

# The relationships between hydrochemical environmental factors and the aquatic macrophytic vegetation in stagnant and slow flowing waters

## I. Water quality and distribution of aquatic associations

By E. PAPASTERGIADOU and D. BABALONAS  
University of Thessaloniki, Greece

With 7 figures and 2 tables in the text

### Abstract

In the most important hydrobiotopes of Northern Greece 16 lakes and channels were studied, more or less strongly inhabited by aquatic macrophytes. The following parameters of water were determined: conductivity; alkalinity (content of  $\text{HCO}_3^-$ ); nitrogen-compounds ( $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$ ) and phosphorus ( $\text{PO}_4\text{-P}$ ). Furthermore, there was noted the natural occurrence of plant associations and their distribution in relation to each hydrochemical factor separately. From the comparative study between the associations it arose that the distribution pattern of the associations of *Lemna* species (*Lemnetum minoris*, *Lemnetum gibbae*, *Lemno-Azolletum filiculoides*) differ clearly from the others due to the fact that they were established in the most eutrophic waters. Ecological differences between the various associations were observed for most of the hydrochemical factors, while the characteristic species of the corresponding associations *Lemna minor*, *Potamogeton perfoliatus*, *Vallisneria spiralis* and *Ceratophyllum demersum*, displayed a more euryoecious behaviour and the species *Lemna gibba*, *Azolla filiculoides*, *Najas marina*, *Potamogeton gramineus* a more stenoecious.

### Introduction

Most of the Greek lakes have up to now not been studied from a limnological point of view. Information in this regard are extremely scarce or are completely lacking (see also OVERBECK et al. 1982). In particular very little has been published about the aquatic vegetation.

The published papers hitherto are usually restricted to macrophytes flora (LAVRENTIADES 1956, KOUMPLI-SOVANTZI 1983, PAPASTERGIADOU & BABALONAS 1993) with few exceptions giving phytosociological and ecological data on macrophytes (e. g. GRANDSTEIN & SMITTENBERG 1977, BABALONAS & PAPASTERGIADOU 1989).

To fill this gap the study of aquatic macrophytic vegetation including some physical and chemical features of the water was undertaken during July 1986 to July 1988, as a part of a basic limnological work. Previous communications have given the aquatic flora of lakes in Northern Greece (PAPASTERGIADOU & BABALONAS 1993) and some ecological studies on isolated plants or lakes (BABALONAS & PAPASTERGIADOU 1989, PAPASTERGIADOU & BABALONAS 1992). According to MOYLE (1945), the distribution of both aquatic plants and their associations are influenced by ecological factors, from which the water chemistry seems to be the most important. Moreover, the type of bottom soil and the physical nature of the water body greatly influence the local distribution of a species within their range of chemical tolerance.

In this work an attempt was made to study the environmental conditions under which the aquatic macrophytes (hydrophytes) present their natural occurrence in Northern Greece. Evenmore, the present study was undertaken to investigate the relationships between hydrochemical environmental factors and the distribution of macrophytic vegetation. It is hoped that these works would contribute to further limnological studies of the Greek lakes, as well as the evaluation of water quality.

### Study areas and methods

The studied areas in Northern Greece include the most important lakes and some natural or artificial channels near the lakes or the rivers. Totally were investigated 16 lakes and channels which are shown in Fig. 1.

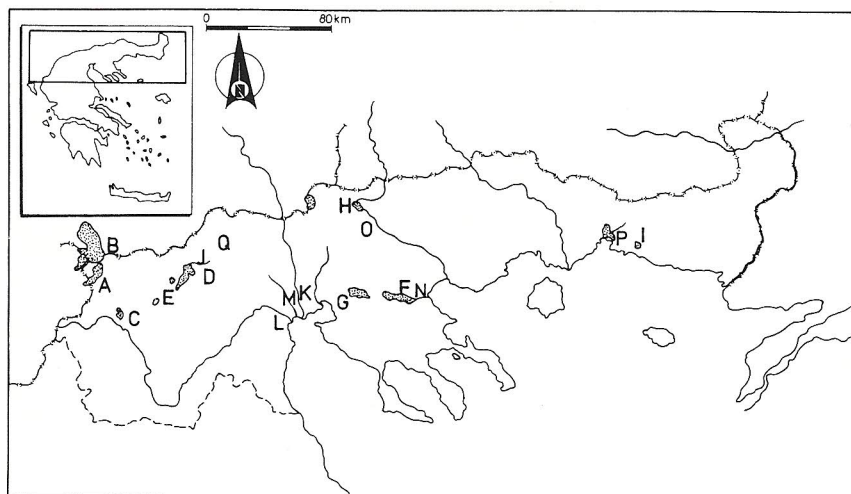


Fig. 1. Map of studied areas in Northern Greece. (Lakes: A – Mikri Prespa, B – Megali Prespa, C – Kastoria, D – Vegoritis, E – Petron, F – Volvi, G – Koronia, H – Kerkini, I – Mitrikou, J – Agra; rivers: K – Axios, L – Aliakmon, M – Loudias, N – Richios (Rentina), O – Strymon, P – Aspropotamos (Vistonis), Q – Channel near of Aridaea).

Geographical situation and morphometric data of the studied lakes are given below (according to MOURKIDES et al. 1978 and the Greek Ministry of Environment Physical Planning and Public Works).

Lake	Latitude	Longitude	M.S.L.	Surface area km <sup>2</sup>	Maximum depth m
			Altitude m		
Mikri Prespa	40°44'	21°04'	853	44	7.5
Megali Prespa	40°46'	21°01'	853	266	55.0
Kastoria	40°31'	21°18'	620	24	8.0
Vegoritis	40°45'	21°47'	520	59	46.0
Petron	40°43'	21°40'	573	6	4.0
Volvi	40°41'	23°28'	37	69	23.0
Koronia	40°41'	23°09'	75	42	8.5
Kerkini	41°13'	23°08'	37	≈ 60–70	≈ 6.5
Mitrikou	40°53'	25°07'	≈ 0.10	≈ 2–3	≈ 1–1.5

According to BALAFOUTIS (1977) the climatic type of the area mentioned above is characterized as mediterranean with mild winters and dry and warm summers (Csa), while only the western parts of Macedonia stand between the mediterranean and the continental types (Cfa). January is the coolest month of the year with the lowest temperatures in the western part of Macedonia. In the same area both spring and autumn have lower mean temperatures too. However, autumn is warmer than spring as far as their lowest temperatures are concerned.

