Occurrence of the rare microflagellates *Prorocentrum arcuatum* Issel and *Hermesinum adriaticum* Zacharias in the marine Lake Rogoznica (eastern Adriatic coast)

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The marine Lake Rogoznica is a small, karstic habitat with potential anthropogenic influence, situated in the eastern-central Adriatic coast. In this naturally eutrophic, hypoxic and periodically anoxic lake, an investigation of the microplankton community was performed during the 1995-1998 period when the ecology of the lake was greatly influenced by strong stratification and the appearance of anoxic conditions in the entire water column. The microplankton community (maximum abundance $1.06 \times 10^7$ cells L$^{-1}$) was composed of 40 taxa, mainly diatoms (62.5%) and dinoflagellates (29%). The research provided evidence of exceptionally dense populations and the seasonally-recurrent appearance of two rare microflagellates: *Prorocentrum arcuatum* Issel (dinoflagellate) and *Hermesinum adriaticum* Zacharias (heterotrophic microflagellate). The development of *H. adriaticum* and *P. arcuatum* mostly increased during the summer under conditions of nitrate deficiency, while the co-dominant diatom *Chaetoceros curvisetus* Cleve appeared during the spring when higher nitrate concentrations were present. Canonical Correspondence Analysis (CCA) indicated the importance of temperature, oxygen, silicate and nitrate on the incidence of these dominant species. The investigation of these microflagellates has allowed for the gaining of insight into their ecophysiological characteristics as well as the monitoring of their distribution in the Mediterranean, which has possibly expanded due to climate changes.

Key words: *Hermesinum adriaticum, Prorocentrum arcuatum*, flagellates, seasonality, marine lake, Rogoznica
INTRODUCTION

Isolated marine systems (CRISAFFI, 1955; SOROKIN & DONATO, 1975; BULJAN & SPAN, 1976) provide extreme conditions that do not change over longer periods of time, with reduced numbers of species and the occurrence of rare organisms (KRŠINIĆ, 2003). In those natural laboratories, repetitive field measurements of biological and physical attributes are possible, thus leading to some authors comparing them to chemostats (HAMNER & HAMNER, 1998; CERRANO et al., 2006).

The small, periodically stratified, marine Lake Rogoznica has very peculiar ecological characteristics, quite different from those of other coastal salt lakes in the Mediterranean (KRŠINIĆ et al., 2000; CIGLENEČKI et al., 2005). In the lake, allochthonous organic matter recycles microbiologically, resulting in oxygen consumption, anoxia in the bottom layer and the formation of a chemocline (CIGLENEČKI et al., 1998; CIGLENEČKI et al., 2005). Under certain conditions, hydrogen sulphide comes to the surface of the lake. Due to the extreme ecological conditions that prevail in this lake, phyto- and zooplankton populations are represented by a relatively small number of species. However, some of these populations are denser than those in the surrounding sea (KRŠINIĆ et al., 2000; CIGLENEČKI et al., 2005).

Prorocentrum arcuatum, a rare, photosynthetic dinoflagellate is known from the eastern Mediterranean (SCHILLER, 1933; RAMPI & BERNHARD, 1980), and according to recent research in the Adriatic Sea it has been detected only in the marine Lake Rogoznica (VILIČIĆ et al., 1997). Hermesinum adriaticum, a heterotrophic and mixotrophic microflagellate (due to the presence of photosynthetic endosymbionts) (HARGRAVES & MILLER, 1974), belongs to Ebriales, a protistan group with uncertain taxonomic position, with an internal siliceous skeleton (DEFLANDRE, 1952; PREISIG, 1994). It was first described in the northern Adriatic Sea (ZACHARIAS, 1906) and is now known as a rare neritic, tropical and temperate species (SOURNIA, 1986). Hermesinum adriaticum has been found in the Black Sea (BODEANU, 1969) and south–eastern Mediterranean (HALIM, 1960; VILIČIĆ et al., 1997; CAROPPO et al., 1999), but not in the northern Mediterranean (TRAVERS & TRAVERS, 1968). It can be found in Pettaquamscutt River in Rhode Island (HARGRAVES & MILLER, 1974), the lower Chesapeake Bay (ROHDES & GIBSON, 1981) and in the saline lake Salton Sea (TAPPAN, 1980). The greatest known abundance of H. adriaticum has been found in the mixohaline extension of the Narragansett Bay (25 x 10^4 cells L^(-1)) (HARGRAVES & MILLER, 1974) and in the Salton Sea, California (45 x 10^4 cells L^(-1)) (CARPELAN, 1961). The centric diatom Chaetoceros curvisetus is a common marine species, usually appearing in early spring-late autumn in the eastern coastal Adriatic (VILIČIĆ et al., 1998).

