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# MICROPLANKTONIC AND MICROBENTHIC ALGAL ASSEMBLAGES IN THE COASTAL BRACKISH LAKE FIESA AND THE DRAGONJA ESTUARY (SLOVENIA)

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**Krivograd Klemenčič, A., Vrhovšek, D. & Smolar-Žvanut, N.: Microplanktonic and Microbenthic Algal Assemblages in the Coastal Brackish Lake Fiesa and the Dragonja Estuary (Slovenia). Nat. Croat., Vol. 16, No. 1., 63–78, 2007, Zagreb.**

Between 1998 and 2000, microplanktonic and microbenthic algal communities were sampled and analysed in the coastal lake Fiesa and in the Dragonja estuary. The purpose of the investigation was to establish qualitative composition and the relative abundance of algal communities. In 1999 and 2000, basic physical and chemical parameters were measured. Altogether, 159 algal taxa were determined, 83 in the coastal lake Fiesa and 120 in the Dragonja estuary. Most of the taxa belonged to the Bacillariophyceae. Thirty four percent of all taxa were typical brackish taxa. *Achnanthes septata*, *Amphora angusta*, *Gyrosigma tenuissimum*, *Gyrosigma wansbeckii* and *Pleurosigma strigosum* (all Bacillariophyceae) were marine species. Brackish and marine taxa were almost exclusively Bacillariophyceae. Nineteen taxa were the first citations for Slovenia, 15 of them belonging to the Bacillariophyceae and four to the Cyanophyceae. Most new taxa belong to the genus *Navicula* (4).

**Key words**: brackish waters, coastal lake, estuary, periphyton, phytoplankton

**Krivograd Klemenčič, A., Vrhovšek, D. & Smolar-Žvanut, N.: Mikroplanktonske i mikrobentoske alge obalnog boćatog jezera Fiesa i ušća Dragonje (Slovenija). Nat. Croat., Vol. 16, No. 1., 63–78, 2007, Zagreb.**

U razdoblju od 1998. do 2000. uzorkovane su i analizirane mikroplanktonske i mikrobentoske zajednice algi u obalnom jezeru Fiesa i na ušću Dragonje. Cilj istraživanja bio je ustanoviti kvalitativni sastav i relativnu abundanciju zajednica algi. Osnovni fizikalni i kemijski parametri mjereni su 1999. i 2000. utvrđeno je 159 svojta algi, 83 u jezeru Fiesa te 120 u ušću Dragonje. Većina taksona pripadala je porodici Bacillariophyceae, a 34% od ukupnog broja bile su tipične vrste boćatih voda. Morske vrste bile su *Achnanthes septata*, *Amphora angusta*, *Gyrosigma tenuissimum*, *Gyrosigma wansbeckii* i *Pleurosigma strigosum* (sve Bacillariophyceae). Boćati i morski taksoni bili su gotovo isključivo Bacillariophyceae. Po prvi puta za Sloveniju zabilježeno je 19 svojti, 15 iz porodice Bacillariophyceae i 4 iz porodice Cyanophyceae. Većina novih svojti pripada rodu *Navicula* (4).

**Ključne riječi**: boćate vode, obalno jezero, ušće, perifiton, fitoplankton

## INTRODUCTION

The Slovenian coast is a part of the Mediterranean, which here reaches deepest into Central Europe. It is characterized by two coastal types: the steep abrasive type and the plane accumulative type (formed by river alluvium) – the Dragonja estuary. The Dragonja River is a border river between Slovenia and Croatia and it is the largest river on the Slovenian coast that flows into the Adriatic Sea. The river is 29 km long and its basin covers 95 $km^2$. Most Slovenian streams, especially in the lowland area, are polluted (VRHOVŠEK *et al.*, 1983, 1994; SMOLAR, 1997; KRIVOGRAD, 1997; KRIVOGRAD KLEMENČIČ *et al.*, 2004a, 2004b). The Dragonja River is one of the very few unpolluted rivers in Slovenia (KRIVOGRAD KLEMENČIČ *et al.*, 2003), as it is the only Slovenian river that does not flow through settlements. It is also the only Slovenian river flowing entirely over flysch terrain. With a view to protecting its natural ecosystems and their constituent parts, including algae, the Dragonja River valley has been planned to acquire the status of landscape park. River estuaries are the zones extending inland from the mouths of rivers into which the tidal movements of the sea penetrate (FAIRBRIDGE, 1980). Organisms living in these estuaries are subjected to strongly fluctuating living conditions. Environmental changes are primarily caused by the tides and the seasons, particularly the seasonal changes in freshwater discharge into the estuary. In addition, there are periodic changes caused by storm tides and spates (KIES, 1997). It should be added that no investigation concerning the algae in brackish waters of river estuaries in Slovenia has been carried out prior to this research.

On the Adriatic Sea coast, between the towns of Piran and Strunjan, surrounded by undulating hills, there is a small bay called Fiesa, interesting for its two lakes near the seafront, the smaller natural and the larger artificial in origin. The smaller lake is freshwater and the larger one brackish. The coastal brackish lake Fiesa is the only Slovenian brackish lake. It is categorized in the inventory of the most important natural heritage sites of Slovenia and, in 1989, it was proclaimed a natural monument by municipal ordinance. Saline lakes may be divided into two categories – those primarily saline because they are endorheic and those secondarily saline (brackish) because of natural or anthropomorphic inputs of seawater (MOSS, 1994). The coastal lake in Fiesa is a secondary saline lake resulting from the filling of a former clay pit. Because of the argillaceous soil, the salty water could not reach the lake despite the nearness of the sea until 1963 when a channel was dug from the sea to the lake, so that freshwater mixes with seawater during high tide. Salinity increases with depth.

In the past, algae in the coastal lake Fiesa were subjected to two studies. VRHOVŠEK (1989) examined both periphyton and phytoplankton, but samples were taken only on one occasion. However, the research carried out by VRHOVŠEK (1994) was limited to phytoplankton only.

The purpose of this research was to establish the species structure and relative abundance of the microphytoplankton and periphyton in the Dragonja estuary and the coastal brackish lake Fiesa.