The research on aquatic macrophytes included two basic stages; the first concerned the associations formed by hydrophytes (after HUTCHINSON 1975: floating-leaved, submerged and free-floating macrophytes), while the second stage regarded their ecological development conditions.

On the basis of the prevalence and better development of the characteristic species of the associations research stations were chosen, where the environmental factors had been carefully examined. In total, 76 stations were examined corresponding to 18 different associations and 1 subassociation.

Water samples were collected from the water surface (0–0.5 m depth) by means of a 1 liter sampler (type: Hydrobios). In all stations the water sampling and analyses were repeated three times (July 1987 to March 1988), and five times in the most interesting cases (May 1987 and July 1988). The samples were transferred in a portable refrigerator to the laboratory and immediately filtered (0.45 µm Whatman GF/C filters), the determination of nutrients, however, took place afterwards.

The water conductivity was measured by means of a portable conductivity meter (type: CDM 80 Radiometer). Chemical analyses of water were made using A.P.H.A. (1976) methods except for ammonia (GRASSHOFF 1976). The dissolved bicarbonate ions were determined by titration, phosphate-phosphorus, nitrate, nitrite and ammonia nitrogen were determined colorimetrically (A.P.H.A. 1976).

Regarding the graphics a PC computer was used loaded with "E.N.G." program.

Table 1. A synoptic table of the aquatic associations constancy in Northern Greece (1–6: alliance Nymphaeion, 7: Ranunculion fluitantis, 8–17: Eu-Potamion, 18: Ceratophyllion, 19–23: Lemnion minoris, 24: Hydrocharition).

	Ass. Number	Tr **1	2	Ny 3	Nm 4	Po 5	6	Ra 7	Pl 8	Pv 9	Pec 10
* Species	Releve' No	15	6	7	6	16	10	11	20	33	13
<i>Trapa natans</i> L.		V <sub>1-5</sub>		III <sub>r-+</sub>		II <sub>r-5</sub>			II <sub>r-2</sub>	I <sub>1-3</sub>	I <sub>1</sub>
<i>Potamogeton perfoliatus</i> L.		I <sub>+-5</sub>					I <sub>4</sub>	I <sub>+</sub>	I <sub>1-3</sub>	III <sub>+-5</sub>	I <sub>2-5</sub>
<i>Myriophyllum spicatum</i> L.		I <sub>r-+</sub>	I <sub>3</sub>		I <sub>5</sub>	II <sub>1-5</sub>	I <sub>4</sub>	III <sub>1-3</sub>	II <sub>+-4</sub>	III <sub>r-5</sub>	I <sub>1-3</sub>
<i>Potamogeton pectinatus</i> L.		I <sub>1</sub>				I <sub>r-1</sub>	I <sub>+-1</sub>	II <sub>+-4</sub>	I <sub>r-1</sub>	II <sub>+-5</sub>	V <sub>2-5</sub>
<i>Potamogeton lucens</i> L.		I <sub>1</sub>							V <sub>2-5</sub>		
<i>Cladophora</i> sp.		I <sub>1</sub>				II <sub>2-4</sub>	I <sub>5</sub>	II <sub>2-3</sub>	I <sub>4-5</sub>		
<i>Ceratophyllum demersum</i> L.		I <sub>r</sub>	II <sub>1</sub>	I <sub>2</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>4-5</sub>	II <sub>3</sub>	II <sub>r-5</sub>	I <sub>+-2</sub>	I <sub>3</sub>
<i>Nuphar lutea</i> (L.) SIBTH & SM. FL.			V <sub>1-3</sub>								
<i>Nymphaea alba</i> L.			V <sub>3-5</sub>	V <sub>3-5</sub>					I <sub>3</sub>		
<i>Myriophyllum verticillatum</i> L.			II <sub>+-1</sub>				I <sub>1-4</sub>				
<i>Potamogeton natans</i> L.				I <sub>1</sub>	I <sub>4</sub>		V <sub>r-5</sub>	I <sub>+</sub>	I <sub>3-4</sub>		
<i>Nymphoides peltata</i> O'KUNTZE				I <sub>1</sub>	V <sub>4-5</sub>				I <sub>4</sub>		
<i>Polygonum amphibium</i> L.				I <sub>r</sub>		V <sub>r-5</sub>			I <sub>+-1</sub>	I <sub>4</sub>	
<i>Salvinia natans</i> (L.) ALL.					I <sub>+</sub>				I <sub>r</sub>	I <sub>1-2</sub>	I <sub>+</sub>
<i>Potamogeton crispus</i> L.						I <sub>+</sub>		I <sub>+</sub>	I <sub>2</sub>	I <sub>+-5</sub>	
<i>Vallisneria spiralis</i> L.						I <sub>+-3</sub>			I <sub>3</sub>	V <sub>r-5</sub>	
<i>Potamogeton nodosus</i> POIRET								V <sub>1-5</sub>			
<i>Ranunculus fluitans</i> LAM.								II <sub>r-2</sub>			
<i>Lemna minor</i> L.								III <sub>+-2</sub>	I <sub>1-5</sub>		
<i>Ceratophyllum submersum</i> L.								I <sub>4</sub>			
<i>Lemna gibba</i> L.								I <sub>+</sub>			
<i>Potamogeton gramineus</i> L.											
<i>Ranunculus trichophyllus</i> CHAIX										I <sub>2</sub>	
<i>Najas minor</i> ALL.										I <sub>r</sub>	
<i>Chara hispida</i> L.											II <sub>2-5</sub>
<i>Zannichellia palustris</i> L.											
<i>Potamogeton trichoides</i> CHAM.											
<i>Najas marina</i> L.									I <sub>2</sub>	I <sub>+-3</sub>	
<i>Azolla filiculoides</i> LAM.											
<i>Spirodella polyrhiza</i> (L.) SHEILDEN											
<i>Hydrocharis morsus-ramae</i> L.										I <sub>2</sub>	
<i>Lemna trisulca</i> L.											
<i>Chara vulgaris</i> L.										II <sub>+-3</sub>	
<i>Ranunculus circinatus</i> SIBTH										I <sub>+</sub>	
<i>Najas gracilima</i> MAGNUS											
<i>Nitella hyalina</i> L.											
<i>Utricularia vulgaris</i> L.											
<i>Utricularia minor</i> L.											
<i>Potamogeton filiformis</i> PERS.											
<i>Riccia fluitans</i> L.											