The objective of this paper is to present the seasonal distribution of two common microflagellates (P. arcuatum, H. adriaticum) and one co-dominant centric diatom (C. curvisetus), as well as the peculiar environmental conditions that maintained such a specific microplankton community in the 1995-1998 period. The chosen investigated period is characterised by strong stratified conditions on one side of the lake and appearance of anoxia in the entire water column on the other side. Because the flagellates studied are rare in the surrounding oligotrophic coastal sea (unpublished data), Lake Rogoznica proves to be an ideal site to study their ecology. These two flagellates are of interest because of the current lack of knowledge concerning their physiological-ecological responses.

MATERIAL AND METHODS

Study area

The marine Lake Rogoznica is located on a small peninsula, in the vicinity of the village of Rogoznica and the city of Šibenik, in the central part of the eastern karstic coast of the Adriatic Sea (Fig. 1). The studied area is sparsely inhabited. The surface area of the lake is 10 300 m^2 and the maximum depth is about 15 m. Due to its weak connection with the sea through the surrounding porous karstic rocks, tides are
detectable in the lake. A certain delay of tidal maxima/minima of approximately two hours as compared with those in the nearby coastal sea was noticed in the lake. The position of the lake protects it from the effect of winds. Meteorological conditions, which include the quantity of rainfall and a cold or mild winter, greatly influence the stratification and mixing of the water column in Rogoznica Lake (CIGLENEČKI et al., 1998; CIGLENEČKI et al., 2005). The water column can be divided into an upper oxic zone (mostly above 9 m depth) and a lower anoxic zone (mostly below 9 m depth) rich in reduced sulphur species (up to 900 µM) (CIGLENEČKI et al., 1996; CIGLENEČKI et al., 2005). An increasing gradient of phosphate, nitrate, nitrite, ammonia, silicate, iodine and sulphur species concentrations has been detected in the layer of a sharp chemocline between 6 and 10 m (CIGLENEČKI et al., 1996; CIGLENEČKI et al., 2005). The saline characteristics of the deeper layers of the lake are influenced by the surrounding sea due to the porosity of the karst. During most of the year, vertical, physical and chemical stratification prevails, giving the lake meromictic characteristics.

**Sampling and analyses**

Water samples for the analyses of phytoplankton were collected approximately monthly in the period from October 1995 to December 1998 (25 field trips). Samples were collected in 5 L Niskin bottles, in the middle of the lake. Eleven discrete samples of the water column were collected on each sampling date (0.2, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 m). The samples were preserved in a 2% (final concentration) neutralised formaldehyde solution. Cell counts were obtained by the inverted microscope method (UTERMÖHL, 1958). Subsamples of 50 ml were analysed microscopically after sedimentation for 24 h. Microplankton (MICRO) cells (longer than 20 µm) were counted under a magnification of 400 X (1-2 transects), as well as 200 and 100 X (transects along the rest of the counting chamber base plate). The precision of the counting method was ±10%.

Salinity was determined by argentometric titration, temperature by an inverted thermometer, and oxygen by Winkler titration. Nutrient concentrations were determined following standard methods (STRICKLAND & PARSONS, 1972; IVANČIĆ & DEGOBBIS, 1984) using the Perkin-Elmer Lambda 15 UV/VIS spectrophotometer. Salinity, oxygen and nutrients were measured once for each depth per field survey.