# STUDY LOCATION

## Coastal Lake Fiesa

The coastal lake Fiesa is located about twenty metres from the sea. The lake covers an area of 2.5 ha and its maximum depth is 8.5 m. The lake littoral is well developed and the bottom descends gradually towards the centre of the lake. The bottom is soft and silty, which permits the introduction of reeds (*Phragmites australis* (Cav.) Trin. Ex Steudel), however, it is not suitable for true submerged macrophytes. The banks are overgrown by a belt of reeds (*Phragmites australis*) with different widths, which is artificially interrupted in some places to provide access to the lake. In two calm places, a small sward of *Potamogeton polygonifolius* Pourret has been maintained, and at the depth of 1 to 2 meters there is a thick belt of *Zannichellia palustris* Linné. Regarding the wood plants that grow on the banks, the dominating species are *Robinia pseudacacia* Linné, *Sambucus nigra* Linné and *Laurus nobilis* Linné. The lake water is badly aerated. The coordinates of the sampling site according to Gaus-Krüger: X=5043180, Y=5389610.

## Dragonja Estuary

The sampling site is located one kilometre from the outflow of the Dragonja River into the sea. In this part, the riverbed is regulated, about 20 metres wide, unshaded and the water flow is slow. Both banks are thickly overgrown by reeds (*Phragmites australis*) and occasionally mown (particularly on the Croatian side). The coordinates of the sampling site according to Gaus-Krüger: X=5037250, Y=5390625.

# MATERIAL AND METHODS

The samples were collected seasonally during 1998, 1999 and 2000 (23.8.1998, 7.4.1999, 29.7.1999, 18.10.1999, 17.1.2000). At the coastal lake Fiesa and the Dragonja estuary, five microphytoplankton and five periphyton samples were collected for qualitative analysis. In the coastal lake Fiesa, periphyton samples were taken for qualitative analysis by scratching the surface of gravel, rocks, macrophytes, wood and other submersed materials (glass and plastic bottles, iron sticks, etc.) and in the Dragonja estuary by scratching the submersed stalks and roots of *Phragmites australis*. The microphytoplankton was sampled using a plankton net (mesh size 25 μm, mouth diameter 20 cm) at both sampling sites. The fixation of the samples was done in situ with 4% formalin. For diatom determination, samples were pre-treated with saturated HNO3 (APHA, 1992), and mounted on slides with NAPHRAX.

The algal samples were determined in the laboratory using the light microscope (magnification 1000×). The relative abundance of the most common species was evaluated using the numbers: 1-single, 2-rare, 3-common, 4-frequent and 5-dominant (CHANDLER, 1970). The algae were determined using the following identification keys: LAZAR (1960), STARMACH (1966, 1972), HINDAK *et al.* (1978), KRAMMER & LANGE-

BERTALOT (1986, 1988, 1991a, b), POPOVSKY & PFIESTER (1990), HINDAK (1996), KOMAREK & ANAGNOSTIDIS (1998).

Similarity in species structure and the abundance of algae were determined by the Bray-Curtis coefficient of similarity (CLARKE *et al.*, 1990).

Temperature, conductivity, pH and dissolved oxygen were measured (APHA, 1992) on 29.7.1999, 18.10.1999 and 17.1.2000 at both sampling sites. In the coastal lake Fiesa, physical and chemical parameters were measured 10 cm below the water surface.

## RESULTS AND DISCUSSION

### Physical and Chemical Parameters

#### The Coastal Lake Fiesa

The values of physical and chemical parameters in the coastal lake Fiesa are shown in Table 1. In the course of the year, water temperature changes followed the air temperature changes. The highest temperature was measured in July (24.2 °C) and the lowest in January (4.5 °C). Conductivity of inland waters increases with their salinity. Salinity depends on the mineral composition of the soil and solubility of minerals, climate, temperatures, decomposition, dust, precipitation, evaporation, winds, distance from the sea, flora and fauna (REJIC, 1988). During the time of measurements, the conductivity in the coastal lake Fiesa was high (3.220–3.990 µS cm$^{-1}$), as the water was brackish due to the mixing of freshwater and seawater. The water was slightly alkaline or alkaline (pH 7.71–8.16). The concentrations of dissolved oxygen and oxygen saturation values were high in June and January. In October, however, the concentration of dissolved oxygen was only 5.3 mg l$^{-1}$, which could be the result of intensive decomposition of organic matter in water.

#### The Dragonja Estuary

The values of physical and chemical parameters in the Dragonja estuary are presented in Table 1. Similar to the situation at the sampling site in lake Fiesa, water

**Tab. 1.** Values of physical and chemical parameters in the coastal lake Fiesa and the Dragonja estuary. Legend: A-Dragonja estuary, B-coastal lake Fiesa

| Parameter | Dates of sampling and sampling sites | | | | | |
|---|---|---|---|---|---|---|
| | July 1999 | | October 1999 | | January 2000 | |
| | A | B | A | B | A | B |
| Temperature [°C] | 20.5 | 24.2 | 13.3 | 16.4 | 6.7 | 4.5 |
| Conductivity [µS cm$^{-1}$] | 15700 | 3520 | 9200 | 3990 | 1780 | 3220 |
| pH | 7.50 | 8.07 | 7.76 | 7.71 | 7.45 | 8.16 |
| Oxygen [mg l$^{-1}$] | 8.5 | 10.4 | 8.7 | 5.3 | 13.7 | 13.4 |

temperature changes followed the air temperature changes during the year. The highest temperature was measured in July (20.5 °C) and the lowest in January (6.7 °C). The conductivity increases and decreases in relation to the inflow of seawater at the mouth of the river. The highest conductivity was recorded in July (15.700 µS/cm) and the lowest in January (1.780 µS/cm). The pH values ranged from 7.45 – 7.76. The concentration of dissolved oxygen reached the highest value in January (13.7 mg/l) and the lowest value in July (8.5 mg/l).

