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Fluorometer measurements and transmission of light in different parts of Lake Ladoga

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A fluorometer and multispectral underwater photodetector was used in different parts of Lake Ladoga during a joint Russian-Finnish expedition in 1995 to measure *in vivo* fluorescence and the intensity of solar and sky radiation. The spectral distribution of radiation at various depths in the water column and penetration of photosynthetically active radiation (PAR) were measured using an underwater multispectral photodetector (420–670 nm). The results were compared with Secchi disk and temperature measurements. The fluorometer values were highest in the pelagic zone of the lake and smallest in areas close to the Burnaya River and in the Volkhov Bay. Light absorption by algae and other suspended matter effectively reduced light penetration especially in the Volkhov Bay. Deepest transmission of light in water and relatively low fluorometer values were found in the western areas of the lake, where light (at 1% level of surface radiation) was transmitted more than six metres. Pulp mill waste waters seemed to decrease the photosynthetic activity in the NE part of the lake.

Introduction

The continuous-flow fluorometer is widely used to measure variations in phytoplankton chlorophyll *a* in lakes (Poryvkina *et al*. 1994, Babin *et al*. 1995, Leppä *et al*. 1995). Fluorometric determination of chlorophyll concentration has many advantages over the traditional spectrophotometric techniques; even if *in vivo* fluorescence is not a direct measure of a chlorophyll *a* concentration, it is sensitive and time saving. There are many variables affecting the fluorescence efficiency of chlorophyll, which may make interpretation of results difficult and reduce the reliability of the method. The quantum efficiency of chlorophyll fluorescence is not only species dependent, but is also highly dependent on the physiological state of the phytoplankton (Kiefer 1973), and the presence of humic materials and detritus (Strickland and Parsons 1968, Anonymous 1983).

In addition to nutrients, the light environment of the phytoplankton is a very important ecologi-

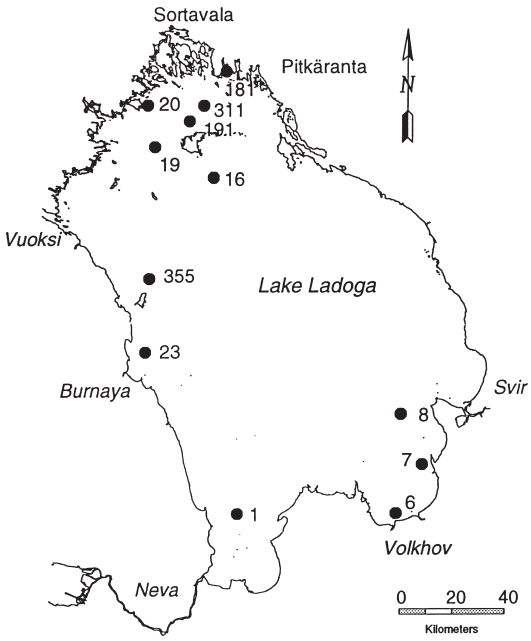

Fig. 1. The sampling stations in Lake Ladoga.

cal factor and probably has a great effect on formation of phytoplankton communities. The photometer can be used for measuring the optical properties of the water, distribution and propagation of light and factors related to the absorption of solar radiation in water (Spence *et al.*1971, Elomaa 1977, Henderson 1977, Eloranta 1978, 1985, Silvennoinen and Turunen 1991). The optical properties of water may be determined for limnological purposes in order to study turbidity, stratification, siltification, sewage or other wastewater distribution, as well as for measuring the depths of the plankton layer or other particle distributions (Schellenberger and Stellmacher 1987, Koenings and Edmundson 1991, Stross *et al.* 1995). Biological investigations include determination of the depth of the euphotic zone. The thickness of this zone varies greatly with the properties of water in each lake, and is important to determine as a basic element of lake productivity. In Finnish clear lakes (water colour < 40 mg Pt l^{-1}), the depth of the euphotic zone is about 1.5 times the Secchi disk visibility (Eloranta 1978).

Spectral measurements of the light extinction of water are made with an underwater photodetector. The spectral extinction of water can be calculated according to Beer's law as the ratio of the spectrum penetrating through water and the spectrum of the subsurface radiation (Garbundy 1965).