\* Except of the emergent macrophytes which participate as companion species

- \*\*1. (Tr) Trapetum natantis MULLER & GORS '60  
2. Myriophyllo-Nupharetum KOCH '26  
3. (Ny) Nymphaetum albae VOLLMAR '47  
4. (Nm) Nymphoidetum peltatae OBERD. & MULLER '60  
5. (Po) Polygonetum amphibii EGGLE '33  
6. Potametum natantis EGGLE '33  
7. (Ra) Ranunculetum fluitantis ALL. '42  
8. (Pl) Potametum lucentis HUEK '31  
9. (Pv) Potamo-Vallisnerietum BR.-BL. '31  
(Pp) potametum perfoliati HORV. & MICEVSKI '58  
10. (Pec) Potametum pectinati CARSTENSEN '55  
11. (My) Myriophylletum spicati SOO '27  
12. (Pg) Potametum graminei KOCH '26





## Results and discussion

According to the BRAUN-BLANQUET (1964) approach 24 associations after 266 relevés were recognized. 17 from these belongs to class Potametea, 6 to Lemnetae and 1 to Ceratophylletea. These are shown in a synoptic constancy table (Table 1), whereas a detailed approach of the above mentioned communities as well as other features of the vegetation has been formerly published (PAPASTERGIADOU 1990). In this part, the distribution pattern of the associations in relation to the hydrochemical factors are examined.

### Chemical parameters of water and distribution of aquatic communities

A broad ecological range is a characteristic of the majority of the aquatic macrophytes. In spite of this, there exists a characteristic combination of ecological factors that makes their development attain perfection. The plant species which form along with others a perfectly developed association were massed in only certain stations (WIEGLEB 1976, 1978). Not rarely there are hydrophyte species with a broad ecological range regarding various quantities which develop in certain concentration areas, a fact indicative of a more or less indifferent behaviour towards defined hydrochemical conditions.

The following figures (2–7) show the ecological range of every association in relation to substantial nutrients of water (conductivity,  $\text{HCO}_3^-$ ,  $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , total inorganic nitrogen), as well as the ecological relations between the associations. In addition to the minimum and maximum values of every association (for abbreviations see Table 1), there are also presented their mean values according to the number of samples of every one shown on Table 2.

On the basis of the distance between the minimum and the maximum values emphasis is given on the stenoeious or euryoeious behaviour of every association.

#### 1. Conductivity

OLSEN (1950) published a widely accepted classification of waters regarding their trophic potentials on the basis of conductivity. The waters can be classified in the following categories:

1. Conductivity less than 100  $\mu\text{S}/\text{cm}$  (waters poor in electrolytes or oligotrophic)

According to WIEGLEB (1976) the waters of this kind are exclusively settled by the Littoreletea associations which were not found in the areas of Northern Greece.

2. Conductivity ranging between 100 and 250  $\mu\text{S}/\text{cm}$  (waters slightly rich in electrolytes or mesotrophic)

To this range belong the Polygonetum amphibii, Potametum crispum and Potametum graminei associations on the basis of the mean values of the sampling

stations. However, their greatest values exceed the upper limits of the scale (Fig. 2).

Table 2. Number of water samples which correspond to 3 and 5 sampling periods for every association which was studied.

Associations	3 sampling periods n	5 sampling periods n
Trapaetum natantis (Tr)	18	21
Nymphaetum albae (Ny)	18	22
Nymphoidetum peltatae (Nm)	9	11
Polygonetum amphibii (Po)	12	14
Ranunculetum fluitantis (Ra)	7	—
Potametum lucentis (Pl)	14	16
Potamo-Vallisnerietum (Pv)	21	—
Potamo-Vallisnerietum potametosum perfoliati (Pp)	6	—
Potametum pectinati (Pe)	9	—
Myriophylletum spicati (My)	11	13
Potametum graminei (Pg)	3	4
Potametum perfoliati (Per)	5	—
Najadetum marinae (Na)	2	—
Potametum crispum (Pc)	5	—
Ceratophylletum demersi (Ce)	11	13
Lemnetum minoris (Lm)	14	—
Lemnetum gibbae (Lg)	6	—
Salvinio-Spirodeletum polyrhizae (Sp)	9	23
Lemno-Azolletum filiculoides (La)	3	—

### 3. Conductivity ranging from 250 to 1000 $\mu\text{S}/\text{cm}$

To this category, which includes waters rich in electrolytes (eutrophic waters), most of the waters with the greatest numbers of associations of Northern Greece are placed. Here one may distinguish two sub-groups (Fig. 2). The stations of *Nymphoidetum peltatae*, *Nymphaetum albae* and *Salvinio-Spirodeletum polyrhizae* belong to the first and their values reach the lower limits of the scale, while concerning their ranging variances they very much resemble the previous groups associations.

Even SEDDON (1972) and PIETSCH (1982) place the *Nymphaea alba* and *Nymphoides peltata* between the euryoecious species, however they emphasize that it looks like that they prefer more the eutrophic to oligotrophic waters.

As far as the *Salvinio-Spirodeletum polyrhizae* is concerned, HEJNY (1960) places it between the *Lemnetum minoris* and *Lemnetum gibbae* in the same group of the mesotrophic-eutrophic waters. The above associations of *Lemna* in our case can be clearly distinguished from the *Salvinio-Spirodeletum polyrhizae* and develop in very eutrophic waters (Fig. 2).