## Biological Parameters

### The Coastal Lake Fiesa

Altogether 83 microplanktonic and microbenthic algal taxa were determined (Table 2). Most of them (56) belonged to the Bacillariophyceae, 13 to the Cyanophyceae, 10 to the Chlorophyceae, two to the Zygnematophyceae, one to the Chrysophyceae

**Tab. 2.** List of algal species occurring in the Dragonja estuary and the coastal lake Fiesa during the years 1998, 1999 and 2000.
Legend: A-Dragonja estuary, B-coastal lake Fiesa; F-freshwater taxa, Br-brackish taxa, M-marine taxa; P-planktonic taxa; *new records for Slovenia.

| taxa | sampling site | |
|---|---|---|
| | A | B |
| **PROKARYOTA** | | |
| **CYANOPHYTA** | | |
| CYANOPHYCEAE | | |
| *Anabaena affinis* Lemmermann (*, F, P) | | * |
| *Aphanocapsa grevillei* (Berkeley) Rabenhorst (F) | | * |
| *Aphanocapsa muscicola* (Meneghini) Wille (F) | | * |
| *Chroococcus turgidus* (Kützing) Nägeli (F) | * | |
| *Gloeocapsopsis crepidinum* (Thuret) Geitler ex Komarek (Br) | | * |
| *Leptolyngbya fragilis* (Gomont) Anagnostidis et Komárek (F) (Br) | * | |
| *Merismopedia smithii* De Toni (F) | | * |
| *Microcystis aeruginosa* (Kützing) Kützing (F, P) | | * |
| *Oscillatoria laetevirens* (Crouan) Gomont (Br) | * | |
| *Oscillatoria subcapitata* Ponomarenko (F) | * | |
| *Phormidium autumnale* (Agardh) Gomont (F) | * | |
| *Phormidium boryanum* (Bory ex Gomont) Anagnostidis et Komárek (F) | | * |
| *Phormidium dimorphum* Lemmermann (*, Br) | | * |
| *Phormidium foveolarum* (Montagne) Gomont (F) | * | |
| *Phormidium henningsii* Lemmermann (*, F) | | * |
| *Phormidium lucidum* Kützing ex Gomont (F) | | * |
| *Phormidium* sp. (F) | * | * |

| taxa | sampling site | |
|---|---|---|
| | A | B |
| *Planktothrix cryptovaginata* (Schkorbatoff) Anagnostidis et Komárek (F, P) | * | |
| *Pseudanabaena constricta* (Szafer) Lauterborn (F) | | * |
| *Pseudanabaena papillaterminata* (Kisselev) Kukk (F) | * | |
| *Pseudospirulina amoena* Pankow et Jahnke (*, F) | | * |
| *Spirulina tenuissima* Kützing (F) | * | |
| **EUKARYOTA** | | |
| RHODOPHYTA | | |
| FLORIDEOPHYCEAE | | |
| *Chantransia chalybea* (Roth) Fries (F) | * | |
| **HETEROKONTOPHYTA** | | |
| CHRYSOPHYCEAE | | |
| *Dinobryon* sp. (F) | | * |
| BACILLARIOPHYCEAE | | |
| *Achnanthes amoena* Hustedt (*, Br) | | * |
| *Achnanthes delicatula* (Kützing) Grunow (F, Br) | * | |
| *Achnanthes flexella* (Kützing) Brun (F) | * | |
| *Achnanthes lanceolata* (Brébisson) Grunow (F) | * | * |
| *Achnanthes lanceolata* ssp. *frequentissima* Lange-Bertalot (*, F) | | * |
| *Achnanthes minutissima* Kützing (F) | * | * |
| *Achnanthes septata* A. Cleve (M) | * | |
| *Achnanthes* sp. | * | |
| *Amphora angusta* (Gregory) Cleve (*, M) | * | * |
| *Amphora coffeaeformis* (Agardh) Kützing (Br) | * | * |
| *Amphora libyca* Ehrenberg (F) | * | |
| *Amphora montana* Krasske (F) | * | |
| *Amphora ovalis* (Kützing) Kützing (F, Br) | * | |
| *Amphora pediculus* (Kützing) Grunow (F) | * | * |
| *Anomoeoneis vitrea* (Grunow) Ross (F) | * | |
| *Bacillaria paradoxa* Gmelin (F, Br) | * | |
| *Caloneis alpestris* (Grunow) Cleve (F) | * | |
| *Cocconeis pediculus* Ehrenberg (F, Br) | * | |
| *Cocconeis placentula* Ehrenberg (F) | * | * |
| *Cyclotella ocellata* Pantocsek (F) | * | |
| *Cyclotella* sp. (F) | * | * |
| *Cymatopleura solea* var. *apiculata* (W.Smith) Ralfs (*, F) | * | * |
| *Cymbella affinis* Kützing (F) | * | * |
| *Cymbella amphicephala* Naegeli (F) | * | |
| *Cymbella cesatii* (Rabenhorst) Grunow (F) | | * |
| *Cymbella delicatula* Kützing (F) | | * |
| *Cymbella microcephala* Grunow (F) | * | * |

| taxa | sampling site | |
|---|---|---|
| | A | B |
| *Cymbella pusilla* Grunow (F, Br) | * | |
| *Cymbella silesiaca* Bleisch (F) | * | * |
| *Cymbella sinuata* Gregory (F) | * | |
| *Cymbella subaequalis* Grunow (F) | * | |
| *Cymbella tumidula* var. *lancettula* Krammer (F) | * | |
| *Denticula kuetzingii* Grunow (F) | * | |
| *Denticula subtilis* Grunow (Br) | * | |
| *Diatoma ehrenbergii* Kützing (F) | * | |
| *Diploneis elliptica* (Kützing) Cleve (F) | * | * |
| *Diploneis oblongella* (Naegeli) Cleve-Euler (F) | * | |
| *Eunotia arcus* Ehrenberg (F) | * | |
| *Eunotia exigua* (Brébisson) Rabenhorst (F) | * | * |
| *Fragilaria biceps* (Kützing) Lange-Bertalot (*, F) | * | * |
| *Fragilaria capucina* Desmazières (F) | * | * |
| *Fragilaria construens* Ehrenberg (Grunow) (F) | * | |
| *Fragilaria fasciculata* (Agardh) Lange-Bertalot (F, Br, M) | * | * |
| *Fragilaria tenera* (W.Smith) Lange-Bertalot (F) | * | |
| *Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot (F) | | * |
| *Fragilaria ulna* (Nitzsch) Lange-Bertalot (F) | * | * |
| *Frustulia rhomboides* (Ehrenberg) De Toni (F) | * | * |
| *Frustulia spicula* Amossé (F) | * | |
| *Frustulia vulgaris* (Thwaites) De Toni (F, Br) | | * |
| *Gomphonema acuminatum* Ehrenberg (F) | * | |
| *Gomphonema angustatum* (Kützing) Rabenhorst (F) | * | |
| *Gomphonema angustum* Agardh (F) | * | * |
| *Gomphonema clavatum* Ehrenberg (F) | * | * |
| *Gomphonema olivaceum* (Hornemann) Brébisson (F) | * | * |
| *Gomphonema parvulum* Kützing (Kützing) (F) | * | |
| *Gomphonema truncatum* Ehrenberg (F) | | * |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst (F) | * | * |
| *Gyrosigma attenuatum* (Kützing) Rabenhorst (F) | * | |
| *Gyrosigma tenuissimum* (W.Smith) Cleve (M) | * | |
| *Gyrosigma wansbeckii* (Donkin) Cleve (M) | * | |
| *Mastogloia smithii* Thwaites (Br) | | * |
| *Melosira moniliformis* (O.F. Müller) Agardh (Br, M) | * | |
| *Melosira nummuloides* (Dillwyn) Agardh (Br, M) | * | |
| *Melosira varians* Agardh (F, P) | * | |
| *Meridion circulare* (Greville) Agardh (F) | * | |
| *Navicula capitatoradiata* Germain (F, Br) | | * |
| *Navicula cincta* (Ehrenberg) Ralfs (*, F, Br) | | * |

