ** | ** | ** | * | ** | ** | ** | ** | * | ** |
| | Zoo-benthos | * | *** | *** | *** | *** | *** | *** | *** | *** | | | | | | *** |
| | Fishfauna | | | | | | * | * | * | * | | | | | | ** |

**Table 2**
**Environmental characteristics of Greek lagoons.**
**(A=Aetoliko, E=Eratino, G=Gialova, K=Klissova, L=Logarou, Ma= Mazoma, Me=Messolonghi, P=Papas, R=Rodia, T=Tsopeli, Ts=Tsoukalio, Va=Vassova).**

| Lagoons | Amvrakikos Gulf | | | | | Patraikos Gulf | | | | Ionian Sea | Eastern Macedonia & Thrace | | Evros Delta |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ma | T | Ts | R | L | K | Me | A | P | G | Va | E | |
| 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 ($^{o}$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 & DIAPOULIS 1984; Ionian Sea: KOUTSOUBAS *et a*l., 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 $10^6$ indiv./$m^3$, 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/$m^2$) 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=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)**

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

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

*(see also HAYDEN *et al*., 2003). Basic sources: Amvrakikos Gulf (LAZARIDOU *et al*., 2002), Partaikos 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.

**Meifauna**

Meiobenthos has only been studied in Gialova lagoon, where 18 meiofaunal taxa were found (McARTHUR *et al*., 2000). These are: foraminiferans, ciliates, cnidarians, turbelarians, 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 $cm^2$, 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 *Nephthys 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=Tsopeli, Ts=Tsoukalio, V=Vivari). * dominant species, + locally or occasionally important species**
**(absence of a mark does not indicate absence of the species)**

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

*(continued)*

**Table 4. (continued)**

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

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.

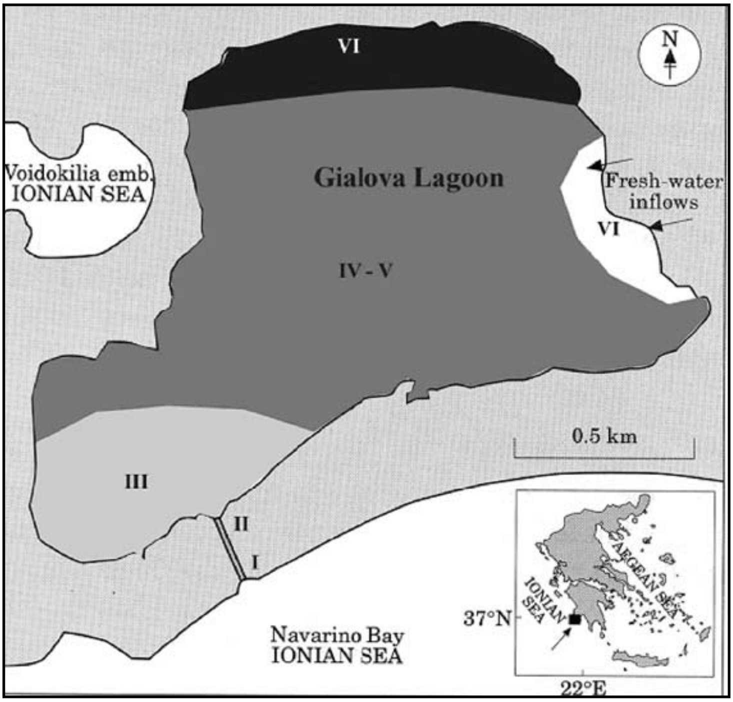


***Fig. 2:*** Biological Zonation in Gialova lagoon, according to the scheme proposed by GUELORGET & PERTHUISOT (1992) for Mediterranean lagoons.