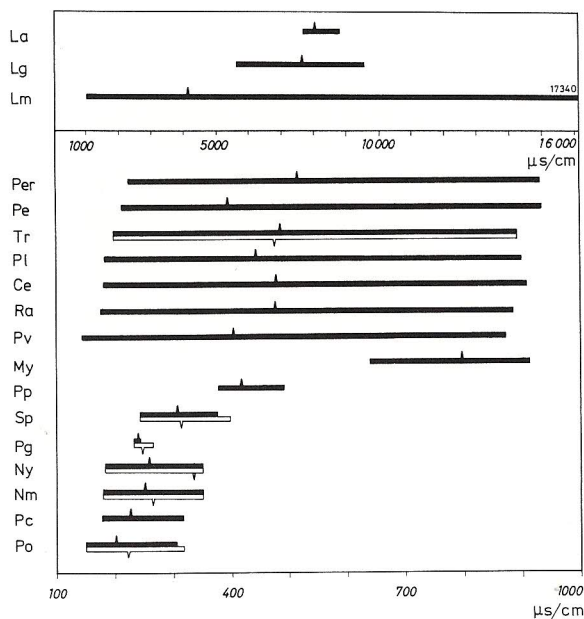


Fig. 2. Relationships between the conductivity of water and the macrophytic vegetation. (■: 3 sampling periods, □: 5 sampling periods)

In the second sub-group are mainly placed associations of the Eu-Potamion (*Potametum perfoliati*, *Potametum pectinati*, *Potametum lucentis*, *Potamo-Vallisnerietum*, *Potamo-Vallisnerietum potametosum perfoliati*, *Myriophylletum spicati*) as well as the *Trapetum natantis*, *Ceratophylletum demersi* and *Ranunculetum fluitantis*. Their range and mean values of their water conductivity are similar and only their lowest values exceed the lower scale limits. The *Myriophylletum spicati* that prefers the area from 640 to 907  $\mu\text{s}/\text{cm}$  and the *Potamo-Vallisnerietum potametosum perfoliati* that prefers the 379 to 481  $\mu\text{s}/\text{cm}$  values are slightly differentiated from the other associations of this sub-group due to their narrower range (Fig. 2).

Most of the characteristic species of the associations belonging to the second sub-group are well-developed in waters rich in electrolytes (LOHAMMAR 1938, SPENCE 1967, HUTCHINSON 1970, HILBIG 1971, JORGA et al. 1982, PIETSCH 1972, 1982 etc.). According to SEDDON (1972) the species *Potamogeton lucens*, *P. pectinatus*, *P. perfoliatus* and *Ceratophyllum demersum* prefer eutrophic waters, however they are resistant even to low conductivity (less than 200  $\mu\text{s}/\text{cm}$ ).



#### 4. Conductivity more than 1000 $\mu\text{S}/\text{cm}$ (waters very rich in electrolytes or hyper-eutrophic)

In these extreme conditions usually only a few associations exist, which are poor in species. This category consists of the Lemnetea associations (*Lemnetum minoris*, *Lemnetum gibbae* and *Lemno-Azolletum filiculoides*). Although their characteristic species usually refer to lower values, in Northern Greece, the waters where they were studied have a conductivity of more than 1000  $\mu\text{S}/\text{cm}$ . Nevertheless, their development is quite satisfactory.

A comparison with the already existing literature leads to the conclusion that certain species may appear in conditions that are quite different from area to area. For instance, *Lemna minor* according to SEDDON (1972) and PIETSCH (1982) belongs to the species living in eutrophic waters, however, it can occasionally occur in waters poor in electrolytes, while HASLAM (1978) states that the species in question is one of the most tolerant to polluted waters. The *Lemnetum gibbae* according to TÜXEN (1974) and POTT (1980) occupy the most eutrophic side of Lemnetea and can stand strong pollution. Its character species, *Lemna gibba*, in countries of central Europe (PIETSCH 1982) as observed in Northern Greece colonizes waters which are very rich in electrolytes.

## 2. Alkalinity

Numerous attempts have been made to define the trophic nature of waters according to their bicarbonate content and, therefore, there are quite many systems of classification. The present research follows the classification of POTT (1980) who distinguishes the categories below:

1. Poor waters, alkalinity less than 1 meq/l  $\text{HCO}_3^-$ .
2. Moderate rich waters, alkalinity between 1 and 3 meq/l  $\text{HCO}_3^-$ .
3. Very rich waters, alkalinity more than 3 meq/l  $\text{HCO}_3^-$ .

Considering the mean  $\text{HCO}_3^-$  values during the whole year on the basis of this classification, the plant associations of Northern Greece areas may be arranged in the last two categories.

Most of them prefer to develop in moderately rich waters (Fig. 3: Po, Nm, Ny, Na, Pp, Pe, Pc, Tr, Pv, Pg, Pl, My, Per). In this group the *Najadetum marinae* and *Potametum graminei* are slightly differentiated because of their narrower range and due to the fact that they prefer waters with less alkalinity ( $<2$  meq/l).

In concentrations more than 3 meq  $\text{HCO}_3^-/\text{l}$  (very rich waters) six associations develop (Sp, Ra, Ce, Lg, Lm, La). The *Lemno-Azolletum filiculoides*, *Lemnetum minoris* and *Lemnetum gibbae* are differentiated from this category, because their mean concentrations in  $\text{HCO}_3^-$  are more than 5 meq/l (Fig. 3) and they are characteristic of very alkaline waters as stated by WIEGLEB (1976).

The development of the *Potametea*, *Ceratophylletea* and *Lemnetea* species in waters rich in bicarbonates is closely connected to their adaptability in aquatic life.

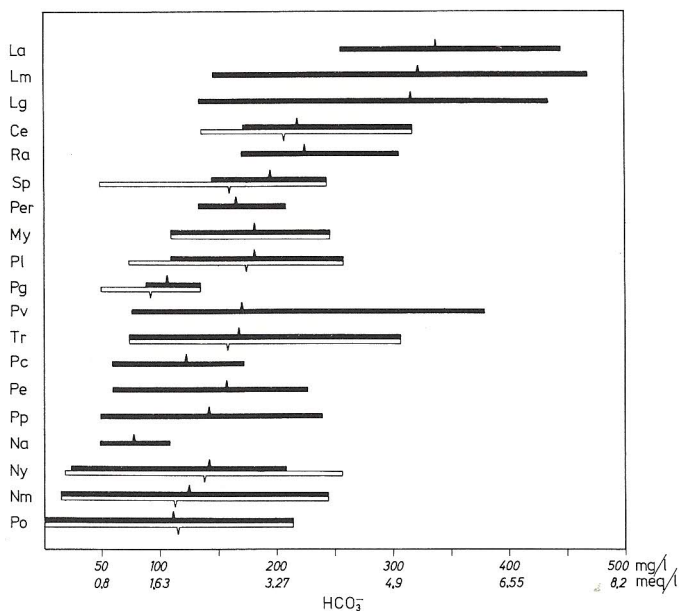


Fig. 3. Relationships between the alkalinity of water and the macrophytic vegetation.