| taxa | sampling site | |
|---|---|---|
| | A | B |
| *Navicula crucicula* (W.Smith) Donkin (Br) | | * |
| *Navicula cryptocephala* Kützing (F, Br) | * | |
| *Navicula cryptotenella* Lange-Bertalot (F) | * | |
| *Navicula cuspidata* Kützing (F, Br) | | * |
| *Navicula duerrenbergiana* Hustedt (Br) | * | |
| *Navicula erifuga* Lange-Bertalot (*, F, Br) | | * |
| *Navicula gregaria* Donkin (F, Br, M) | * | |
| *Navicula halophila* (Grunow) Cleve (F, Br) | * | |
| *Navicula incertata* Lange-Bertalot (Br) | * | |
| *Navicula margalithii* Lange-Bertalot (Br) | * | |
| *Navicula mutica* Kützing (F, Br) | * | |
| *Navicula radiosa* Kützing (F) | * | |
| *Navicula recens* Lange-Bertalot (Lange-Bertalot) (F,Br) | * | |
| *Navicula rhynchocephala* Kützing (F, Br) | * | |
| *Navicula salinarum* Grunow (*, F, Br) | * | |
| *Navicula* sp. (F) | | * |
| *Navicula tripunctata* (O.F. Müller) Bory (F, Br) | * | * |
| *Navicula veneta* Kützing (F, Br) | * | * |
| *Navicula viridula* var. *rostellata* (Kützing) Cleve (*, F) | | * |
| *Neidium affine* (Ehrenberg) Pfitzer (F) | | * |
| *Nitzschia amphibia* Grunow (F) | * | |
| *Nitzschia angustata* (W.Smith) Grunow (F) | | * |
| *Nitzschia brevissima* Grunow (F, Br) | * | |
| *Nitzschia commutatoides* Lange-Bertalot (*, Br) | | * |
| *Nitzschia compressa* (Bailey) Boyer (Br) | * | |
| *Nitzschia constricta* (Kützing) Ralfs (*, F) | * | * |
| *Nitzschia dissipata* (Kützing) Grunow (F) | * | |
| *Nitzschia dubia* W.Smith (Br) | * | * |
| *Nitzschia filiformis* (W.Smith) Van Heurck (F, Br) | | * |
| *Nitzschia filiformis* var. *conferta* (Richter) Lange-Bertalot (*, F, Br) | | * |
| *Nitzschia fonticola* Grunow (F) | | * |
| *Nitzschia frustulum* (Kützing) Grunow (F, Br) | * | * |
| *Nitzschia granulata* Grunow (Br) | * | |
| *Nitzschia levidensis* var. *salinarum* Grunow (F, Br) | * | |
| *Nitzschia linearis* (Agardh) W.Smith (F) | * | |
| *Nitzschia reversa* W. Smith (Br, P) | * | |
| *Nitzschia lorenziana* Grunow (Br) | * | |
| *Nitzschia microcephala* Grunow (F) | * | |
| *Nitzschia navicularis* (Brébisson) Grunow (Br) | * | |
| *Nitzschia palea* (Kützing) W.Smith (F) | * | * |

| taxa | sampling site | |
|---|---|---|
| | A | B |
| *Nitzschia scalpelliformis* Grunow (Grunow) (Br) | * | |
| *Nitzschia sigma* (Kützing) W.Smith (F, Br) | * | |
| *Nitzschia* sp. | * | |
| *Nitzschia tryblionella* Hantzsch (Br) | | * |
| *Pinnularia maior* (Kützing) Rabenhorst (F) | * | |
| *Pinnularia microstauron* (Ehrenberg) Cleve (F) | * | |
| *Pinnularia subrostrata* (A.Cleve) Cleve-Euler (F) | * | * |
| *Pleurosigma salinarum* Grunow (Br) | * | |
| *Pleurosigma strigosum* W.Smith (M) | * | |
| *Rhizosolenia eriensis* H.L.Smith (*, F, P) | | * |
| *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot (F, Br) | * | * |
| *Rhopalodia constricta* (W.Smith) Krammer (Br) | * | |
| *Stauroneis tackei* (Hustedt) Krammer et Lange-Bertalot (F) | | * |
| *Surirella biseriata* Brébisson (F) | * | |
| *Surirella brebissonii* Krammer et Lange-Bertalot (*, F, Br) | * | * |
| *Surirella spiralis* Kützing (F) | * | |
| *Surirella striatula* Turpin (*, Br, P) | | * |
| **DINOPHYTA** | | |
| DINOPHYCEAE | | |
| *Peridinium bipes* F.Stein (F) | * | * |
| **CHLOROPHYTA** | | |
| CHLOROPHYCEAE | | |
| *Chaetophora incrassata* (Hudson) Hazen (F) | | * |
| *Cladophora fracta* (O.F. Müller ex Vahl) Kützing (F) | * | * |
| *Cladophora glomerata* (Linné) Kützing (F) | | * |
| *Coelastrum reticulatum* (Dangeard) Senn (F, P) | * | |
| *Microspora amoena* (Kützing) Rabenhorst (F) | * | * |
| *Microspora pachyderma* (Wille) Lagerheim (F) | * | |
| *Oedogonium* sp. (F) | * | * |
| *Oocystis* sp. (F) | * | * |
| *Pediastrum duplex* Meyen (F, P) | | * |
| *Rhizoclonium hieroglyphicum* (Agardh) Kützing (F) | | * |
| *Scenedesmus quadricauda* (Turpin) Brébisson (F, P) | | * |
| *Ulothrix tenerrima* Kützing (F) | * | * |
| *Uronema confervicolum* Lagerheim (F) | * | |
| ZYGNEMATOPHYCEAE | | |
| *Cosmarium* sp.(F) | * | |
| *Mougeotia* sp. (F) | * | * |
| *Spirogyra* sp. (F) | | * |
| No. of taxa | 120 | 83 |

