ECOLOGICAL STUDY OF THREE LAGOONS OF AMVRAKIKOS RAMSAR SITE, GREECE

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SUMMARY

Amvrakikos Gulf is situated in Western Greece, and the complex system of lagoons in its northern part, is among the most important shallow ecosystems of Greece. Amvrakikos Gulf is protected by the Ramsar convention and it is also included into the Natura 2000 network. Monitoring of key water quality parameters in Amvrakikos lagoons (Rodia, Tsoukalio, and Logarou) was carried out from May 2003 to October 2004 to determine trends in water quality and the trophic state of the lagoons. Two of the Amvrakikos lagoons, Tsoukalio and Rodia, are interconnected but separated from the third (Logarou) by a narrow strip of land. Logarou lagoon has a better water exchange with the sea. The study is based on monitoring data on the seasonal variation during the vegetated periods of 2003 and 2004 on submerged vegetation, nutrients of nitrogen and phosphorus, and physical and chemical parameters, such as temperature, pH, salinity, and dissolved oxygen. The submerged flora in the Rodia and Tsoukalio lagoons is dominated by *Lamprothamnium papulosum* and *Zostera noltii*. In Logarou lagoon macroalgae *Gracilaria-bursa pastoris* and *Acetabularia mediterranea*, were abundant while *Zostera noltii* was found in limited presence. Nutrient characteristics of the water body and the distribution of submerged macrophyte species in three lagoons are further discussed.

KEYWORDS: water quality parameters, macrophytes, nutrients, Ramsar Mediterranean wetland, Greece.

INTRODUCTION

Mediterranean wetlands are unique and valuable habitats but also fragile due to the climatic conditions. Coastal lagoons are natural, autonomous, dynamic systems with a high productivity potential and a number of common morphological and ecological features. They are characterized by shallow depths and partially isolated from the open sea by coastal barriers that maintain some communication channels or inlets. Lagoons are economically and ecologically important wetlands in coastal areas, due to intensive fishing and the development of recreational activities. Coastal lagoons are classified as priority habitat types under the Habitats Directive (European Directive 92/43/EEC). Their unstable conditions due to their confinement to the open sea and their shallowness results in typically low values of diversity, low number of species and strong dominance of a few species often found in lagoon ecosystems [1].

Aquatic macrophytes represent about 40% of the primary production of the coastal zone and are key constituents of these ecosystems [2]. Macrophytes play both a trophic role, as important primary producers in coastal ecosystems and a structural role, by which they provide habitat and refuge for a number of organisms. Several factors regulate growth and distribution of the plants in these areas. Although macrophytes are of great importance, most of the published papers on Greek lagoons concern fauna distribution and population dynamics [e.g. 3- 7]. Up today only a few papers focused on the lagoons vegetation have been published [8, 9].

Amvrakikos lagoons, which are located at the northern side of the Gulf, are among the most important shallow, semi-enclosed ecosystems of Greece. Monitoring of key water quality parameters (temperature, pH, transparency, salinity, dissolved oxygen and nutrients of nitrogen and phosphorus) in Amvrakikos lagoons were carried out from May 2003 to October 2004 to determine trends in water quality and the trophic state of the lagoons. Samplings in Logarou lagoon were conducted during July and September of 2003 and on July, September and October of 2004. Furthermore, the species composition, the seasonal variations of submerged macrophytes and the abundance of different species, were examined in three lagoons.

MATERIALS AND METHODS

The study was carried out in three shallow brackish lagoons of Amvrakikos gulf, Rodia, Tsoukalio and Logarou during the vegetated periods from May 2003 to October 2004 (Fig. 1). The spatial and temporal variability of environmental characteristics of three lagoons were examined. All lagoons are small in size (areas range between 2600 ha in Rodia, 2900 ha in Tsoukalio, and 4900 ha in Logarou), shallow (mean depths range between 1.1m in Rodia, 0.8m in Tsoukalio and 0.5m in Logarou) and are affected by similar tidal influence at their mouths. Mean annual rainfall at the meteorological station of the Amvrakikos watershed area during the study period was 90.84 mm. Rainfall period ranged from October to April 2004. The rainiest month was December 2004, with a mean rainfall of 187.5mm [10].