*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 communication 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-

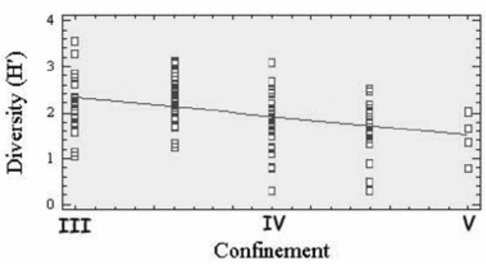


***Fig. 3:*** Regression of diversity against confinement (based on data from the lagoons of Amvrakikos, Messolonghi, Papas, Vivari, and Gialova).

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

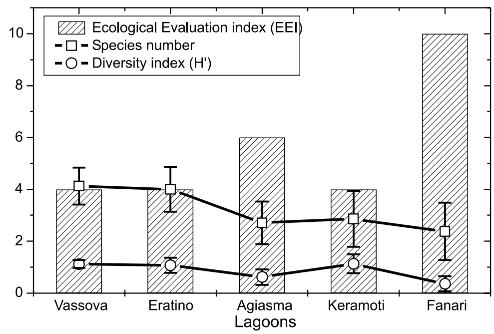


*Fig. 4:* Ecological Evaluation Index (EEI) in comparison to diversity indices in five Greek lagoons. Line bars indicate 95% confidence intervals.

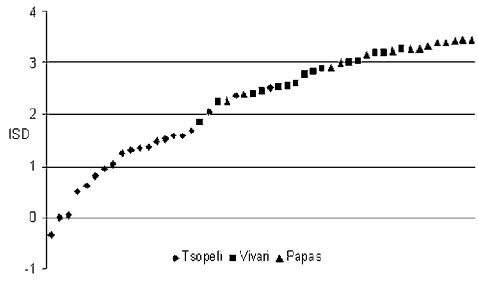


*Fig. 5:* Index of Size Distribution (ISD) in three Greek lagoons. Higher values correspond to the most disturbed lagoon, Papas, and low to the less affected, Tsopeli (REIZOPOULOU & NICOLAIDOU, in press).

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 presence 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.

**References**


ANANIADIS, C. 1984. Quelques aspects du problème d'amenagement des pêcheries des lagunes et des étangs côtières de Grèce. In: *Management of coastal lagoon fisheries*. General Fisheries Council for the Mediterranean, Studies and Reviews, vol. 2, pp. 477-520. Edited by J.M. Kapetsky and G. Lassere, 438 pp.

ARVANITIDIS, C., HATZIGEORGIOU, G., KOUTSOUBAS, D., DOUNAS, C., ELEFTHERIOU, A. & KOULOURI, P., 2005. Mediterranean Lagoons revisited: weakness and efficiency of the rapid Biodiversity Assessment Techniques in a severely fluctuating environment. *Biodiversity and Conservation* 14: 2347-2359.

ARVANITIDIS, C., KOUTSOUBAS, D., DOUNAS, C. & ELEFTHERIOU, A. 1999. Annelid fauna of a Mediterranean lagoon (Gialova lagoon, South-West Greece): Community structure in a severely fluctuating environment. *Journal of the Marine Biological Association of the United Kingdom*, 79: 849-856.

BOGDANOS, K. & DIAPOULIS, A., 1984. Contribution to the knowledge of zoobenthos and phytobenthos of the Messolonghi lagoon. *Thalassographica*, 7: 39-52 (in Greek).

KARYOTIS, TH., ORFANIDIS S. & REIZOPOULOU, S., 2006. Marine benthic macrophytes as possible nitrogen source in agriculture. *Journal of Plant Nutrition and Soil Science* 169:1-7.

CHRISTAKI, U. & GOTSIS-SKRETAS, O., 1990. Phytoplankton structure in the lagoons Rodia, Tsoukalio and Logarou (Western Greece) from February to September 1987) *Proceedings of the 3rd Hellenic Symposium for Oceanography and Fisheries pp. 469-478* (in Greek).

CLARKE, K.R. & WARWICK, R.M., 2001. A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Marine Ecology Progress Series*, 216: 265-278.

CLOERN, J. E., 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series*, 210: 223-253.