The vertical averaged potential energy anomaly, $\Phi$ (SIMPSON et al., 1982), was used as a bulk index of stratification. The value, $\Phi$ (J m$^{-3}$), is the energy input required to cause complete vertical mixing of the water column and is thus directly proportional to the strength of stratification. For data analysis Grapher 5, Surfer 6,7 and Statistica 7 programs were used.

Canonical Correspondence Analysis (CCA; (TER BRAAK, 1995)) was used to display environment – phytoplankton relationships in the period from July 1996 to December 1998. In the species data matrix, only dominant species relevant for this study were used ($P$. arcuatum, H. adriaticum, C. curvisetus and Eunotia sp.). A logarithmic transformation ($\log(x+1)$) was used on the phytoplankton abundance data to obtain the normal distribution. In the samples that had
no target species present, the log abundance value of 0.1 was used.

**RESULTS**

Temperature in the marine Lake Rogoznica ranged from 8 to 28.2 °C and salinity from 23 to 38.8 (Fig. 2). The index of stratification decreased during the June - October 1997 period (Fig. 3). Stratified conditions were most evident in 1996 (March-April, October), February-March 1997, and January and July 1998.

The maximum oxygen concentration of 21 mg L⁻¹ was detected in May 1996 in the 9-10 m layer (Fig. 4), while anoxic conditions were frequently detected below 12 m depth. In October 1997, anoxia was detected throughout the entire water column.

The vertical distribution of nutrients was characterised by the positive gradient of orthophosphate, ammonia and silicate from the surface to the bottom, with a sharp increase in concentrations, mostly below the depth of 9 m (Fig 5). In contrast to orthophosphates, which exhibited strong concentration gradients through the water column (0.02-8.26 µmol L⁻¹ in May 1997), vertical concentration gradients of nitrates were lower (6.95-1.54 µmol L⁻¹ in September 1996). In November 1997 concentrations of nutrients,
particularly ammonia and orthophosphates, were significantly higher (p < 0.01) than in October of the same year, and remained high during the rest of the study period.

N:P ratios showed minimum values in summer months while a maximum ratio value of 51 was measured in November 1997. Silicate concentrations ranged from 0.44 to 66.22 µmol L\(^{-1}\) in the 0-5 m layer, 9.64 to 175.67 µmol L\(^{-1}\) in the 7-11 m layer, and 4.9 to 301.57 µmol L\(^{-1}\) in the 12-14 m layer.

The microplankton population was mainly composed of Bacillariophyceae (62.5% of the total taxa) and Dinophyceae (29%) (Table 1). Dominant species were *C. curvisetus, P. arcuatum* (Fig. 6) and *H. adriaticum* (Fig 7). The diatoms *Pseudo-nitzschia* spp. and *Eunotia* sp. were sporadically abundant (Table 1).

Higher microplankton abundances (> 10\(^6\) cells L\(^{-1}\)) were generally detected in summer months (June 1996, July 1997) and autumn (October 1996) in the upper layer (< 9 m depth) of the water column (Fig. 8). After anoxic conditions in October 1997, to the end of studied period, a low abundance of microplankton was detected, with the exception of the upper layer where gymnodinoid species developed. Dominant species *Prorocentrum arcuatum* and

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**Fig. 5.** Depth vs. time contour plots for nitrates, ammonia and orthophosphates (µmol L\(^{-1}\)) in the marine Lake Rogoznica

**Fig. 6.** LM of dinoflagellate *Prorocentrum arcuatum*

**Fig. 7.** LM of *Hermesinum adriaticum*
Table 1. List of dominant microphytoplankton taxa, with frequency of findings (F) ≥2%, and maximum cell abundance ≥1000 cells L⁻¹, in Rogoznica lake, in the period from 1995 to 1998. Number of samples = 278