The selection of sampling sites was based on the hydrological and morphological characteristics of each lagoon, as well as, the presence or absence of aquatic macrophytes. A total of 10 representative sampling stations (Fig. 1) were established, 3 in Rodia lagoon (R_1, R_2, R_3), 3 in Tsoukalio lagoon (T_4, T_5, T_6) and 4 in Logarou lagoon (L_7-L_{10}). The stations were reached as precisely as possible by boat and the exact position of each sampled station were recorded in the field by GPS (Fig. 1).

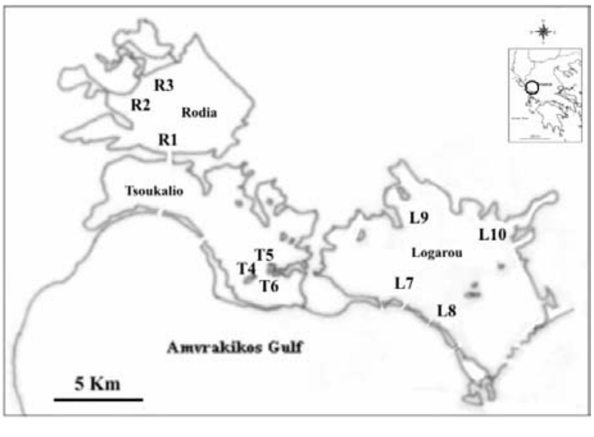

FIGURE 1 - Map of the studied area, and sampling stations Rodia, Tsoukalio and Logarou lagoons in the Amvrakikos gulf, Greece.

In each sampling station the following water parameters such as depth (m), transparency (Secchi disk), temperature (°C), salinity (‰), dissolved oxygen (mg/l) and pH were measured in situ with portable equipment (WTW 340/ SET). Additionally, water samples were collected from the surface layer (0-0.5m depth) for further chemical analyses. Water samples were filtered through a glass fibre filter (0.45μm). The determination of nitrogen (NH_4-N, NO_3-N, NO_2-N) and phosphate nutrients (PO_4-P), was carried out spectrophotometrically (SHIMADZU No 601228) using the methods described in APHA [11].

At each station the cover of submerged macrophytes was measured using quadrates of 50 x 50cm surface. The relative frequency and abundance cover was estimated for all plant samples present within the quadrate using an ordinal scale. Statistical analyses were performed with SPSS (V12). The correlation between physicochemical parameters of water was performed with Pearson's correlation coefficient.

RESULTS AND DISCUSSION

Abiotic variables

Temperature – Salinity — pH – Dissolved Oxygen

Figure 2 shows the monthly patterns of water temperature, salinity, pH and dissolved oxygen in the three lagoons of Amvrakikos Gulf, Rodia, Tsoukalio, and Logarou.

Temperature followed the expected seasonal pattern with maximum values ranging from 26.9°C to 28.5°C during summer months, while minimum values (15.8°C) were recorded in early April (Fig. 2). From April 2004 until August, temperature followed the same seasonal pattern with a maximum value (28.5°C) recorded at R_3 station (Fig. 2). Temperature decreased during autumn months (September-October 2004) and the minimum value that has been measured was 19.8°C (Fig. 2).

Shallow coastal lagoons are characterized by frequent fluctuations in salinity on seasonal basis. Meteorological conditions and hydrographic circulation are the main environmental factors that influence the salinity gradient. Salinity reached its maximum value during September 2004 in Logarou lagoon, while the lowest value (34‰) was recorded on July 2004 at L_9 station (Fig. 2). Logarou lagoon retains a high mean annual salinity (S= 40.1‰) probably due to diminished fresh water inflows and high evaporation caused by its shallowness.

Salinity values recorded during summer months in Tsoukalio lagoon fluctuated widely and were higher than those recorded in Rodia during the sampling period. At R_1 and R_2 stations in Rodia lagoon and T_5, T_6 in Tsoukalio, salinity reached its maximum value (40‰) during October 2003. A dramatic decrease of salinity was observed during April 2004 at Rodia stations (11‰) probably due to conservation measures at the surrounding marshes that resulted to high inputs of freshwater from Louros River [10]. The same trend was also observed at the Tsoukalio lagoon stations, where the lowest value (15‰) was measured in April 2004 at T_4 and T_5 stations (Fig. 2). Salinity values were lower almost ten years ago [12] in Rodia (11.5-25‰), Tsoukalio (13-28.9‰) and Logarou (15.7-26.6‰) comparing to the results of the present study.