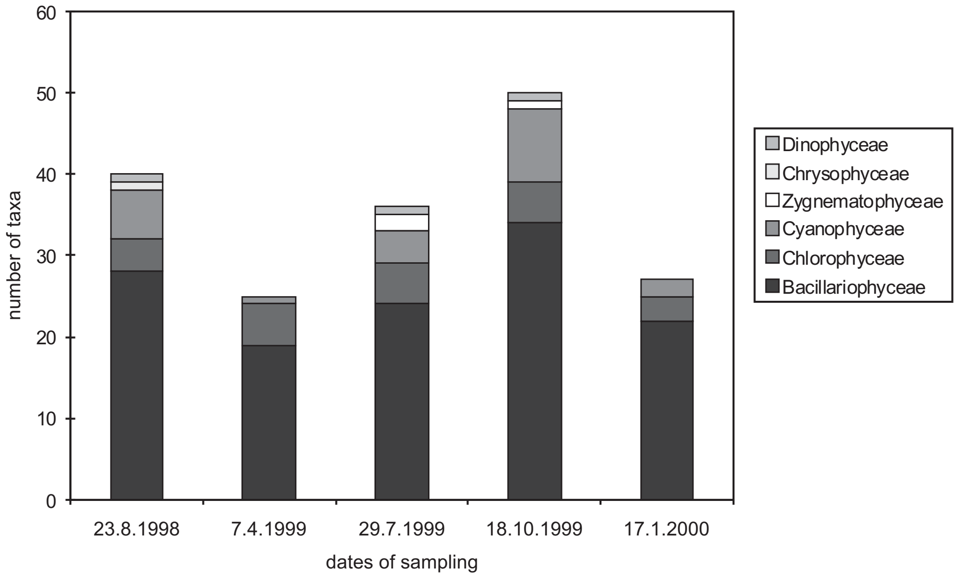


**Fig. 1.** Algal community structure in the coastal lake Fiesa.

and one to the Dinophyceae. The algal community structure by dates is presented in Fig. 1. In view of the number of species, Bacillariophyceae dominated in all seasons of the year, followed by Chlorophyceae in April, July and January and by Cyanophyceae in August and October. The Bacillariophyceae was the class of algae with the highest number of taxa in other research into brackish lakes as well (VRHOVŠEK, 1989, 1994; DE ANGELIS, 1989, 1994). In the research carried out by VRHOVŠEK (1994), the species composition of phytoplankton in the coastal lake Fiesa was extremely modest, as only five different algal species were determined from 1991 to 1993. Among others, he found *Phacus longicauda* (Ehrenberg) Dujardin and *Nitzschia palea* (Kützing) W. Smith, which are characteristic of polluted waters. VRHOVŠEK (1989) defined four species of phytoplankton and 12 species of periphyton. In addition to cosmopolitan species, he found also some species typical of high salinity environments: *Synedra tabulata* (C. Agardh) Kützing, *Nitzschia apiculata* (Gregory) Grunow and *Mastogloia braunii* Grunow. Considering the measurement of chlorophyll, he classified the lake among hypereutrophic lakes. Brackish lakes do not have a high diversity of marine communities, but they often have comparable, if slightly lesser, diversities with those of freshwater lakes (MOSS, 1994). MOSS (1994) found out that pennate diatoms dominate in brackish lakes. In the coastal lake Fiesa, there were almost exclusively pennate diatoms present, while of the centric diatoms there was only *Cyclotella* sp. Besides freshwater taxa, there were also typical brackish and marine taxa present in the coastal lake Fiesa (Tab. 2). There were 28 % (23 taxa) of typical brackish taxa *sensu* Starmach (1966), *sensu* KRAMMER & LANGE-BERTALOT (1986, 1988, 1991a, b) and *sensu* KOMAREK & ANAGNOSTIDIS (1998). The most frequent brackish taxa were: *Fragilaria fasciculata* (Agardh) Lange-Bertalot, *Nitzschia dubia*