The aim of this investigation was to describe the vertical distribution of *in vivo* fluorescence and light penetration in different parts of Lake Ladoga and to compare these values with Secchi depth, temperature and spatial distribution of pollution. This study is part of the joint multidisciplinary Russian-Finnish evaluation of human impact on Lake Ladoga.

Material and methods

Samples for fluorometric, light, temperature and Secchi disk measurements were collected from 8 sampling stations in different parts of Lake Ladoga on 1–8 August 1995 (Fig. 1). Considerable differences in water quality and hydrobiological characteristics were found at those sampling points and the trophic state of the lake varied from oligotrophic to eutrophic (Holopainen *et al.* 1996, Niinioja *et al.* 1996). The content of humic compounds in the water was relatively low: the colour of the water ranged from 25 to 30 mg Pt l^{-1} in the pelagic zone, but was higher (70 mg Pt l^{-1}) in the Volkhov Bay, where the amount of suspended solids in water was also higher.

Samples for fluorometric measurements were taken at one-metre intervals, usually from the surface to about 20 metres at deep stations, and to 5 metres at shallow stations. Measurements were made with a Turner Designs model 10 continuous-flow fluorometer. The fluorometer had a red sensitive photomultiplier and the recommended excitation (CS5–60) and emission (2–64) filters for chlorophyll *a*. Before the measurements, the fluorometer was adjusted to zero with distilled water. Calibration samples were filtered (Whatman GF/C filter) for spectrophotometrical determination of the chlorophyll *a* concentration, and background fluorescence was measured from the filtrate. The chlorophyll *a* concentration was determined spectrophotometrically in the laboratory according to the standard (SFS 5772, 1993) with ethanol as a solvent.

Light was measured with the underwater multispectral detector constructed and tested by Silvennoinen and Turunen (1991), and Turunen and Silvennoinen (1993). The six-channel photo-

detector was constructed using BPW-21 and BPW-20 photodiodes. The underwater radiation intensity was indicated by the photocurrent of the diodes. The underwater intensity of illumination was measured with the spectral bands of 420–470 nm representing photosynthetically active radiation (PAR). The depth of the euphotic zone was defined as the depth to which 1% of the subsurface PAR penetrates. The intensity of the surface light was measured just under the surface of the water by holding the sensor vertically. The intensity of the subsurface light was measured in the same way from one metre depth down to the depth where less than about 1% of the total radiation intensity remained. Water temperature was measured at 20 cm intervals with the Sea-Bird Electronic 19-03 CTD system.

Results and discussion

In Lake Ladoga, the depth of the euphotic layer varied in different parts of the lake (Figs. 2 and 3). The depth of the 1% light level was at 2–4 metres close to the Volkhov and Burnaya rivers, but in the pelagic zone of the lake it was at 5–6 m. An exceptional situation was found in the western part of the lake (Sampling station 355), where 1% of the light seemed to be transmitted to more than 6 metres. In natural conditions, measurements of the spectrum of the subsurface radiation and measurements at greater depths cannot usually be made at the same time (Henderson 1977). The time delay between these measurements is typically several minutes, and therefore, the light measurements from greater depths are not always comparable with those made near the surface.

In the pelagic zone, the fluorometer values were highest above the depth of 4–5 m (Fig. 2) in the layer of maximum light. The values decreased with increasing depth, especially below the 1% light level. According to these light transmission measurements the productive layer in Lake Ladoga is typically 4–6-m thick, which is similar to the values calculated from the Secchi depth (Fig. 2). Because the differences in water colour are small in offshore areas, the productive layer can be assumed to be the same in the whole pelagic zone of the lake. In eutrophic areas influenced by large rivers, where suspended matter and humic compounds increase the colour values, the depth of the productive layer is smaller. According to Eloranta (1978), Ilmavirta (1982) and Jones and Arvola (1984), the depth of the euphotic zone decreases very rapidly with increasing colour when the water colour is weak, but when water colour increases, the colour has little effect on the depth of the euphotic zone. In this study, the effect of water colour on the depth of the productive layer could not be seen, because the strong flow of the Volkhov River mixed the water at this shallow sampling station. In the Volkhov Bay, the turbidity of the water limited effectively light penetration and the light intensity was small already at the depth of 1 m.