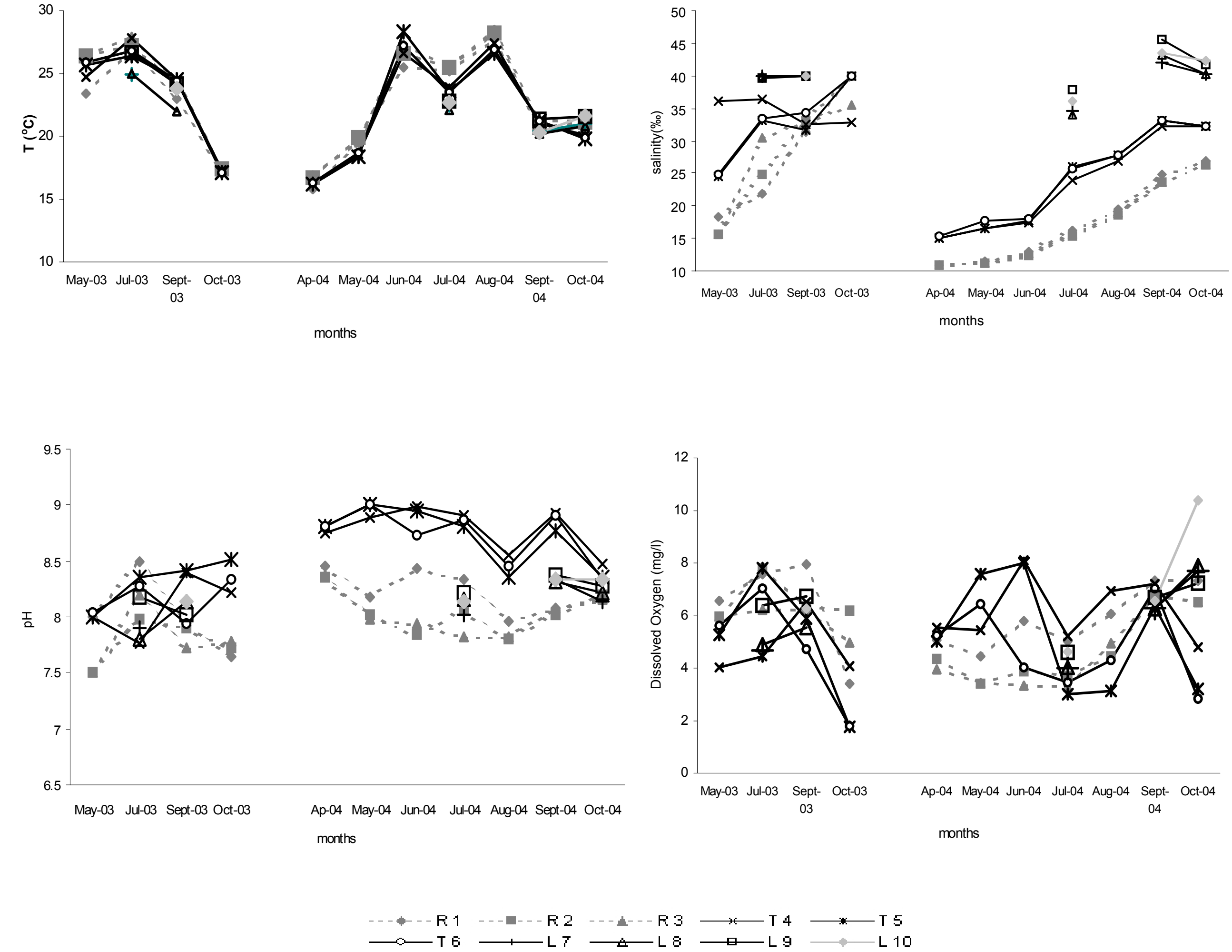

FIGURE 2 - Monthly variation of physicochemical parameters (temperature, salinity, pH, dissolved oxygen) per sampling station of Rodia, Tsoukalio and Logarou lagoons.

In three lagoons of Amvrakikos gulf pH varies from 7.5 to 9. More specific, in Rodia lagoon were recorded pH values from 7.5 to 8.49. In Tsoukalio pH ranged from 7.5 to 9 and in Logarou from 7.8 to 8.38. pH values that have been measured during the study period were considered to be suitable for the growth of submerged plants and were common to other lagoon systems in Greece [13]. On the whole charophytes grow in water with high pH and the majority of species could tolerate a range from 6 to 9 [14].