<table>
<thead>
<tr>
<th>Taxa</th>
<th>F</th>
<th>F (%)</th>
<th>Maximum abundance (cells L⁻¹)</th>
<th>Date of recorded maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRYMNESIOPHYCEAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Caiyprosphaera oblonga</em> Lohm.</td>
<td>10</td>
<td>3.6</td>
<td>4 000</td>
<td>OCT 27, 95</td>
</tr>
<tr>
<td><strong>DINOPHYCEAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ceratium furca</em> (Ehrenb.) Claparede et Lachmann</td>
<td>14</td>
<td>5.0</td>
<td>3 600</td>
<td>FEB 18, 97</td>
</tr>
<tr>
<td><em>Diplopsalis</em> “group”</td>
<td>10</td>
<td>3.6</td>
<td>2 400</td>
<td>JUN 17, 98</td>
</tr>
<tr>
<td><em>Glenodinium</em> spp.</td>
<td>11</td>
<td>4.0</td>
<td>3 600</td>
<td>APR 29, 97</td>
</tr>
<tr>
<td><em>Gyrodinium</em> spp.</td>
<td>8</td>
<td>2.9</td>
<td>220 000</td>
<td>JUN 13, 96</td>
</tr>
<tr>
<td><em>Prorocentrum arcautum</em> Issel</td>
<td>114</td>
<td>41.0</td>
<td>467 000</td>
<td>MAY 01, 96</td>
</tr>
<tr>
<td><em>Scrippsiella</em> spp</td>
<td>16</td>
<td>5.8</td>
<td>30 530</td>
<td>APR 29, 97</td>
</tr>
<tr>
<td>Gymnodinoid cells</td>
<td>65</td>
<td>23.4</td>
<td>45 800</td>
<td>APR 29, 97</td>
</tr>
<tr>
<td><strong>BACILLARIOPHYCEAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cerataulina pelagica</em> (Cleve) Hendey</td>
<td>10</td>
<td>3.6</td>
<td>205 400</td>
<td>JUN 13, 96</td>
</tr>
<tr>
<td><em>Chaetoceros affinis</em> Lauder</td>
<td>16</td>
<td>5.8</td>
<td>12 900</td>
<td>FEB 22, 96</td>
</tr>
<tr>
<td><em>Chaetoceros convolutus</em> Castr.</td>
<td>10</td>
<td>3.6</td>
<td>2 400</td>
<td>OCT 01, 97</td>
</tr>
<tr>
<td><em>Chaetoceros curvisetus</em> Cleve</td>
<td>189</td>
<td>68.0</td>
<td>9 031 000</td>
<td>APR 02, 98</td>
</tr>
<tr>
<td><em>Chaetoceros danicus</em> Cleve</td>
<td>27</td>
<td>9.7</td>
<td>169 800</td>
<td>JUL 07, 97</td>
</tr>
<tr>
<td><em>Chaetoceros decipiens</em> Cleve</td>
<td>18</td>
<td>6.5</td>
<td>21 600</td>
<td>OCT 06, 98</td>
</tr>
<tr>
<td><em>Cyclotella</em> sp.</td>
<td>17</td>
<td>6.1</td>
<td>146 000</td>
<td>OCT 27, 95</td>
</tr>
<tr>
<td><em>Dactyliosolen fragilissimus</em> (Bergon) Hasle</td>
<td>55</td>
<td>19.8</td>
<td>3 890 000</td>
<td>JUN 13, 96</td>
</tr>
<tr>
<td><em>Eunotia</em> sp.</td>
<td>40</td>
<td>14.4</td>
<td>7 432 000</td>
<td>AUG 21, 96</td>
</tr>
<tr>
<td><em>Leptocylindrus danicus</em> Cleve</td>
<td>6</td>
<td>2.2</td>
<td>3 200</td>
<td>AUG 25, 98</td>
</tr>
<tr>
<td><em>Nitzschia longissima</em> (Breb.) Ralfs</td>
<td>25</td>
<td>9.0</td>
<td>4 780 000</td>
<td>JUN 13, 96</td>
</tr>
<tr>
<td><em>Pseudo-nitzschia</em> spp.</td>
<td>43</td>
<td>15.5</td>
<td>6 520 000</td>
<td>JUN 05, 97</td>
</tr>
<tr>
<td><em>Synedra</em> spp.</td>
<td>33</td>
<td>11.9</td>
<td>101 700</td>
<td>FEB 18, 97</td>
</tr>
<tr>
<td><em>Thalassiosira leptopus</em> (Grun.) Hasle et Fryxell</td>
<td>19</td>
<td>6.8</td>
<td>754 700</td>
<td>NOV 18, 97</td>
</tr>
<tr>
<td><em>Thalassionema nitzschioide</em> Grun.</td>
<td>54</td>
<td>19.4</td>
<td>815 000</td>
<td>SEP 30, 96</td>
</tr>
<tr>
<td><strong>EBRIALES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hermesinum adriaticum</em> Zach.</td>
<td>85</td>
<td>30.6</td>
<td>203 800</td>
<td>JUN 17, 98</td>
</tr>
</tbody>
</table>
**Hermesinum adriaticum** had a significant positive correlation ($r = 0.3; p < 0.01$) in blooms, while *Chaetoceros curvisetus* did not show a significant correlation. *C. curvisetus* bloomed in February (1996 and 1997), and *P. arcuatum* and