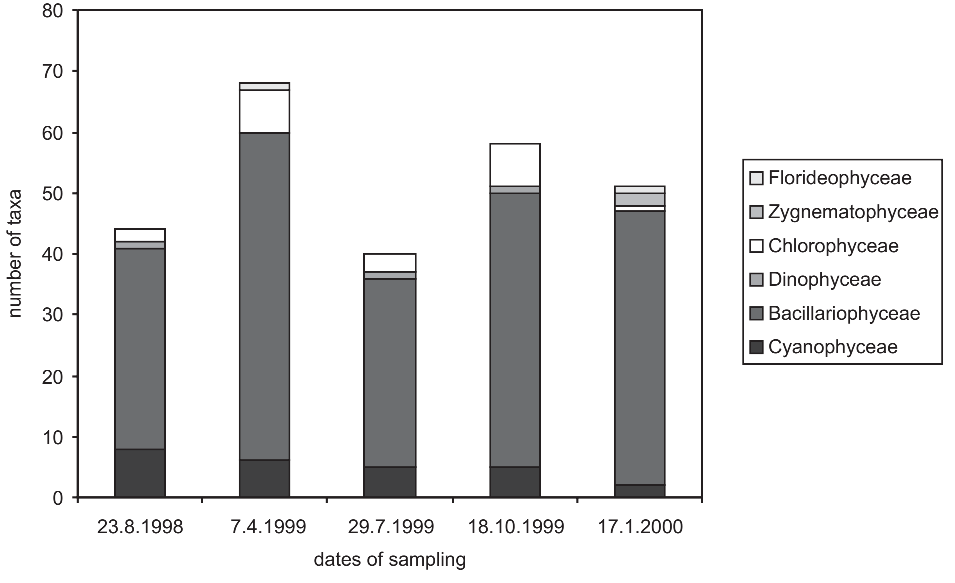


**Fig. 2.** Algal community structure in the Dragonja estuary.

W. Smith, *Nitzschia filiformis* (W. Smith) Van Heurck, *Nitzschia frustulum* (Kützing) Grunow, *Navicula crucicula* (W. Smith) Donkin, *Navicula salinarum* Grunow and *Phormidium dimorphum* Lemmermann. There was also *Amphora angusta* (Gregory) Cleve present, which is a true marine species.

The Bray-Curtis similarity coefficient points to qualitative changes in the structure of assemblages and it ensures a fast and simple examination of similarities and differences between biotic assemblages. The upper cluster in Fig. 3 refers to the coastal lake Fiesa. As shown in the upper part of the dendrogram (Fig. 3), there was a great similarity between the samples of microplankton on the one hand and the samples of periphyton on the other hand. There was a great similarity between the microplankton samples taken in summer and spring and on the other hand between autumn and winter samples. As regards the periphyton, there was a great similarity between spring and winter samples and between summer and autumn samples.

## Microphytoplankton

There were 55 different algal taxa determined in microphytoplankton samples (Tab. 2). Only six typical plankton species were present: *Anabaena affinis* Lemmermann, *Microcystis aeruginosa* (Kützing) Kützing, *Rhizosolenia eriensis* H. L. Smith, *Surirella striatula* Turpin, *Pediastrum duplex* Meyen and *Scenedesmus quadricauda* (Turpin) Brébisson. In his research into a brackish lake in Italy, De Angelis (1994) found only a small number of typical phytoplankton species, while others were benthic or epiphytic species. Typical phytoplankton species occurred both in summer and autumn samples, but they were not present in samples taken in winter. In the spring

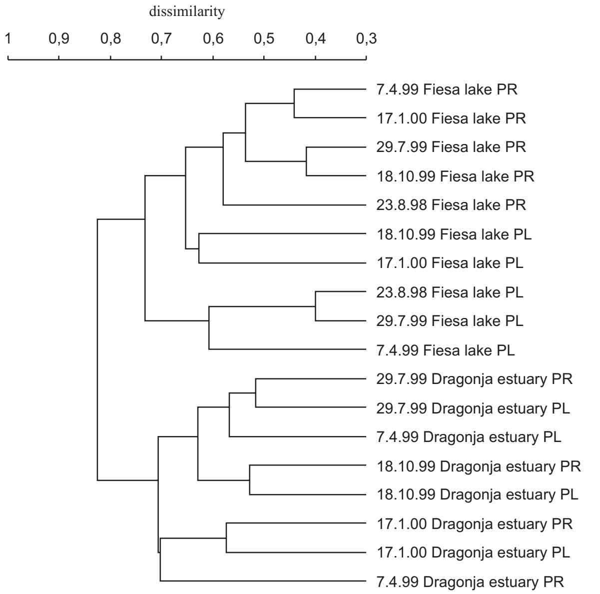


**Fig. 3.** Bray-Curtis coefficient of similarity for phytoplankton and periphyton samples from the coastal lake Fiesa and the Dragonja estuary. Legend: PL – phytoplankton, PR – periphyton

sample, there was *Anabaena affinis*, which is a planktonic species typical of standing and slowly moving waters. It often causes water bloom (CVIJAN & BLAŽENČIĆ, 1996). The cyanobacterium *Microcystis aeruginosa* was present in large numbers in August 1988 (relative abundance = 4). Cyanophyceae from the genus *Microcystis* are the most common cause of water blooms in Slovenian freshwaters (SEDMAK & KOSI, 1997). *Peridinium bipes* Stein species occurred in large numbers (relative abundance = 5) in summer and autumn plankton samples. The number of true phytoplankton taxa varied significantly among seasons. The lowest number of taxa (10) was determined in April 1999 and the highest in October 1999. The lowest number of phytoplankton species occurred in spring and the increase of species number in summer and autumn was also observed by DE ANGELIS (1994).

## Periphyton

There were 61 different algal taxa determined in periphyton samples. The most frequent species were *Achnanthes minutissima* Kützing, *Diploneis elliptica* (Kützing) Cleve, *Fragilaria fasciculata*, *Nitzschia constricta* (Kützing) Ralfs, *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot, *Oedogonium* sp. And *Rhizoclonium hieroglyphicum* (Agardh) Kützing. *Achnanthes minutissima* and *Fragilaria fasciculata* were the dominating species (relative abundance = 5) in the sample taken in April 1999, while *Rhoicosphenia abbreviata* was the main species in the sample from August 1998. The number of taxa was quite constant during different seasons. Only the sample taken in August 1988 stands out, as the largest number of taxa (34) was defined that year.