Oxygen concentration in water was generally high and never reached limiting values in any lagoon. In Rodia lagoon dissolved oxygen ranged from 3.29mg/l at R_3 station on July 2004 to 7.95mg/l on September 2003 at R_1 station. On the other hand, in Tsoukalio lagoon dissolved oxygen reached its minimum value (1.76mg/l) on October 2003 at T_5 station while on June 2004 at T_4 station the parameter reached its maximum value (8.11mg/l) (Fig. 2). The dissolved oxygen concentrations were always higher in Logarou lagoon (9.2-12.1mg/l) [12]. From the available data, in Logarou, dissolved oxygen indicated values from 9mg/l at L_7 station on July 2004 to 10.38mg/l on October 2004 at L_{10} station. The higher dissolved oxygen levels in Logarou might be enhanced not only by better water mixing with open seawater but also by the contribution of macroalgae [15].

Minimum values of dissolved oxygen observed during autumn months could probably affected by the decomposition of plant biomass, a process in which large amounts of oxygen were consumed [16]. Macrophytes need oxygen to supply the metabolism of above ground and below ground tissue. Anoxic conditions influence the metabolism of the plants resulting in poor energy availability and production of toxic metabolites, both of which may negatively affect growth and survival of the plants [17].

Nutrients of phosphorus and nitrogen (Phosphates–Nitrates–Nitrites–Ammonium)

Phosphorus is found in waterbodies in both dissolved and particulate forms. The dissolved form is readily available for plants and consists of inorganic orthophosphate and organic phosphorus compounds [16]. Phosphate concentrations remained rather low throughout the entire study except when perturbed by external events (Fig. 3). Compared to the results from Kormas et al. [12], phosphate levels were lower in the present study.

Significantly higher levels occurred in Tsoukalio lagoon on August 2004 at T_4 station (0.022mg/l), in Logarou lagoon at L_{10} station in October 2004 (0.019mg/l) and in Rodia lagoon at R_3 station in October 2004 (0.014mg/l, Fig. 3).

The nitrogen nutrients (nitrate, nitrite) showed similar temporal patterns of variation (Fig. 3). A sharp increase of nitrate concentrations was observed during spring with a marked peak on May 2003. During summer and early autumn (June to September), nitrate was completely depleted, while during autumn the regeneration processes of both nitrogen nutrients took place and a significant increase in their concentrations was observed (Fig. 3). Nitrates in the lagoon of Rodia indicated higher values comparing to those of Tsoukalio and Logarou lagoon (Fig. 3) on May 2003. The highest concentration of nitrates in Rodia lagoon (1.52mg/l) was recorded at R_3 station. The nitrate concentrations were higher on April and May 2004 at R_1 (0.768mg/l) and R_2 (0.613mg/l) stations comparing to May 2003. During the summer months of 2004 low values of nitrates (0.007mg/l) and nitrites (0.002mg/l) were recorded in all three lagoons. Nitrates were higher in autumn due to the decomposition of organic matter. During winter the uptake from macrophytes and phytoplankton is lower. The results indicate that the main origin of nutrients is the agricultural run-off.

In Logarou lagoon maximum values of nitrates were recorded in July 2003 at L_9 station (0.216mg/l) and minimum in July and September of 2004 (0.011mg/l) at L_7, L_8 and L_{10} stations (Fig. 3).