**H. adriaticum** were mostly co-occurent in summer months (Fig 9). From October 1997 to April 1998, the seasonal development of dominant species was not recorded.

The CCA biplot indicated a higher influence of temperature on the distribution of dominant species (Fig 10). Oxygen, silicate and nitrate had a correlation greater than 0.100 with the first two axes (cumulative variance explained by first two axis = 35.2%). Salinity, nitrite, phosphate and ammonia had a correlation lower than 0.1 with first two axes, which indicates the low significance of the distribution of the species the biplot space, and therefore no important role on the occurrence of the dominant species in our samples. The diatom *C. curvisetus* showed a significantly negative correlation ($r = -0.22, p < 0.01$), while *P. arcuatum*, *H. adriaticum* and *Eunotia sp.* were significantly positively correlated ($r = 0.25; r = 0.26; r = 0.2; p < 0.01$) to temperature. Only one of the dominant species, *C. curvisetus*, was significantly correlated to oxygen ($r = 0.02; p < 0.01$).
DISCUSSION

The microflagellates *P. arcuatum* and *H. adriaticum*, as well as the diatom *C. curvisetus*, were found to be the most frequent and abundant microplankton species, and appeared recurrently during annual plankton succession in Lake Rogoznica. Specific environmental conditions which usually characterise Rogoznica Lake were even more pronounced during the investigated period, influencing the successful development of above mentioned species which might have excluded inferior competitive species.

The centric diatom *Chaetoceros curvisetus* in the CCA biplot is situated among samples from late autumn, winter and early spring (winter group) on the lower temperature gradient. Its position on the higher nitrate gradient also points to the dominance of this species in early spring-time, ensured by the larger amount of nitrates.

The abundant autotrophic dinoflagellate *P. arcuatum* and heterotrophic *H. adriaticum* mostly occurred in the higher temperature period. In the summer, a period characterised by nitrate deficiency, *P. arcuatum*, and *H. adriaticum* were found abundant, with the probable intake of suspended particulate matter as a source of nutrients.

Among nutrients, only nitrate showed a clear seasonal pattern while ammonia, orthophosphate and silicates did not show a yearly recurrent seasonal pattern. Silicates did not change as much as phosphorus and nitrogen during the research period. The increased N:P ratio in October 1997 was the result of exceptionally high ammonia concentrations throughout the water column. A high N:P ratio indicates that this system tends to P- rather than N-limitation, but P-concentrations must be low for P to actually become limiting. Since the PO₄³⁻ concentrations were still about 2 µmol in October 1997, the phosphorus limitation was probably not the reason for the decline in phytoplankton abundance.