As pure hydrophytes may be characterized these species that can directly use the bicarbonates (WIEGLEB 1976). The usual spreading of the characteristic species *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton lucens* and *P. pectinatus* in alkaline waters is related to their ability of using the  $\text{HCO}_3^-$  as the main source of carbon for photosynthesis (SPENCE 1967, WEBER-OLDECOP 1972, KOLLMAN & WALI 1976).

According to PIETSCH (1972) *Trapa natans*, *Nymphoides peltata*, *Potamogeton lucens*, *Lemna minor*, *Salvinia natans* and *Ceratophyllum demersum* prefer waters which are poor in dissolved carbon dioxide ( $\text{CO}_2$ ) and rich in bicarbonates ( $\text{HCO}_3^-$ ), with the following sequence of anion content in the water:  $\text{HCO}_3^- > \text{SO}_4^- > \text{Cl}^-$ . The same author (1982) mentions an even greater alkalinity range in comparison to our results, referring to Central Europe species *Nymphaea alba*, *Polygonum amphibium*, *Ranunculus fluitans* and *Potamogeton nodosus*. HASLAM (1978) mentions the presence of *Potamogeton perfoliatus*, *P. pectinatus* and *P. crispus* in areas of much higher alkalinity than those in Northern Greece, while MOYLE (1945) reports higher alkalinity values for the *Najas marina* in contrary to our results. It is possible that this difference is a consequence of the small number of measurements for this species (summer period only, Fig. 3).

To conclude, it could be said that we observed an evident relation between the inorganic carbon of the bicarbonates and the development of aquatic vegetation which confirm the theory of PIETSCH (1972).

### 3. Phosphorus

The number of aquatic plants that develop in narrow limits of phosphorus concentrations is relatively small (PIETSCH 1982).

The classifications of the phosphate content of water vary among the different scientists quite a lot. This can be explained by the fact that characterizations such as "poor", "rich", etc. are relative and not absolute on account of the particular conditions each area presents.

According to THOMAS (1953) and VOLLENWEIDER (1968), concentrations of phosphate-phosphorus ( $\text{PO}_4\text{-P}$ ) less than  $10\text{ }\mu\text{g/l}$  characterize the waters as "poor" (oligotrophic), between  $10$  and  $20\text{ }\mu\text{g/l}$  "nearly rich" (mesotrophic), while more than  $20\text{ }\mu\text{g/l}$  as "rich" in phosphorus (eutrophic). On the basis of the above classification the vegetation units occurring in Northern Greece in waters poor in phosphorus ( $<10\text{ }\mu\text{g/l}$ ) are delimited (Fig. 4). The subassociation Potamo-Vallisnerietum potametosum perfoliati may be characterized as oligotrophic (considering the mean values of  $\text{PO}_4\text{-P}$ ). The Potametum graminei, Salvinio-Spirodeletum polyrhizae, Nymphaeetum albae, Ceratophylletum demersi, Ranunculetum fluitantis, Nymphoidetum peltatae and Potamo-Vallisnerietum occur in mesotrophic waters.

Large differences characterize the mean values of Potametum graminei and Salvinio-Spirodeletum polyrhizae which result from sampling of 3 and 5 periods respectively, probably due to the fluctuations of the water level of the artificial

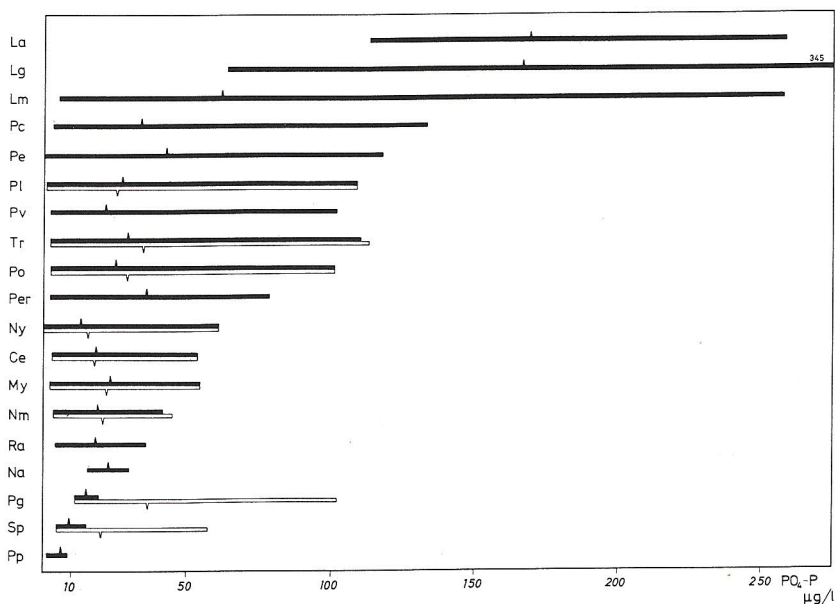


Fig. 4. Relationships between the phosphate-phosphorus ( $\text{PO}_4\text{-P}$ ) content of water and the macrophytic vegetation.

lake Kerkini (PAPASTERGIADOU 1990), where they were studied. In eutrophic waters (mean value  $>20 \mu\text{g/l PO}_4\text{-P}$ ) all other associations develop. Especially the associations with *Lemna* (*Lemnetum gibbae* and *Lemno-Azolletum filiculoides*) cover very high concentrations (Fig. 4). According to GILGEN (1989) the phosphorus content of waters may become the main limiting factor of the Lemnaceae distribution. LANDOLT (1975) gives variations of the phosphorus concentrations in *Lemna* associations similar to these of Northern Greece ( $10\text{--}120 \mu\text{g/l}$ ), while HASLAM (1978) reports a wider range ( $30\text{--}1200 \mu\text{g/l}$ ).

*Potamogeton crispus*, *P. perfoliatus* and *Myriophyllum spicatum* are mentioned as tolerant to high phosphorus concentrations (JANAUER 1981, DYKYJOVA et al. 1985). Moreover, the *Polygonetum amphibii* found in waters rich in  $\text{PO}_4\text{-P}$  is mentioned by POTT (1980) as indicative of waters contaminated with phosphorus.

#### 4. Nitrogen

The distribution of the studied associations in Northern Greece on the basis of the ammonia and nitrate nitrogen content of water is shown in Figs. 5 and 6.