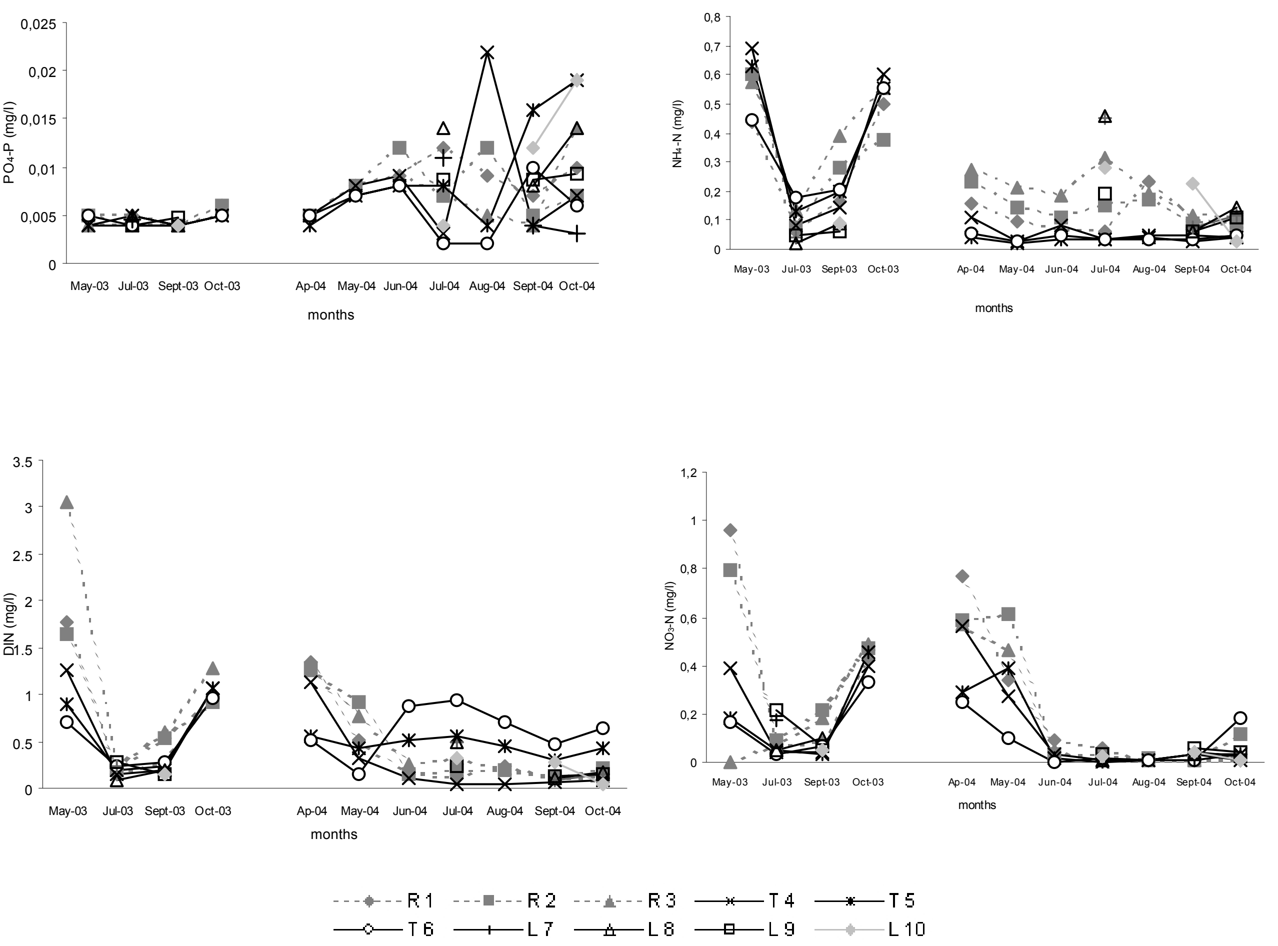

FIGURE 3- Monthly variation of PO_4-P, NH_4-N, DIN, NO_3-N, at stations of Rodia, Tsoukalio and Logarou lagoon during the vegetated period 2003-'04.

TABLE 1- Pearson correlation coefficient between environmental variables of water at the three lagoons.

	Transp. (m)	T (ºC)	pH	D.O. (mg/l)	Salinity (‰)	PO_4-P (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	NH_4-N (mg/l)	DIN (mg/l)
Depth (m)	0.973**	-0.176*	-0.268**	-0.193*	-0.317**	-0.084	0.273**	0.399**	0.350**	0.385**
Transp.(m)		-0.167*	-0.213**	-0.212**	-0.314**	-0.099	0.304**	0.373**	0.361**	0.417**
T (ºC)			-0.182*	0.145	-0.029	0.039	-0.386**	-0.443**	-0.170*	-0.408**
pH				0.148	-0.096	0.086	-0.049	-0.140	-0.465**	-0.257**
D.O.(mg/l)					0.231**	0.058	-0.187*	-0.207*	-0.333**	-0.285**
Salinity (‰)						-0.051	-0.348**	-0.314**	0.055	-0.248**
PO_4-P (mg/l)							-0.197*	-0.215**	-0.157	-0.227**
NO_2-N (mg/l)								0.806**	0.337**	0.842**
NO_3-N (mg/l)									0.482**	0.937**
NH_4-N (mg/l)										0.715**
DIN (mg/l)										