In spring, *C. curvisetus* and *P. arcuatum* produced higher oxygen concentrations, indicating their important role in the photosynthetically active phytoplankton community. The appearance of high oxygen production during relatively low microphytoplankton abundance in March-April 1996 may be interpreted as a result of picoautotrophic photosynthetic activity (COSOVIĆ et al., 2000). At the beginning of October 1997 concentrations of nutrients, particularly NH₄⁺ and PO₄³⁻, were significantly higher (p < 0.01) than in September and anoxia was determined throughout the entire water column. Exceptionally low marine phytoplankton abundance (< 10³ cells L⁻¹) was found in that period. Although nutrient concentration remained high during the rest of 1997, and one month later in 1998, oxygen saturation increased with saturation achieving the usual values during subsequent months. The occurrence of extreme environmental conditions (anoxia and reduced sulphur compounds) throughout the water column in October 1997 was the result of mixing conditions which replaced the ordinary stratified (meromictic) conditions in the lake (BARIĆ et al., 2003). The appearance of mixing conditions are a result of lake cooling followed by pycnocline dissolution which allows the upward transport of reduced sulphur species from the bottom to the surface. The considerable release of reduced sulphur species causes oxygen depletion (due to oxidation) and the appearance of anoxia in the whole water column, which further influences the mass mortality of phytoplankton and benthic organisms (CIGLENEČKI et al., 2005).

Hydrogen sulphide (CIGLENEČKI et al., 1996) and subsequently high nutrient concentrations (especially ammonia) in the post–anoxic period probably influenced the seasonality of the analysed microplankton species shortly after the anoxia. High nutrient concentrations near the bottom in the post–anoxic period (following October 15, 1997) indicated intensive microbial degradation of organic matter at the sediment–water interface. One month after the anoxia, in November, the ecological stabilisation of the water column resulted in the development of gymnodinoid species near the surface.

Moderate microphytoplankton abundance (>10⁶ cells L⁻¹), high concentrations of inorganic nutrients and organic matter, as well as hypoxia, indicated that Lake Rogoznica is a naturally eutrophic system.
Accumulation of microplankton around the halocline has already been studied during the 1994 to 1995 period (VILIČIĆ et al., 1997). Subsurface accumulations were probably due to the sinking of cells and their retention along the halocline/pycnocline (RASMUSSEN & RICHARDSON, 1989; VILIČIĆ et al., 1989; TISELJUS et al., 1994), thermocline (CARRETO et al., 1995) or nitraceine (TREES et al., 1986). The subsurface accumulation of *P. arcuatum* could be attributed to the availability of some nutrients stimulating growth, and swimming/sinking around the halocline. The halocline layer could constitute a refuge from predation. This is the layer where osmotic stress regulates the behaviour of zooplankton, resulting in their escape to more favourable living conditions above and below the halocline and decreased grazing in the halocline. Zooplankton was not abundant in the halocline (KRŠINIĆ et al., 2000). According to the vertical distribution of zooplankton we can speculate that grazing was mostly greater in the 6–12 m layer (KRŠINIĆ et al., 2000), i.e. mostly below the maximum abundance of *P. arcuatum*.

Due to the impact of stratification/mixing on phytoplankton succession during the investigated period, *P. arcuatum* and *C. curvisetus* occupied different domains with the dinoflagellate being favoured in stratified conditions and the diatom in mixed water columns. The same effect of stratification (and irradiance) on phytoplankton community structure has been previously recorded (SIMPSON et al., 1982; JONES & GOWEN, 1990).

*H. adriaticum* is known to be a heterotrophic (herbivorous) species (TAPPAN, 1980; SANDERS, 1991). The fact that *H. adriaticum* accumulates (and possibly grows) at the chemocline requires further research to verify the nutrition of this species. Its occurrence during warmer months, in the same period as *P. arcuatum*, could be a result of the successful supply of nutrients. In summer, abundant endosymbionts (probably cyanobacteria) were noticed by phase contrast microscopy inside the cells of *H. adriaticum*. Such a commensalism may be indirect evidence how *H. adriaticum* cells might be supplied with additional nutrients by using photosynthetic products produced by the endosymbiont (CARON, 2000). Commensalsisms between *Hermesinum* and cyanobacteria have already been recorded (HARGRAVES & MILLER, 1974).