The prevalence of the ammonia towards the nitrates was observed mainly at the stands of *Lemno-Azolletum filiculoides*, *Nymphaeetum albae*, *Salvinio-Spirodeletum polyrhizae*, *Ceratophylletum demersi*, *Potametum lucentis* and *Potametum crispum* (Figs. 5, 6). *Nymphaea alba*, according to WIEGLEB (1976) and POTT (1980), prefer waters rich in ammonia nitrogen, while PIETSCH (1982) gives a wider range

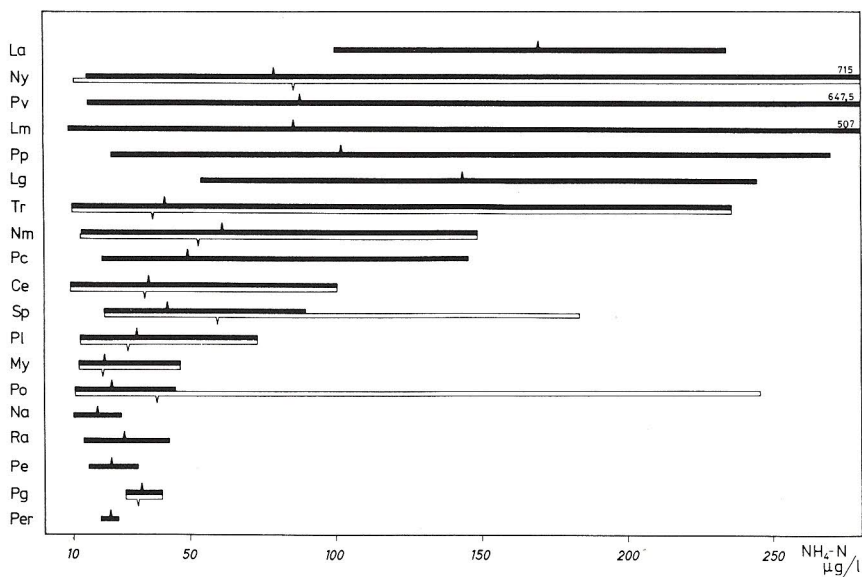


Fig. 5. Relationships between the ammonia-nitrogen ( $\text{NH}_4\text{-N}$ ) of water and the macrophytic vegetation.

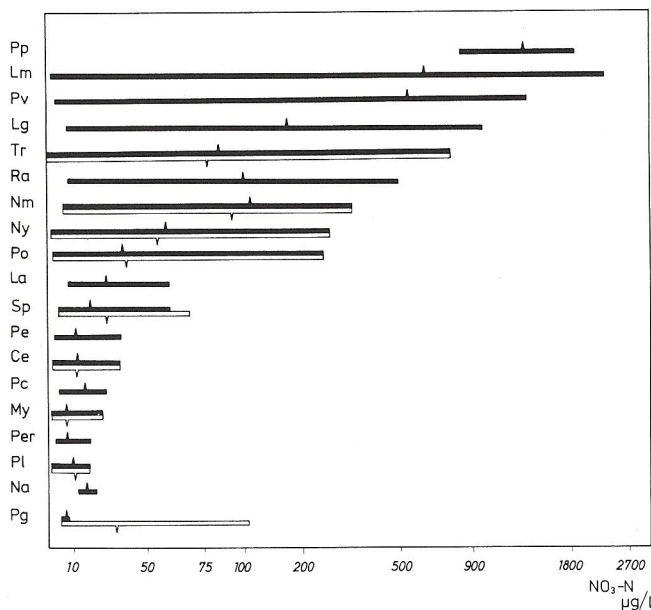


Fig. 6. Relationships between the nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) of water and the macrophytic vegetation.

of concentrations regarding this species in Central Europe. Concerning the nitrates content of water it belongs to the group of "indifferent" species (WIEGLEB 1978). AGAMI et al. (1976) found that under experimental conditions an increased quantity of ammonia may damage *Nymphaea*, while nitrates and phosphates do not influence the plants at all.

Although ammonia nitrogen prevails over all other nitrogen compounds in the stands of *Potametum lucentis*, the concentration is low (Fig. 5). WIEGLEB (1976, 1978) mentions this association in areas of Germany as tolerant to waters lacking ammonia. Moreover, our results regarding the *Potametum crispum* and *Ceratophylletum demersi*, which develop in waters poor in nitrates, are contrary to WIEGLEB (1976) who states that *Potamogeton crispus* is one of the most demanding species in nitrate nitrogen after *Zannichelia*, while, on the other hand, *Ceratophyllum demersum* is comparable concerning its competitiveness with the *Potamogeton* species (magnopotamids) and well developing in waters with high maximum values of nitrates. Especially the *Ceratophylletum demersi* is an indicator of waters rich in nitrates. Also GOULDER & BOATMAN (1971) consider *Ceratophyllum demersum* as a nitrophilous plant and NICHOLS & KEENEY (1976) investigated that this species assimilates quicker the nitrate than the ammonia nitrogen under experiment conditions.

The *Nymphoidetum peltatae* in Northern Greece develops in waters with high concentrations of nitrate nitrogen. According to HILD & REHNELT (1965,



1971) the development conditions of this species are clearly distinguished from the associations of other nymphaeids which especially prefer stations rich in nitrates.

WIEGLEB (1978) reports *Polygonum amphibium* to belong to the widely indifferent species, since it is absent from stations with a high content of ammonia while HASLAM (1978) mentions a wider range of concentrations (300 µg/l), that agrees with our results and classifies it in the category of the very tolerant species.

In Northern Greece the subassociation Potamo-Vallisnerietum potametosum perfoliati develops at the most rich stations in nitrates (Fig. 6) along with the Potamo-Vallisnerietum and Lemnetum minoris. Regarding *Vallisneria spiralis* there are no sufficient elements neither for its ability to become an associate member nor for their ecology. In our area it is likely that it prefers waters rich in nitrogen although it occurs in poorer waters.

The *Lemna* associations were also found in waters rich in inorganic nitrogen. Their distribution, according to LANDOLT (1981) is related to the nitrate nitrogen content of water. The vegetation variations at the same stations with a successive prevalence of the *Lemna* species as well as the *Azolla* or *Salvinia* studied in Northern Greece is due on the one hand to the increment of the intensity of light and on the other to the decrement of nitrates or other compounds of nitrogen (WHITE 1937, In: EWEL 1975).