Dissolved Inorganic Nitrogen (DIN, Fig. 3) followed the similar pattern in Rodia and Tsoukalio, with maxima in May 2003, (3.059 mg/l and 1.255 mg/l, respectively). Higher values of DIN were recorded in Rodia lagoon at R_1 (1.355mg/l) and R_3 (1.266mg/l) stations in April 2004. DIN values were lower comparing to those measured during 2003. In Logarou lagoon the highest DIN values pointed on July 2004 at L_7 (0.496mg/l) and L_8 (0.5mg/l) stations. Minimum values were recorded in July 2003 at L_8 (0.088mg/l) station and in September 2004 (0.091mg/l) at L_7 station. During the period of high precipitation and river flow, e.g. in winter and early spring as compared to summer and autumn, higher values of DIN were recorded (Fig. 3).

Pearson correlation

Correlation analyses were carried out between all parameters measured in the three lagoons of Amvrakikos Gulf, with Pearson's correlation coefficient (Table 1). All correlations that have a statistically important difference of $p< 0.01$ were represented with two small stars (**) and of $p< 0.05$ with one (*).

Depth is positively correlated with the transparency and nutrient concentrations while transparency is negatively correlated with pH, dissolved oxygen and salinity (Table 1). Dissolved oxygen is positively correlated with salinity that constitutes an important parameter of water quality and depends mainly on temperature and dissolved nutrients. It also presents negative correlation with DIN concentration, as well as, with ammonium. Salinity presents negative correlation with NO_2-N, NO_3-N and DIN. The reduction of salinity caused an increase in nitrates and reverse. Salinity does not correlate significantly with the ammonium, a correlation that also reported for the Mobile Bay [18].

Furthermore ammonium presents negative correlation with water pH and dissolved oxygen, while it is correlated positively with nitrogen (NO_2-N, NO_3-N), depth and transparency. The same pattern is also followed by the concentrations of nitrates and nitrites. With regards to nitrate concentrations in the water column, the observed negative correlation with temperature and salinity was also found at Thau lagoon [19] and Mobile Bay USA [18]. The same correlation that exhibited in Lido lagoon is probably related with the increased production of macrophytes biomass [20]. Nitrates were taken up directly from the phytoplankton during summer months, so the negative correlation with temperature might be explained.

Phosphates were negatively correlated with NO_3-N and DIN. According to Tournier et al. [19] phosphate is recycled in water during summer when the activity of aquatic organisms, including microorganisms and fish, is high and prevents this nutrient from returning to the sediment. The latter process takes place in autumn/winter.

Biotic variables

Vegetation cover

Many species characterising lagoons are rare, legally protected and of conservation importance. Saline lagoons often support filamentous green and brown algae, charophytes and several vascular plants that are able to tolerate the large environmental variables in salinity and hydrology [21].

The submerged flora in the Rodia and Tsoukalio lagoons was dominated by the charophyte, *Lamprothamnium papulosum* (Wallr.) Groves, and the angiosperm *Zostera noltii* Hornemann. In Logarou lagoon two species of macroalgae *Gracilaria bursa-pastoris* (Gmelin) Silva and *Acetabularia mediterranea* Lamouroux, were abundant while *Zostera noltii* occurred in limited presence.

Charophyte *Lamprothamnium papulosum* was abundant in the Tsoukalio lagoon during the whole study (Fig. 4).

In spring 2003 in the Rodia lagoon, *Lamprothamnium papulosum* had the highest abundance. Unfortunately, a dramatic decrease in the total coverage of the charophyte was exhibited from April to October 2004 and was replaced by the angiosperm *Zostera noltii* (Fig. 4). Conservation actions in the marshes of Rodia and especially the input of large amounts of freshwater from Louros River during June and July 2003 and March 2004 combined with a high precipitation, increased the water level of the lagoon, a fact that probably resulted in the reduction of submerged macrophytes [10].

Green algae like *Ulva rigida* C. Agarth, *Enteromorpha sp*., *Chaetomorpha sp*., and *Cladophora glomerata* (L.) Kutz*,* were present mainly in autumn 2003 and spring 2004 at the southern part of the Tsoukalio lagoon. These opportunistic macroalgae are capable to uptake, assimilate and store large amounts of nitrogen in areas of high nitrogen loading resulting in low water column concentrations of nutrients [15].