COGNETTI, G. & MALTAGLIATI, F., 2000. Biodiversity and adaptive mechanisms in brackish water fauna. *Marine Pollution Bulletin*, 40: 7-14.

DIMITRIOU, E., ROGDAKIS, I. & BATARGIAS, K., 1997. Production structure of Messolonghi-Etolikon lagoons for the years 1988-1995. *Proceedings of the 5th Hellenic Symposium on Oceanography and Fisheries, Kavala, Greece,* 1: 233-236. (in English with Greek Abstract).

DOUNAS, C. & KOUTSOUBAS, D., 1996. Environmental Impact Assessment of Oil Pollution, in Navarino Bay and Gialova Lagoon. Technical Report, Ministry of Agriculture, Greece, 298 pp. (in Greek).

DOUNAS, C., KOUTSOUBAS, D., ARVANITIDIS, C., PETIHAKIS, G., DRUMMOND, L. & ELEFTHERIOU, A., 1998. Biodiversity in the Mediterranean Lagoons and the Impact of the Anthropogenic Activities: The case of Gialova lagoon, SW Greece. *Oebalia*, 24: 81-96.

GONTIKAKI, E., ANTONIADOU, C. & CHINTIROGLOU, C.C., 2003. Population structure of *Cerastoderma glaucum* and *Abra ovata* in Vouliagmeni Lagoon (Attiki). *Journal of the Marine Biological Association of the United Kingdom*, 83: 1095-1097.

GOTSIS-SKRETAS, O. & SATSMADJIS, J., 1989-90. Notes on the environmental

response of phytoplankton in Greek lagoons. *Oebalia*, 16: 99-115.
GOUVIS, N., & KOUKOURAS, A., 1993. Macrozoobenthic assemblages of the Evros Delta (North Aegean Sea). *Internationale Revue der Gesamten Hydrobiologie* 78: 59-82.
GOUVIS, N., KEVREKIDIS, T. & KOUKOURAS, A., 1997. Temporal changes of a macrobenthic assemblage in Evros Delta (North Aegean Sea). *Internationale Revue der Gesamten Hydrobiologie*, 82: 67-80.
GUELORGET, O. & PERTHUISOT, J. P., 1992. Paralic ecosystems. Biological organization and functioning. *Vie et Milieu*, 42: 215 -251.
KARAKIRI, M. & NICOLAIDOU, A., 1987. Population studies on the Amphipoda of Mazoma lagoon, Greece. *Helgoländer Meeresuntersuchungen,* 41: 453-464.
KARYOTIS, T., ORFANIDIS, S. & REIZOPOULOU S., 2004. Marine benthic macrophytes as a possible nitrogen source for agricultural use. *Journal of Environmental Management* (in press).
KEVREKIDIS, T., 1997. Seasonal variation of the macrobenthic fauna in an isolated area of the Evros Delta (North Aegean Sea). *Israel Journal of Zoology*, 43: 243-255.
KEVREKIDIS, T., 2004a. Seasonal variation of the macrozoobenthic community structure at low salinities in a Mediterranean lagoon (Monolimni Lagoon, Northern Aegean). *International Review of Hydrobiology*, 89: 407-425.
KEVREKIDIS, T., 2004b. Population dynamics, growth and reproduction of *Corophium insidiosum* (Crustacea: Amphipoda) at low salinities in Monolimni Lagoon (Evros Delta, North Aegean Sea). *Hydrobiologia*, 522: 117-132.
KEVREKIDIS, T., 2005. Population dynamics, reproductive biology and productivity of *Streblospio shrubsolii* (Polychaeta: Spionidae) in different sediments at low salinities in a Mediterranean lagoon (Monolimni Lagoon, Northern Aegean). *International Review of Hydrobiology*, 90: 100-121.
KEVREKIDIS, T., (in press) Life history, aspects of reproductive biology and production of *Corophium orientale* (Crustacea: Amphipoda) in Monolimni Lagoon (Evros Delta, North Aegean Sea). *Hydrobiologia*.
KEVREKIDIS, T. & KOUKOURAS, A., 1988/89. Life cycle and reproduction of *Gammarus aequicauda* (Crustacea: Amphipoda) in the Evros Delta (NE Greece). *Israel Journal of Zoology*, 35: 137-149.
KEVREKIDIS, T. & KOUKOURAS, A., 1989. Seasonal variation of abundance of *Gammarus aequicauda* (Crustacea: Amphipoda) in the Evros Delta (NE Greece). *Israel Journal of Zoology*, 36: 113-123.
KEVREKIDIS, T. & KOUKOURAS, A., 1992. Population dynamics, growth and productivity of *Abra ovata* (Mollusca, Bivalvia) in Evros Delta (N. Aegean Sea). *Internationale Revue der Gesamten Hydrobiologie*, 77: 291-301.
KEVREKIDIS, T. & LAZARIDOU-DIMITRIADOU, M., 1988. Relative growth and secondary production of the Amphipod *Gammarus aequicauda* (Martynov, 1931) in the Evros Delta (N. Aegean Sea). *Cahiers de Biologie Marine*, 29: 483-495.
KEVREKIDIS, T. & WILKE T., 2005. Life cycle, population dynamics and productivity of the larviparous mudsnail *Ventrosia maritima* in the Evros Delta (Northern Aegean Sea). *Journal of the Marine Biological Association of the United Kingdom*, 85: 375-382.
KEVREKIDIS, T., BOUBONARI, T. & GOUTNER, V., 2004. Seasonal variation of abundance of *Corophium orientale* (Crustacea: Amphipoda) in Monolimni lagoon (Evros Delta, North Aegean Sea). *Belgian Journal of Zoology,* 134: 165-167.
KEVREKIDIS, T., KOKKINAKIS, A.K. & KOUKOURAS, A., 1990. Some aspects