In the associations Lemno-Azolletum filiculoides and Salvinio-Spirodeletum polyrhizae there is a prevalence of ammonia nitrogen, while in the Lemnetum minoris and Lemnetum gibbae prevails the nitrate.

As mentioned above for other nutrients there are also different classifications of waters on the basis of their concentration in inorganic nitrogen.

THOMAS (1953, 1969) distinguishes the following categories:

1. Total inorganic nitrogen (T.I.N.) less than 200 µg/l characterizes the waters as "poor" or oligotrophic. In this category are included the associations Potametum pectinati, Potametum graminei, Potametum lucentis, Potametum perfoliati, Potametum crispum, Myriophylletum spicati, Najadetum marinae, Ceratophylletum demersi, Salvinio-Spirodeletum polyrhizae and Polygonetum amphibii which are the most, concerning their number (Fig. 7).

2. Total inorganic nitrogen between 200 and 400 µg/l characterizes the waters as "relatively rich" or mesotrophic. In this category are classified the Lemno-Azolletum filiculoides as well as the Trapetum natantis, Nymphaeetum albae, Nymphoidetum peltatae and Ranunculetum fluitantis which, however, should be considered as oligomesotrophic since certain stations of them belong to the previous category.

3. Total inorganic nitrogen between 300 and 650 µg/l characterizes the waters as "rich" or mesoeutrophic. The Lemnetum gibbae is also arranged in this category which is mentioned by WIEGLEB (1978) as indicative of the abundant presence of ammonia nitrogen in the water.

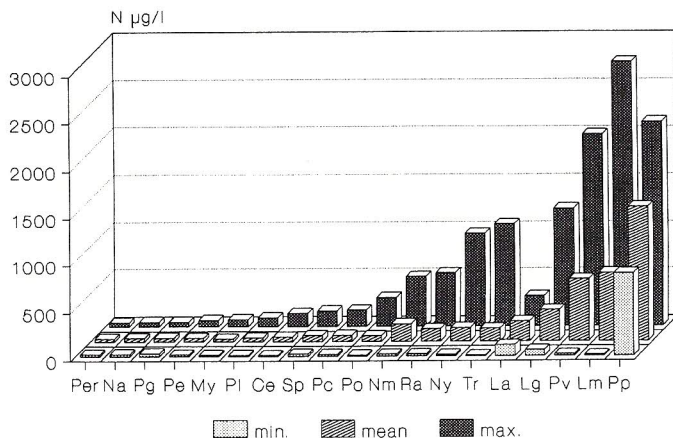


Fig. 7. Relationships between the total inorganic nitrogen –  $(\text{NH}_4\text{-N} + \text{NO}_3\text{-N} + \text{NO}_2\text{-N})\text{N}$  – of water and the macrophytic vegetation.

4. Total inorganic nitrogen between 500 and 1500  $\mu\text{g/l}$  characterizes the waters as “very rich” or eutrophic. The Lemnetum minoris and Potamo-Vallisnerietum belong to this category.

5. Waters with a total inorganic nitrogen content larger than 1500  $\mu\text{g/l}$  are characterized as “very eutrophic” or “polytrophic”. The subassociation Potamo-Vallisnerietum potametosum perfoliati may be considered as typical of this category, because its presence is indicative of abundant nitrogen in water (Fig. 7).

### References

- AGAMI, M.; LITAV, M. & WAISEL, Y. (1976): The effects of various components of water pollution on the behaviour of some aquatic macrophytes of the coastal rivers of Israel. – Aquat. Bot. 2: 203–213.
- American Public Health Association (A.P.H.A.) (1976): Standard methods for the examination of water and waste water. – 14<sup>th</sup> ed., 1200 p.; New York.
- BABALONAS, D. & PASTERGIADOU, E. (1989): The waterfern *Salvinia natans* (L.) All. in the Kerkini Lake (North Greece). – Arch. Hydrobiol. 116 (4): 487–498.
- BALAFOUTIS, CH. (1977): Contribution to the study of the climate in Macedonia and Western Thrace. – Doct. Diss., Univ. Thessaloniki, 121 pp.
- BRAUN-BLANQUET, J. (1964): Pflanzensoziologie. – 865 pp., Springer, Wien.
- DYKYJOVA, D.; KOSANOVA, A.; HUSAK, S. & SLADECKOVA, A. (1985): Macrophytes and water pollution of the Zlata Stoka (Golden canal), Trebon biosphere Reserve, Czechoslovakia. – Arch. Hydrobiol. 105 (1): 31–58.
- EWEL, K. C. (1975): Seasonal changes in distribution of waterfern and duckweed in cypress domes receiving sewage. – 3rd annu. rep. Nat. Sci. Found., Prog. Res. Appl. Nat. Needs (RANN): 164–170; Centre for Wetlands Un., Florida.
- GILGEN, R. (1989): Relation between quality of water and occurrence of Lemnaceae in the Hansried (Zurich). – Ber. Geobot. Inst. ETH Zurich 55: 89–131.