From the available data for the Logarou lagoon, the *Zostera noltii* and *Lamprothamnium papulosum* abundance was lower comparing to the Tsoukalio and Rodia lagoons. The highest abundance of *Zostera noltii* was noted in September 2003 while a significant reduction was estimated in September and October 2004. *Lamprothamnium papulosum* was scarce in Logarou and the highest coverage was observedin July 2004 (Fig. 4). Also, the increased salinity (45.5‰) in Logarou lagoon caused a significant decrease of angiosperms and charophyte species and the expansion of red algae *Gracilaria bursa-pastoris* and green algae *Acetabularia mediterranea*.

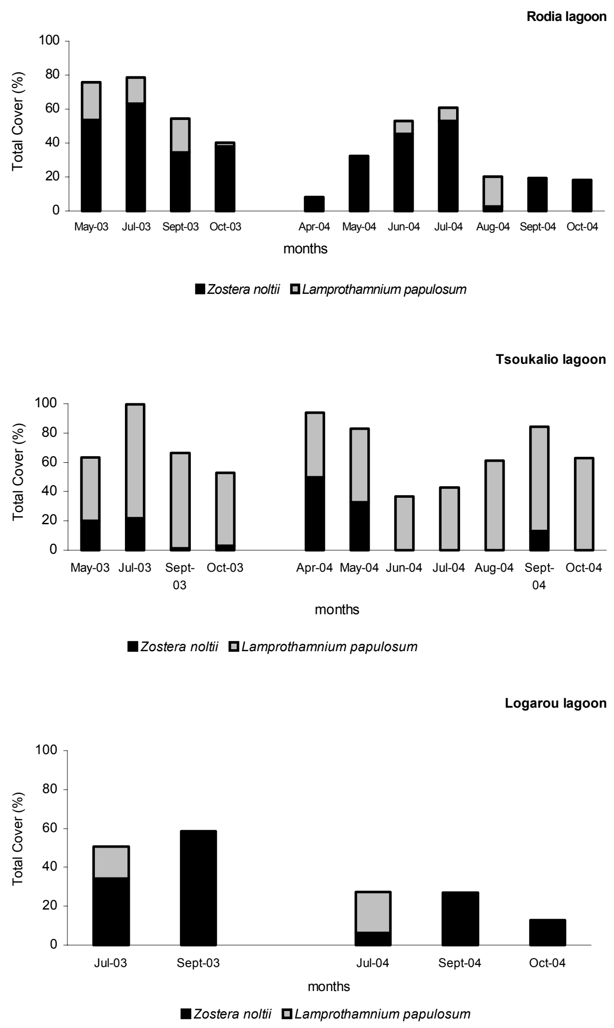

FIGURE 4 - Monthly variation of total cover (%) of *Zostera noltii* and *Lamprothamnium papulosum* at Rodia, Tsoukalio and Logarou lagoons, during the vegetated period 2003-'04.

Diversity indices

Species Shannon Diversity (H') and Evenness (E) for each lagoon are shown on Figure 5. In studied areas diversity was comparable to that of other Mediterranean lagoons [20, 24].

Diversity values in Rodia lagoon ranged from almost zero on May 2004 to 0.681 on July 2004. The highest diversity value during the survey period was estimated in Tsoukalio lagoon. On May 2003 diversity was 0.33 but in spring 2004 and especially on April there was observed an increase and the diversity reached to the value 0.838. In Logarou lagoon an increase on species diversity was pointed on September 2004 (0.514) comparing to that on September 2003 (0.228). Low species diversity is the result of variable conditions in lagoons such as their shallowness and their restricted communication with the marine environment [4, 17].

Tsoukalio lagoon had lower Evenness value comparing to Rodia, which was ranged from 0.249 on May 2003 to 0.666 on April 2004. Evenness (E) in Rodia ranged from zero on May 2004 to 0.706 on August of the same year.

