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Long-term changes and seasonal development of phytoplankton in a strongly stratified, hypertrophic lake

Kersti Kangro*, Reet Laugaste, Peeter Nõges & Ingmar Ott
Institute of Zoology and Botany, Estonian Agricultural University, Võrtsjärv Limnological Station, 61101, Rannu, Tartu County, Estonia
*(*Author for correspondence: E-mail: kiti@ut.ee)*

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Abstract

Changes in the phytoplankton community of the hypertrophic, sharply stratified Lake Verevi have been studied over eight decades. Due to irregular discharge of urban wastewater, the trophic state of the lake has changed from moderately eutrophic to hypertrophic. We found that the trophic state in summer increased in the 1980s and remained at a hypertrophic level since then. *Planktothrix agardhii* was recorded first in the 1950s and became the dominant species in the 1980s, forming biomass maxima under the ice and in the metalimnion during the vegetation period. In summer 1989, *P. agardhii* contributed almost 100% of the phytoplankton biomass. Generally, the highest biomass values occurred in the metalimnion. In spring, when *P. agardhii* was less numerous, diatoms and cryptophytes prevailed. In springs 2000 and 2001 different diatoms dominated – *Synedra acus* var. *angustissima* (18.6 g m^{-3}) and *Cyclostephanos dubius* (9.2 g m^{-3}), respectively. In recent years, the spring overturn has been absent. In the conditions of strong thermal stratification sharp vertical gradients of light and nutrients caused a large number of vertically narrow niches in the water column. During a typical summer stage, the epilimnion, dominated by small flagellated chrysophytes, is nearly mesotrophic, and water transparency may reach 4 m. The lower part of the water column is hypertrophic with different species of cryptophytes and euglenophytes. A characteristic feature is the higher diversity of Chlorococcales. Often, species could form their peaks of biomass in very narrow layers, e.g. in August 2001 *Ceratium hirundinella* (18.6 g m^{-3}) was found at a depth of 5 m (the lower part of the metalimnion with hypoxic conditions), *Cryptomonas* spp. (56 g m^{-3}) at 6 m (with traces of oxygen and a relatively high content of dissolved organic matter) and euglenophytes (0.6 g m^{-3}) at 7 m and deeper (without oxygen and a high content of dissolved organic matter).

Introduction

Being a classical object of limnology, stratified lakes still attract the attention of many researches. These lakes differ greatly from non-stratified shallow lakes, where the water column is constantly mixed. Due to thermal stratification, the upper water layer is isolated from the lower part and also from the sediments (Scheffer, 1998), which causes differences in biological and chemical parameters. The gradients of light, temperature, oxygen and inorganic substances combine and cause a variety of microhabitats (Davey & Heany, 1989; Reynolds, 1992; Gasol et al., 1991; Nõges & Nõges, 1998). The stratification processes are important for phytoplankton, providing advantages to some species and influencing the community structure, which tends to be more complex than in shallow lakes. The situation where the light needed by phytoplankton for

photosynthesis is available in the epilimnion while the mineral nutrient pool is located mainly in the hypolimnion has been called the paradox of stratification (Mann, 1991; Klausmeier & Litchman, 2001).

Vertical distribution of phytoplankton affects the distribution and functioning of other components of the food web. The maximum activity of plankton can be found in the lower layers of the water column (Wetzel, 1983) both in oligotrophic and hypertrophic lakes. Nutrients can become available in the epilimnion during short periods of deeper mixing, which allows the coexistence of a great variety of species as well as occasionally high biomasses of phytoplankton in different layers. In the metalimnion, steep environmental gradients causing higher nisches diversity can be found. In addition species from lower and upper layers are present there, which makes the metalimnetic community more diverse compared to other layers. The distribution of the species depends on the nutrient amount, nutrient ratios, turnover speed, sedimentation rate, temperature, water density and viscosity, light attenuation, species mobility, grazers, as well as on internal loading of the lake. Lake Verevi is a special case, where the phytoplankton has been greatly affected by the lack of vernal circulation and by the rapid formation of stratification in the past years.

The aim of this paper is to analyze the changes in the phytoplankton over eight decades. This long period allows to follow the development of the lake from a natural moderately eutrophic to a hypertrophic state.

Material and methods

Lake description

L. Verevi is located in the town of Elva (6400 inhabitants) in S-E Estonia. The lake has an elongated shape with a deeper and broader part at the southern end. The southern and eastern shores are sandy, sloping towards the lake; the other shores are flat, muddy, or peaty framed by a swampy bank or reed belt. Both the sandy and swampy areas are covered mostly by pine forest. A road with heavy traffic passes the lake from the east. The area of the lake is 12.6 ha; maximum depth is 11 m, the mean depth is 3.6 m. The watershed area is 1.1 km^{-2} including the lake area. Small ditches and bottom springs in the narrow northern part form the bulk of the inflowing water; the outflow is via a larger ditch from the western side. The water exchange rate is 0.63 times per year (Loopmann, 1984). Mostly the water of the surface layers is exchanged as water from the deeper layers can flow out only during a short vernal and a longer fall turnover. No vernal turnover occurred in 2000 and 2001. The ice-free period lasts on the average from April to November. The lake is sheltered, which further enhances stratification. The temperature gradient in the metalimnion may exceed 10 °C m^{-1} (Nõges & Nõges 1998) and is accompanied by steep gradients in dissolved oxygen content, nutrients, and biota. Below 6 m the water is usually anoxic during the summer stagnation, winter anoxia may occupy the entire water column. This caused several fish kills in eighties (Kangur, 1991). The lake has been polluted by irregular discharge of urban wastewaters from oxidation ponds probably since the 1970s.

Historical plankton records

The first data about the lake were collected in the 1920s by Riikoja (1930) and since then the lake has been investigated repeatedly and more thoroughly in the 1980s and in 2000 and 2001.

Samples for phytoplankton analysis were collected at the deepest point of the lake located in the broader part near the western shore. Most samples were taken from the surface layer (0.5 m) and at depths of 4–5 and 7–9 m by the Ruttner or van Dorn sampler. In the 1920s and 1950s, only qualitative samples were taken by a 85 μm net. Since the 1980s quantitative samples were taken as well (Fig. 1). After settling from 500 ml, phytoplankton was counted by a light microscope at 400× magnification.

In 2000 water was taken from eight layers (2 in the epi-, 4 in the meta- and 2 in the hypolimnion) on 17 occasions from April to October and in 2001 from April to August on nine occasions. The absolute sampling depths differed from case to case depending on the temperature and oxygen profiles. The metalimnion was defined as the layer in which the temperature gradient