## The Dragonja Estuary

Altogether, there were 120 microplanktonic and microbenthic algal taxa determined (Tab. 2). Most of them (98) belonged to the Bacillariophyceae, 10 to the Chlorophyceae, 10 to the Cyanophyceae, one to the Florideophyceae and one to the Dinophyceae. The algal community structure by dates is presented in Fig. 2. In view of the number of species, Bacillariophyceae dominated in all seasons of the year, followed by Cyanophyceae in summer and winter samples and by Chlorophyceae in spring and autumn samples. Bacillariophyceae are the dominant group of algae also in other river estuaries (IDIEM' OPUTE, 1990; CHINDAK & PUDO, 1991; WOLFSTEIN & KIES, 1995; SCHULZ-STEINERT & KIES, 1996; KIES, 1997). By nature, river estuaries are eutrophic and dynamic systems resulting in a large number of species (IDIEM' OPUTE, 1990). As well as freshwater taxa, there were also typical brackish and marine taxa present in the Dragonja estuary (Tab. 2). Thirty two percent (38 taxa) of all taxa are typical brackish water taxa *sensu* STARMACH (1966) and *sensu* KRAMMER & LANGE-BERTALOT (1986, 1988, 1991a, b). Among the halophytic brackish water taxa, the most frequent were: *Amphora coffeaeformis* (Agardh) Kützing, *Denticula subtilis* Grunow, *Fragilaria fasciculata*, *Navicula halophila* (Grunow) Cleve, *Navicula margalithii* Lange-Bertalot, *Navicula mutica* Kützing, *Nitzschia frustulum* (Kützing) Grunow, *Surirella brebissonii* Krammer and Lange-Bertalot and *Pleurosigma salinarum* Grunow. In periphyton samples from August and April, *Nitzschia frustulum* reached the relative abundance of 5. *Navicula halophila* was present in a larger number in the periphyton sample from April (relative abundance = 4), *Navicula mutica* occurred in larger numbers in April and August periphyton samples (relative abundance = 3) and *Pleurosigma salinarum* also occurred with the same relative abundance of 3 in plankton of the sample taken in August 1998. In addition, five true marine species were determined: *Achnanthes septata* A. Cleve, *Amphora angusta* (Gregory) Cleve, *Gyrosigma tenuissimum* (W.Smith) Cleve, *Gyrosigma wansbeckii* (Donkin) Cleve and *Pleurosigma strigosum* W.Smith, which generally do not appear in freshwater and in brackish water (CHOLNOKY, 1968). *Achnanthes septata* was present in large numbers in the periphyton of the August sample (relative abundance = 5). Very similar brackish and marine species were found also in the estuaries of other rivers in the world (FREESE, 1952; WOOD, 1968; IDIEM' OPUTE, 1990), which reflects the cosmopolitan nature of most abovementioned algal species. Regarding freshwater taxa, the most frequently present were the following species: *Cocconeis placentula* Ehrenberg, *Fragilaria biceps* (Kützing) Lange-Bertalot, *Navicula radiosa* Kützing, *Nitzschia constricta* (Kützing) Ralfs, *Surirella brebissonii* Krammer and Lange-Bertalot and *Peridinium bipes* Stein. In the Dragonja estuary, freshwater species belonged mainly to the classes Chlorophyceae, Bacillariophyceae and Cyanophyceae, while marine and brackish species were almost explicitly of the class Bacillariophyceae. Similar results were obtained also in investigations by Idiem' OPUTE (1990) and CHINDAK & PUDO (1991).

In microplankton samples, there were four typical plankton species present: *Lyngbya cryptovaginata* Schkorbatoff, *Melosira varians* Agardh, *Nitzschia reversa* W.Smith and *Coelastrum reticulatum* (Dangeard) Senn. *Nitzschia reversa* and *Coelastrum reticulatum* occurred individually in the sample taken in October and *Lyngbya cryptovaginata*, also individually, in the samples taken in August and April.

The largest number of taxa (57) in periphyton samples was determined in April and the lowest number (26) in the sample taken in August. In microphytoplankton samples, the largest number of taxa (46) was determined in October and the lowest number (23) in July sample.

As shown in the lower part of the dendogram (Fig. 3), there were no significant differences between the periphyton and microphytoplankton samples with regard to the species composition and the abundance of taxa. This can be explained by the special hydrology of the estuary.

## CONCLUSIONS

In the coastal lake Fiesa and in the Dragonja estuary there were altogether 159 different taxa from six algal classes determined, of which 83 occurred in the lake and 120 in the estuary. Diatoms dominated in the number of species. The most numerous algal genera were *Nitzschia* with 24 taxa and *Navicula* with 21 taxa. Thirty four percent of all taxa were typical brackish water taxa, of which there were 28 % in the coastal lake Fiesa and 32 % in the Dragonja estuary. There were five true marine species identified (3 %): *Achnanthes septata*, *Amphora angusta*, *Gyrosigma tenuissimum*, *Gyrosigma wansbeckii* and *Pleurosigma strigosum*. *Amphora angusta* was present at both sampling sites. Brackish and marine taxa belonged almost exclusively to the Bacillariophyceae.

As expected, the algal communities in the coastal lake Fiesa and in the Dragonja estuary differ significantly as regards the species composition and the relative abundance, which is evident from the two separate dendrograms (Fig. 3). Twenty-five percent of taxa (40) are common to both sampling sites.

A total of 19 taxa identified in the samples from this study were the first citations for Slovenia (according to Limnos and National Institute of Biology of Slovenia algal data base DABA); of these, 15 taxa belonged to the Bacillariophyceae and four to the Cyanophyceae. The highest number of newly recorded taxa (four species and subspecies), belong to the genus Navicula. New records for Slovenia are presented in tab. 2.

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## REFERENCES

AMERICAN PUBLIC HEALTH ASSOCIATION (APHA). AWWA, WPCF, 1992: Standard methods for the examination of water and waste water, 18th ed.

CHANDLER, J. R., 1970: A biological approach to water quality management. Water Pollution Control, **69**, 415–422.

CHINDAH, A. C. & J. K. PUDO, 1991: A preliminary checklist of algae found in plankton of Bonny River in Niger Delta, Nigeria. Fragmenta floristica et geobotanica (Wroclaw), **36**, 117–126.

CHOLNOKY, B. J., 1968: Die Ökologie der Diatomeen in Binnengewässern. Verlag von J. Cramer. Berlin, Stuttgart.

CLARKE, K. R. & R. M. WARWICK, 1990: Lecture notes for the training workshop on the statistical treatment and interpretation on marine community data. Split, 26. June – 6. July 1990. Part II-Long term programme for pollution monitoring and research in the Mediterranean sea. FAO, UNESCO, UNEP, Split.

CVIJAN, M. & J. BLAŽENČIĆ, 1996: Algal flora of Serbia. Cyanophyta. Naučna knjiga, Beograd.

DE ANGELIS, G., 1989: Phytobenthos and phytoplankton in the Caprolace brackish lake in 1988–89. Nova Thalassia, **10**, 241–243.

DE ANGELIS, G., 1994: Phytoplankton and phytobenthos in the coastal brackish pond of Caprolace (Latium – Italy). Oebalia, **XX**, 21–32.