of the biology and ecology of *Knipowitschia caucasica* (Teleostei: Gobiidae) in the Evros Delta (North Aegean sea). *Helgolander Meeresuntersuchungen*, 44: 173-187.

KEVREKIDIS, T., MOGIAS, A. & GOUVIS, N., 2000. Interannual changes in the composition of the macrobenthic fauna of Drana lagoon (Evros Delta, N. Aegean Sea): Preliminary note. *Belgian Journal of Zoology*, 130 (Suppl.): 105-111.

KEVREKIDIS, T., WILKE, T. & MOGIAS, A., 2005. When DNA puts ecological works back on the right track: genetic assessment and distribution patterns of mudsnail populations in the Evros Delta lagoons. *Archiv für Hydrobiologie*, 162: 19-35.

KORMAS, K.A., NICOLAIDOU, A. & REIZOPOULOU, S., 2001. Temporal variations of nutrients, chlorophyll a and particulate organic matter in three coastal lagoons of Amvrakikos Gulf (Ionian Sea, Greece). *PSZNI Marine Ecology*. 22: 201-213.

KOUTRAKIS, E. & TSIKLIRAS, A., 2003. Length-weight relationships of fishes from three northern Aegean estuarine systems (Greece). *Journal of Applied Ichthyology*, 19 (4): 258-260.

KOUTSOUBAS, D., ARVANITIDIS, C., DOUNAS, C. & DRUMMOND, L., 2000a. Community Structure and Dynamics of the Molluscan Fauna in a Mediterranean Lagoon (Gialova Lagoon, SW Greece). *Belgian Journal of Zoology*, 130: 135-142.

KOUTSOUBAS, D., DOUNAS, C., ARVANITIDIS, C., KORNILIOS, S., PETIHAKIS, G., TRIANTAFYLLOU, G. & ELEFTHERIOU, A., 2000b. Macrobenthic Community Structure and Disturbance Assessment in a Mediterranean Lagoon (Gialova lagoon, Ionian Sea). *ICES Journal of Marine Science*, 57: 1472-1480.