The highest fluorometer values were measured at Station 23 close to the Burnaya River, in the central-northern archipelago (Station 311), and in the Volkhov Bay (Station 6). Areas influenced by the rivers Burnaya and Volkhov are among the most eutrophied regions in Lake Ladoga. High phytoplankton biomasses are encountered in the archipelago, too (Holopainen *et al.* 1996). The high biomasses are often caused by blue-green algae, which may be transported by wind currents to the pelagic zone. Photoinhibition might be one explanation to the low fluorescence values in the surface waters at Stations 20 and 311.

Fluorometer values were very low at Station 181 in the north-eastern part of Lake Ladoga, which also can be seen as better transmission of light to the deeper layers of water. In this area the waste waters from Läskelä and Pitkäranta pulp mills may affect the photosynthetic activity. Leppä *et al.* (1995) found a similar decrease in fluorometer and chlorophyll *a* concentration values in Lake Saimaa, caused by loads of suspended solids or due to their toxic effects.

The low fluorometer values at Station 355, which indicated small phytoplankton biomass, were related to better transmission of light to the deeper layers of water. The low phytoplankton biomass and its vertical distribution (Rahkola *et al.* 1999) corroborate the fluorometer values measured at this station. At Station 311, where the biomass of phytoplankton (Rahkola *et al.* 1999) was higher at the surface, the light was also extinguished earlier.

Fluorometer values are presumed to give only a rough indication of the chlorophyll *a* content in water. However, a significant correlation between