FAIRBRIDGE, R., 1980: The estuary. Its definition and geodynamic cycle. In: OLAUSSON, E. & CATO, I. (eds): Chemistry and biochemistry of estuaries, pp. 1–35, New York.

FREESE, L. R., 1952: Marine diatoms of the Rockport, Texas, Bay Area. Texas Journal of Science, **3**, 331–386.

HINDAK, F., 1996: Kluč na určovanie nerozkonarenych vlaknitych zelenych rias (Ulotrichineae, Ulotrichales, Chlorophyceae). Slovenska botanicka spoločnost pri SAV, Bratislava.

HINDAK, F., P. MARVAN, J., KOMAREK, K. ROSA, J. POPOVSKY & O. LHOTSKY, 1978: Freshwater algae. Slovenske pedagogicke nakladatelstvo, Bratislava.

IDIEM' OPUTE, F., 1990: Phytoplankton flora in the Warri/Forcados Estuary of southern Nigeria. Hydrobiologia, **208**, 101–109.

KIES, L., 1997: Distribution, biomass and production of planktonic and benthic algae in the Elbe estuary. Limnologica, **27**, 55–64.

KOMÁREK, J. & K. ANAGNOSTIDIS, 1998: Cyanoprokaryota 1. Teil: Chroococcales. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 19/1. G. Fischer, Stuttgart.

KOSI, G., 1999: The occurrence of toxic cyanobacteria in the Slovenian fresh-water bodies. Dissertation thesis. Biotehnical faculty, Department of Biology, Ljubljana.

KRAMMER, K. & H. LANGE-BERTALOT, 1986: Bacillariophyceae 1. Teil: Naviculaceae. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 2/1. G. Fischer, Stuttgart.

KRAMMER, K. & H. LANGE-BERTALOT, 1988: Bacillariophyceae 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 2/2. G. Fischer, Stuttgart.

KRAMMER, K. & H. LANGE-BERTALOT, 1991a: Bacillariophyceae 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 2/3. G. Fischer, Stuttgart.

KRAMMER, K. & H. LANGE-BERTALOT, 1991b: Bacillariophyceae 4. Teil: Achnanthaceae, Kritische Ergänzungen zu Navicula (Lineolate) und Gomphonema. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 2/4. G. Fischer, Stuttgart.

KRIVOGRAD, A., 1997: Existence of diatoms in the river Meža. Graduation thesis. Biotechnical faculty, Department of Biology, Ljubljana.

KRIVOGRAD KLEMENČIČ, A., D. VRHOVŠEK & G. KOSI, 2003: Algae in Dragonja river. Annales, **13**, 83–90.

KRIVOGRAD KLEMENČIČ, A., D. VRHOVŠEK & G. KOSI, 2004a: Algae on travertine barriers of the Krka River near Žužemberk, Slovenia. Natura Croatica, **13**, 371–379.

KRIVOGRAD KLEMENČIČ, A., D. VRHOVŠEK, N. SMOLAR-ŽVANUT & G. KOSI, 2004b: Algae of specific environments in Slovenia. Acta Biologica Slovenica, **47**, 31–43.

LAZAR, J., 1960: Algae of Slovenia. List of freshwater algae and key for determination. SAZU, Ljubljana.

MOSS, B., 1994: Brackish and freshwater shallow lakes-different systems or variations on the same theme? Hydrobiologia, 275/276: 1–14.

POPOVSKY, J. & L. A. PFIESTER, 1990: Dinophyceae (Dinoflagellida). In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.): Süßwasserflora von Mitteleuropa, vol. 6. G. Fischer, Stuttgart.

REJIC, M., 1988: Freshwaters ecosystems and water protection. Biotechnical Faculty. Department of Forestry, Ljubljana.

REMANE, A. & C. SCHLIEPER, 1971: Biology of brackish water. Stuttgart.

SCHULZ-STEINERT, M. G. & L. KIES, 1996: Biomass and primary production of algal mats produced by *Vaucheria compacta* (Xanthophyceae) in the Elbe estuary (Germany). Archiv für Hydrobiologie, **110**, 159–174.

SEDMAK, B. & G. KOSI, 1997: Cyanobacterial blooms in fish ponds of Slovenia and their toxicity. Ichthyos, **14,** 9–19.

SMOLAR, N., 1997: An estimation of influence of water abstraction from different types of running waters on periphyton under low flow conditions. Master of science thesis. Biotechncal faculty, Department of Biology, Ljubljana.

STARMACH, K., 1966: Cyanophyta – Sinice, Glaucophyta – Glaukofity. In: Flora słodkovodna Polski. Pañstwowe Wydawnictwo Naukowe, Warszawa.

STARMACH, K., 1972: Chlorophyta III. Zielenice Nitkowate: Ulotrichales, Ulvales, Prasiolales, Sphaeropleales, Cladophorales, Chaetophorales, Trentepohliales, Siphonales, Dichotomosiphonales. In: Flora słodkovodna Polski. Pañstwowe Wydawnictwo Naukowe, Warszawa.

VRHOVŠEK, D., 1989: Ecological study in the frame of the project Fiesa-Piran. Study research project. National institute of Biology, Ljubljana.

VRHOVŠEK, D., 1994: Statement of condition of standing waters with united methods as basis for preventive and curative steps. Report. Vodnogospodarski inštitut Ljubljana, Ljubljana.

VRHOVŠEK, D., G. KOSI, M. KRALJ & M. BRICELJ, 1983: An estimation of pollution of the Sava river from its source to the city of Ljubljana. Acta Biologica Slovenica, **31**, 2.

VRHOVŠEK, D., G. KOSI & N. SMOLAR, 1994: Limnological researches of the Sotla river with regard to the barrier at Podčetrtek. Croatian Waters, **5**, 293–301.

WOLFSTEIN, K. & L. KIES, 1995: A case study on the oxygen budget in the freshwater part of the Elbe estuary. Variations in phytoplankton pigments in the Elbe estuary before and during the oxygen minima in 1992 and 1993. Archiv für Hydrobiologie, **110**, 39–54.

WOOD, E. J. F., 1968: Studies of phytoplankton ecology in tropical and sub-tropical environments of the Atlantic Ocean. Oceanography Bullet of Marine Science, **18**, 481–583.