LAZARIDOU, E., TSIRIKA, A. & SEFERLIS, M., 2002. Study and mapping of the macrophytic communities of Amvrakikos lagoons. *Proc. 1st Scientific Conference of European Federation of Marine Science and Technology Societies (EFMS)*.

MALEA, P., KEVREKIDIS, T. & MOGIAS, A., 2004. Annual versus perennial growth cycle in *Ruppia maritima* L.: temporal variation in population characteristics in Mediterranean lagoons (Monolimni and Drana Lagoons, Northern Aegean Sea). *Botanica Marina*, 47: 357-366.

MALEA, P., MOGIAS, A., KEVREKIDIS, T. & HARITONIDIS, S., 2003. Factors affecting the distribution of macrophytes in three lagoons of the Evros Delta (North Aegean Sea). *Proceedings of the7th Greek Symposium of Oceanography & Fish*eries, p.375 (in Greek).

McARTHUR, V., KOUTSOUBAS, D., LAMPADARIOU, N. & DOUNAS, C., 2000. The Meiofaunal Community Structure of a Mediterranean Lagoon (Gialova Lagoon, Ionian Sea). *Helgoland Marine Research*, 54: 7-17.

MOGIAS, A. & KEVREKIDIS, T., 2005. Macrozoobenthic community structure in a poikilohaline Mediterranean lagoon (Laki Lagoon, Northern Aegean). *Helgoland Marine Research,* 59 (in press).

MOGIAS, A., 2005. Ecological study of lagoons in the Evros river estuarine area and utilization of the lagoon ecosystem structure and function knowledge in the organizing of educational material. *Doctoral Dissertation, Democritus University of Thrace, 197 p. (*in Greek).

MOGIAS, A., KOKKINAKIS, A.K., KEVREKIDIS, T., ELEFTHERIADIS, E.A. & BOUBONARI, T., 2002. Abiotic factors affecting the distribution and abundance of the fish fauna in two lagoons of Evros Delta (N.E. Greece). 9th *International Congress on the Zoogeography and Ecology of Greece and Adjacent Regions*, The Hellenic Zoological Society, Thessaloniki 22-25 May 2002, p. 108.