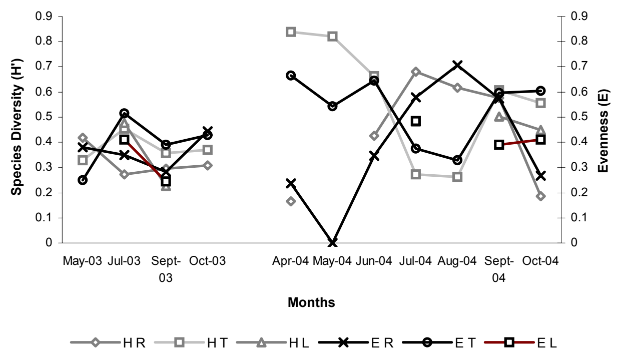

FIGURE 5 - Monthly variation of Species diversity (H') and Evenness (E) during the vegetated period 2003-'04 in Rodia, Tsoukalio and Logarou lagoons of Amvrakikos Gulf.

DISCUSSION

Coastal water bodies vary in size, depth, water dynamics (such as tidal exchange) and geomorphology however, they support a variety of biotic assemblages that are common to many coastal aquatic systems [1]. This may be a product of the highly dynamic environment at the land-sea interface where species may have to tolerate environmental fluctuations greater than those of their freshwater, marine or estuarine counterparts [21].

The growth and distribution of aquatic macrophytes is controlled by the physical, chemical and biological conditions of their habitats. Sufficient light and nutrients are fundamental factors for photosynthesis, but also a suitable substratum, temperature and various biological factors affect the distribution of plants. A complicated interaction between the factors makes it difficult to separate the effects of single factors. Variable environmental conditions in the lagoons results in low species diversity [20, 22].

The macrophytic community in the Amvrakikos gulf lagoons could be characterized as typical of brackish water lagoons with species that could develop in a wide range of salinities. In a grid of 10 sampling stations surveyed at three coastal lagoons of Amvrakikos gulf, 7 aquatic macrophytes were recorded in the Rodia, 11 in Tsoukalio and 8 in Logarou lagoon. The submerged flora of the studied areas was dominated by the angiosperm *Zostera noltii* and the charophyte *Lamprothamnium papulosum*.

Temperature affects all biological processes primarily by increasing reaction rates of the biochemical pathways. The most important processes, photosynthesis and respiration are slow at very low temperatures. However, the overall parameter, controlling the geographical distribution of species in Europe, is therefore temperature [17]. In three studied coastal lagoons of Amvrakikos the temperature showed the expected seasonal pattern and pointed out a significant negative correlation with nitrogen nutrients. According to Wetzel and Penhale [23] temperature is a factor that affects the seasonal growth of *Zostera noltii*. The optimum temperature is 20-24°C and out of that limits a significant reduction could be observed.

Several studies have described changes in the distribution of aquatic macrophytes along spatial salinity gradients [24, 25]. Macrophytes grow at salinity values ranging between 5‰ and 45‰ [13]. Salinity affects the osmotic pressure in the cells, but many seagrasses are well adapted to sudden changes. Low salinity values were exhibited during spring months in accordance to higher precipitation [10]. Significant negative correlations also suggested with nitrogen nutrients, depth and transparency. Increasing evaporation and low freshwater inputs from the land resulted to higher salinities during summer and early autumn. In Logarou, the salinity values were higher comparing to Rodia and Tsoukalio. The decrease in salinity during the second year of the survey (spring 2004) allowed a rapid disappearance of submerged vegetation in Rodia lagoon.

Nutrients of nitrogen and phosphorus presented significant seasonal changes. Nitrate concentrations were higher in spring and autumn according to inputs from catchment's area. Nitrogen concentrations could affect the presence or absence of submerged macrophytes. The low phosphorus levels in Rodia, Tsoukalio, and Logarou lagoons point to P-limitation. The temporal variability of nutrients at the lagoons shows the influence of fresh water discharge on water quality.

The unstable conditions in lagoons and their shallowness results to typically low values of diversity, low number of species, high productivity potential and strong dominance of a few species that creates monospecific types of aquatic vegetation often found in such ecosystems [2, 20]. Also it is well known that increasing anthropogenic pressure on Mediterranean lagoons (e.g. agriculture, aquaculture, domestic waste, etc.) has led to decline or even disappearance of macrophytes and to proliferation of Chlorophyta, which is more favored by increase in nutrients and pollutants [26].

The results of this study indicate that monitoring programs provide useful information for the assessment of water quality and the management of coastal lagoons. The conservation and management of coastal lagoons is being hampered by a lack of knowledge of the factors structuring lagoonal communities. Further research is needed in order to understand the lagoons functions and to apply an integrated management plan for the protection of this coastal zone.

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