*H. adriaticum* is a species common in other stratified ecosystems such as the Black Sea (BODEANU, 1969) or Pettaquamscutt River (HARGRAVES & MILLER, 1974). Occasionally, this species can be found in the eastern Adriatic’s highly stratified Krka and Zrmanja estuaries (VILIČIĆ et al., 2002). *H. adriaticum* is not recorded on the northern Adriatic microplankton check-list (REVELANTE et al., 1985), probably due to its scarce abundance in the seventies and eighties. This species has recently been migrating from the eastern Mediterranean into the Adriatic (VILIČIĆ et al., 1997) during episodes of higher (average) salinity of the Adriatic Sea (MIKOVIĆ et al., 2001).

**CONCLUSIONS**

Moderate microphytoplankton abundance, high concentrations of inorganic nutrients and organic matter, as well as periodic hypoxia and anoxia occurrence, indicated that Lake Rogoznica is a naturally eutrophic system. Hydrogen sulphide and subsequent high nutrient concentrations (especially ammonia) in the post–anoxic period probably influenced the seasonality of the analysed microplankton species.

The most frequent and abundant microplankton species were *P. arcuatum* and *H. adriaticum*, as well as the diatom *C. curvisetus*. These species appeared recurrently during annual plankton succession in Lake Rogoznica. The development of *H. adriaticum* and *P. arcuatum* mostly increased during the summer under nitrate deficiency. Co-dominant diatom *C. curvisetus* appeared in early spring during higher nitrate concentrations.

Due to the impact of stratification/mixing on phytoplankton succession during the investigated period, *P. arcuatum* and *C. curvisetus* occupied different domains. The dinoflagellate *P. arcuatum* being favoured in stratified conditions and the diatom *C. curvisetus* in mixed water columns. *H.
adriaticum occurrence during warmer months, in the same period as P. arcuatum, could be the result of the successful supply of nutrients. In summer, abundant endosymbionts (probably cyanobacteria) were noticed inside the cells of H. adriaticum. Such a commensalism may be indirect evidence how H. adriaticum cells might be supplied with additional nutrients.

The investigation of the relatively rare microflagellates H. adriaticum and P. arcuatum merits further experimental work, the next step being the gaining of some insight into the eco-

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REFERENCES


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Pojava rijetkih mikroflagelata *Prorocentrum arcuatum* Issel i *Hermesinum adriaticum* Zacharias u Rogozničkom jezeru (istočna Jadranska obala)

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SAŽETAK

Rogozničko jezero, smješteno u obalnom dijelu srednjeg Jadrana, je prirodni eutrofizirani morski sustav s potencijalnim antropogenim utjecajem. U tom ekstremnom okolišu, sa značajkama meromiktičkog i anoksičnog sustava, provedeno je istraživanje mikroplanktona u razdoblju od 1995. do 1998. godine. U mikroplanktionskoj zajednici (maksimalna abundancija 1.06 x 10^7 stanica L^-1) određeno je 40 taksona, većinom dijatomeja (62.5%) i dinoflagelata (29%). Zabilježene su iznimno visoke abundancije i sezonsko opetovano pojavljivanje dva rijetka mikroflagelata: *Prorocentrum arcuatum* Issel (dinoflagelat) i *Hermesinum adriaticum* Zacharias (hetrotrofan mikroflagelat). Maksimalan razvoj *P. arcuatum* i *H. adriaticum* zabilježen je ljeti u uvjetima nedostatka dušika. Kodominantna vrsta u zajednici bila je dijatomeja *Chaetoceoros curvisetus* Cleve koja je imala maksimalan razvoj u proljeće u uvjetima bogatim dušikom. Statistička analiza ukazala je na važnost temperature, kisika, silikata i nitrata na razvoj navedenih vrsta. Ovim istraživanjem dobivene su nove spoznaje o ekofiziološkim svojstvima rijetkih vrsta, kao i spoznaje o njihovom prisustvu i razvoju u Mediteranu, koje bi moglo biti pod utjecajem klimatskih promjena.

Ključne riječi: *Hermesinum adriaticum*, *Prorocentrum arcuatum*, flagelati, sezonalnost, slano jezero, Rogoznica