NICOLAIDOU, A. & ANAGNOSTAKI, K., 1983. Spatial and temporal variation

in the distribution of the mussel *Mytilaster minimus* in a brackish water lagoon of the Amvrakikos Gulf. *Rapport de Congrès de la Commission Internationale pour l'exploration Scientifique de la Mer Méditerranée*, 28(6): 237-238.
NICOLAIDOU, A. & KARAKIRI, M., 1989. The distribution of Amphipoda in a brackish water lagoon in Greece. *PSZNI Marine Ecology*, 10: 131-139.
NICOLAIDOU, A., KARAKIRI, M. & TRICHOPOULOU, V., 1985. Seasonal changes in the fauna of a brackish water lagoon. *Rapport de Congrès de la Commission Internationale pour l'exploration Scientifique de la Mer Méditerranée*, 29 (4): 125-126.
NICOLAIDOU, A. & KARLOU, C., 1983. A benthic survey in the brackish water lagoon Mazoma of the Amvrakikos Gulf *Rapport de Committee international de la Mer Mediterranee*, 28(6): 235-236.
NICOLAIDOU, A. & KOSTAKI-APOSTOLOPOULOU, M., 1988. Growth of *Abra ovata* in a brackish-water lagoon. *Vie marine*, 9: 7-10.
NICOLAIDOU, A., PETROU, K., KORMAS, K. & REIZOPOULOU, S., 2006. Inter-annual variability of soft bottom macrofaunal communities in two Ionian Sea lagoons. *Hydrobiologia* 555: 89-98.
ORFANIDIS, S., STAMATIS, N., TSIAGGA, E., RAGIAS, V. & SCHRAMM, W., 2000. Eutrophication and marine benthic vegetation in the Lagoon of Vassova, Prefecture of Kavala. *Proeedingsof the 6th Hellenic Symposium of Oceanography & Fish*eries, v 1: 429-433. (in Greek).
ORFANIDIS, S., PANAYOTIDIS, P. & STAMATIS, N., 2001a. Ecological evaluation of transitional and coastal waters: A marine benthic macrophyte-based model. *Mediterranean Marine Science*, 2: 45-65.
ORFANIDIS, S., STAMATIS, N. & TSIAGGA, E., 2001b. Variability of the characteristics of seaweed communities in a eutrophic lagoon (Vassova, N. Greece). *Proceedings of The 7th International Phycological. Congress Phycologia*, 40 (4), supplement: 117.
ORFANIDIS, S., PANAYOTIDIS, P. & STAMATIS, N., 2003. An insight to the ecological evaluation index (EEI). *Ecological Indicators*, 3 (1): 27-33.
PETIHAKIS, G., TRIANTAFYLLOU, G., KOUTSOUBAS, D., ALLEN, I. & DOUNAS, C., 1999. Modelling the annual cycles of nutrients and phytoplankton in a Mediterranean lagoon (Gialova, Greece). *Marine Environmental Research*, 48: 37-58.
REIZOPOULOU, S., THESSALOU-LEGAKI, M. & NICOLAIDOU, A., 1996. Assessment of disturbance in Mediterranean lagoons: an evaluation of methods. *Marine Biology*, 125: 189-197.
REIZOPOULOU S. KORMAS, K., & NICOLAIDOU, A., 1998. Benthic biodiversity in five coastal brackish water lagoons of Amvrakikos Gulf, Hellas. *Rapport de Congrès de la Commission Internationale pour l'exploration Scientifique de la Mer Méditerranée*, 35:580-581.
REIZOPOULOU, S. & NICOLAIDOU, A., 2004. Benthic diversity of coastal brackish-water lagoons in Western Greece. *Aquatic Conservation Marine and Freshwater Ecosystems* 14:S93-S102.
REIZOPOULOU, S. & NICOLAIDOU, A., 2006. Index of size distribution (ISD): a method of quality assessment for coastal lagoons. *Hydrobiologia, (*in press).
SCHRAMM, W. & NIENHUIS, P.H. (Eds) 1996. Marine benthic vegetation: recent changes and the effects of eutrophication. *Ecological studies* 123. Springer-Verlag, 470 p.
SIOKOU-FRANGOU, I., 1986. Contribution a l'etude du zooplankton de la lagune de Messologhi. *Thalassographica*, 9: 29-38.
SoHelME, 2005. *State of the Hellenic Marine Environment*. E.Papathanassiou & A. Zenetos (Eds), HCMR Publ., 360 pp.
TRIANTAFYLLOU, G., PETIHAKIS, G., DOUNAS, C., KOUTSOUBAS, D.,

ARVANITIDIS, C. & ELEFTHERIOU, A., 2000. Temporal Variations on Benthic Communities and their Behaviour to Physicochemical Forcing. A Numerical Approach. *ICES Journal of Marine Science*, 57: 1507-1516.

VERHOEVEN, J.T.A., 1979. The ecology of *Ruppia*-dominated communities in western Europe. I. Distribution of *Ruppia* representatives in relation to their autoecology. *Aquatic Botany*, 6: 197-268.

WARWICK, R.M. & CLARKE, K.R., 1998. Taxonomic distinctness and environmental assessment. *Journal of Applied Ecology*, 35: 532-543.

ZALIDIS, C. & MANTZAVELAS, A.L (Eds) 1994. *Inventory of Greek wetlands as natural resources. Greek Biotope/Wetland Centre* (EKBY), 587 pp.

ZOULIAS, TH., 2003. Composition, dynamics and integrated management in coastal lagoonal ecosystems: the case of Papas and Gialova lagoons. *MSc Thesis, University of the Aegean, Department of Marine Science*, 124 pp. (in Greek).