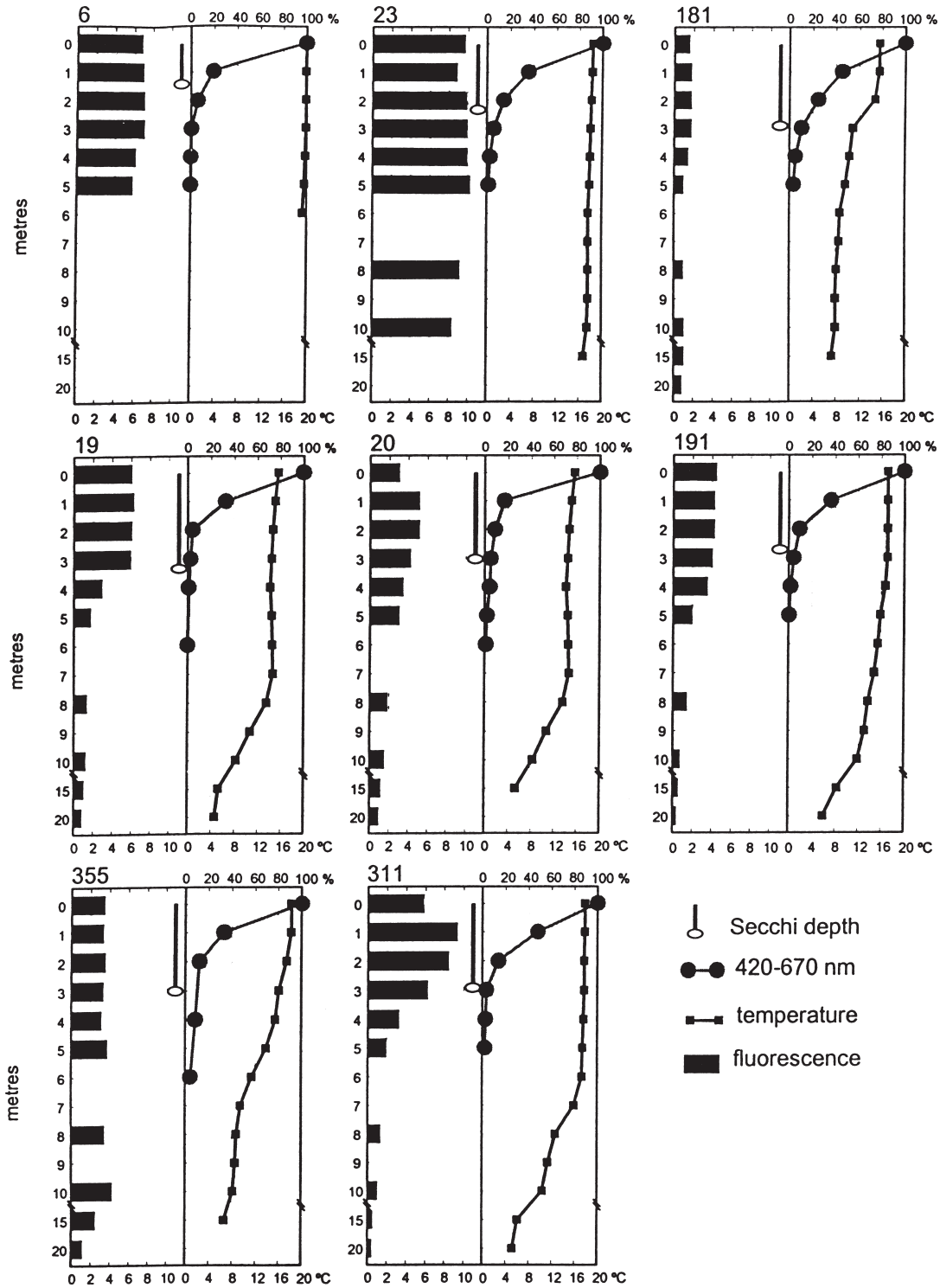

Fig. 2. Fluorometer values (relative units corrected with background values), transmission of photosynthetically active radiation (PAR 420–670 nm), Secchi depth (m) and temperature (°C) of the water in different stations of Lake Ladoga in 1995.

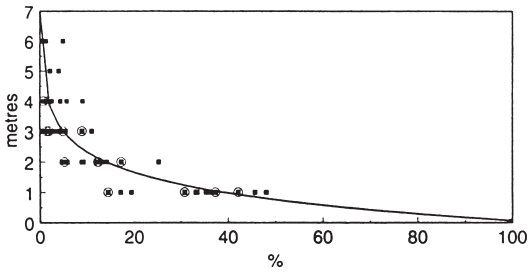

Fig. 3. Average transmission of photosynthetically active radiation (PAR 420–670 nm) in Lake Ladoga in 1995 (12 sampling stations).

the fluorometer values and chlorophyll *a* content ($r = 0.788$, $p < 0.001$) was found in the 1995 data in Lake Ladoga (Fig. 4). This is equal to the results of Lake Saimaa (Leppä *et al*. 1995).

Several studies have shown that there are many factors, e.g. humic materials, detritus, other dissolved fluorescing compounds and phytoplankton species composition, that strongly influence the comparability of fluorescence readings and concentrations of extractable chlorophyll *a* (Loftus and Seliger 1975, Slovacek and Hannan 1977, Jacobsen 1982, Anonymous 1983, Jacobsen *et al*. 1988, Leppä *et al*. 1995). Physiological stress, oversaturation with light, nutrient limitation and sample pretreatment can also change the fluorescence values of phytoplankton cells (Vaquer and El-Hafa 1991).

The transmission of light and its spectral composition are of great importance for phytoplankton communities. Different algal groups have many differences in their pigment composition, which is why the underwater light climate has appreciable ecological impact on the community structure, in addition to e.g. turbidity and nutrient content of the water. According to these results, the interactions between light transmission, production and *in vivo* fluorescence should be studied in order to obtain more information about the effects of light on the vertical distribution of photosynthetic activity.

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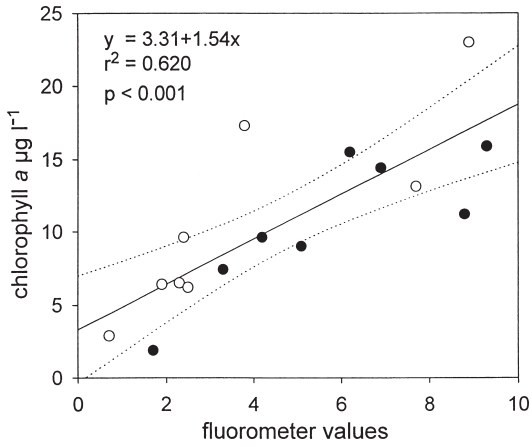

Fig. 4. The correlation between fluorometer values and chlorophyll *a* content in Lake Ladoga in the year 1995. Open dot = all sampling stations in 1995, black dot = sampling stations, where light transmission has been measured. Broken lines denote the 95% confidence belt.

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