- GOULDER, R. & BOATMAN, D. J. (1971): Evidence that nitrogen supply influences the distribution of a freshwater macrophyte, *Ceratophyllum demersum*. — J. Ecol. 59: 783–791.
- GRANDSTEIN, S. R. & SMITTENBERG, J. H. (1977): The hydrophyllous vegetation of Western Crete. — Vegetatio 34 (2): 65–86.
- GRASSHOFF, K. (1976): Methods of seawater analysis. — Verlag & Chemie, New York.
- HASLAM, S. M. (1978): River plants. — Cambridge Univ. Press. London, 396 p.
- HEJNY, S. (1960): Ökologische Charakteristik der Wasser- und Sumpfpflanzen in der Slowakischen Tiefebene. — Slowak. Akad. Wiss., Bratislava, 478 pp.
- HILBIG, W. (1971): Übersicht über die Pflanzengesellschaften des südlichen Teiles der DDR. I. Die Wasserpflanzengesellschaften. — Hercynia N.F. 8 (1): 4–33.
- HILD, J. & REHNELT, K. (1965): Hydrobiologische Untersuchungen an niederrheinischen Gewässern. — Hydrobiologia 25: 442–465.
- (1971): Ökosozologische Untersuchungen an den Kühlen der Berendonk und des Kermisdahl. — Vegetatio 22: 65–82.
- HUTCHINSON, G. E. (1970): The chemical ecology of three species of *Myriophyllum* (Angiospermae, Haloragaceae). — Limnol. & Oceanogr. 15 (1): 1–5.
- (1975): A Treatise on Limnology. III. Limnological Botany. — New York, John Wiley & Sons, Inc., 660 pp.
- JANAUER, G. A. (1981): Die Zonierung submerser Wasserpflanzen und ihre Beziehung zur Gewässerbelastung am Beispiel der Fische (Niederösterreich). — Verh. Zool. Bot. Ges. Österreich, Wien, 120: 73–98.
- JORGA, W., PIETSCH, W. & WEISE, G. (1982): Beiträge zur Ökologie und Bioindikation von *Trapa natans* L. — Limnologica 14 (2): 385–394.
- KOLMAN, A. L. & WALI, M. K. (1976): Intraseasonal variations in environmental and productivity relation of *Potamogeton pectinatus* communities. — Arch. Hydrobiol., Suppl. 50 (4): 439–472.
- KOUMPLI-SOAVANTZI, L. (1983): Studies on the Tracheophytes in the Lakes and adjacent Hydrobiotopes of Aetoloakarnania, Greece. — Doct. Diss., Univ. Athens, 346 pp.
- LAVRENTIADIS, G. (1956): On the hydrophytes of Greek Macedonia. — Thesis, Thessaloniki, 48 pp.
- LANDOLT, E. (1975): Morphological differentiation and geographical distribution of the *Lemna gibba*-*Lemna minor* group. — Aquat. Bot. 1: 345–363.
- (1981): Distribution pattern of the family Lemnaceae in North Carolina. — Veröff. Geobot. Inst. ETH 77: 112–148.
- LOHAMMAR, G. (1938): Wasserchemie und höhere Vegetation schwedischer Seen. — Symb. Bot. Upsal. 3: 1–252.
- MOURKIDES, G.; TSIKRITZIS, G.; TSIOURIS, S. & MENKISOGLU, O. (1978): The lakes of Northern Greece. I. Trophic status. — Sci. Ann. Agric., Univ. Thessaloniki 21: 93–131.
- MOYLE, J. B. (1945): Some chemical factors influencing the distribution of aquatic plants in Minnesota. — Amer. Midl. Nat. 34: 402–420.
- NICHOLS, D. S. & KEENEY, D. R. (1976): Nitrogen nutrition of *Myriophyllum spicatum* uptake and translocation of  $^{15}\text{N}$  by Shoots and roots. — Freshwater Biology 6: 145–154.
- OLSEN, S. (1950): Aquatic plants and hydrospheric factors. — Svensk. Bot. Tidsskr. 44: 1–34, 332–374.
- OVERBECK, J.; ANAGNOSTIDES, K. & ECONOMOU-AMILLI, A. (1982): A Limnological survey of three Greek lakes: Trichonis, Lyssimachia and Amvrakia. — Arch. Hydrobiol. 93: 365–394.
- PAPASTERGIADOU, E. (1990): Phytosociological and ecological studies of aquatic macrophytes (hydrophytes), in Northern Greece. — Doct. Diss., Univ. of Thessaloniki, 266 pp.

- PAPASTERGIADOU, E. & BABALONAS, D. (1992): Ecological studies on aquatic macrophytes of a dam lake – Lake Kerkini, Greece. – Arch. Hydrobiol./Suppl. 90 (2): 187–206.
- (1993): Aquatic flora of Northern Greece. I. Hydrophytes. – Willdenowia 23. [in press]
- PIETSCH, W. (1972): Ausgewählte Beispiele für Indikatoreigenschaften höherer Wasserpflanzen. – Arch. Naturschutz u. Landschaftsforsch. 12, H 25: 121–151.
- (1982): Makrophytische Indikatoren für die ökochemische Beschaffenheit der Gewässer. In: Ausgewählte Methoden der Wasseruntersuchung, II, 2. Aufl.: 67–88. VEB Gustav Fischer, Jena.
- POTT, R. (1980): Die Wasser- und Sumpflvegetation eutropher Gewässer in der Westfälischen Bucht – Pflanzensoziologische und hydrochemische Untersuchungen. – Abh. Landesmus. Naturk. Münster/Westf. 42 (2): 1–156.
- SEDDON, B. (1972): Aquatic macrophytes as limnological indicators. – Freshwater Biology 2: 107–130.
- SPENCE, D. H. N. (1967): Factors controlling the distribution of freshwater macrophytes with particular reference to the lochs of Scotland. – J. Ecol. 55: 147–170.
- THOMAS, E. (1953): Zur Bekämpfung der See-Eutrophierung: Empirische und experimentelle Untersuchungen zur Kenntnis der Minimumstoffe in 46 Seen der Schweiz und angrenzender Gebiete. Monatsbull. – Schweiz. Ver. Gas. Wasserfachmännern: 25–32, 71–79.
- (1969): The Process of Eutrophication in Central European Lakes. In: Eutrophication, Proceedings of a Symposium: 29–49. – Nat. Acad. Sci., Washington, D. C.
- TÜXEN, R. (1974): Die Haselünner Kuhweide. Die Pflanzengesellschaften einer mittelalterlichen Gemeindeweide. – Mitt. Flor.-soz. Arbeitsgem. N.F. 17: 69–102.
- VOLLENWEIDER, R. A. (1968): Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris, OECD, 160 p.
- WEBER-OLDECOP, D. W. (1972): Über einige kleine *Potamogeton*-Arten. – Gott. Flor. Rundbr. 6: 7–9.
- WIEGLEB, G. (1976): Untersuchungen über den Zusammenhang zwischen Chemismus und Makrophytenvegetation stehender Gewässer in Niedersachsen. – Diss. Göttingen, 113 p.
- (1978): Untersuchungen über den Zusammenhang zwischen hydrochemischen Umweltfaktoren und Makrophytenvegetation in stehenden Gewässern. – Arch. Hydrobiol. 83 (4): 443–484.

Submitted: 10 June 1991; accepted: 12 March 1992.

Address of the authors:

Assoc. Prof. Dr. D. BABALONAS, Dr. E. PAPASTERGIADOU, Institute of Systematic Botany and Phytogeography, Aristotelian University of Thessaloniki, GR-540 06 Thessaloniki, Greece.