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Development of filamentous green algae in the benthic algal community in a littoral sand-beach zone of Lake Biwa

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Abstract Temporal changes of biomass and dominant species in benthic algal communities were investigated in a littoral sand-beach zone in the north basin of Lake Biwa from December 1999 to September 2000. Chlorophyll-*a* amounts of benthic algal communities per unit area of the sandy sediments rapidly increased from late April to June. Increases in biomass of the benthic algal communities are considered to result from the propagation of filamentous green algae *Oedogonium* sp. and *Spirogyra* sp. The cell numbers of filamentous green algae and chlorophyll-*a* amounts of benthic algal communities at depths of 30 and 50 cm at a station protected by a breakwater in May were significantly higher than those of a station exposed directly to wave activity. Thus, the biomass accumulation of the benthic algal communities seems to be regulated strongly by wave disturbance. The development of filamentous green algae may contribute to the increase in biomass of the benthic algal community and to the changes in seasonal patterns of biomass in the sand-beach zone of Lake Biwa. We consider that the development of the filamentous green algal community in the littoral zone of Lake Biwa is the result of eutrophication.

Key words Littoral sand-beach zone · Benthic algal biomass · Filamentous green algae · Eutrophication

Introduction

The landscape of the littoral zone of a lake consists of rocky, stony, macrophyte (reed), and sand-beach zones. To arrive at a comprehensive overview of the whole lake ecosystem (e.g., Yoshimura 1937; Wetzel 2001), we must not neglect a study of sand-beach zones. Benthic algae play an important role as primary producers in the littoral zone of lakes. These algae are divided mainly into three groups, i.e., epilithic algae growing on bedrock and stone, epiphytic algae growing on plants, and epipelic algae growing on sandy and muddy sediments (Burkholder 1996; Wetzel 2001). Although sandy and muddy sediments often constitute the main substrate in lakes, epipelic algae have received little attention (Lowe 1996; Cyr 1998).

Sand-beach zones are the dominant landscape in the littoral zone of Lake Biwa, rather than rocky, stony, or macrophyte (reed) zones (Nishino 2000). However, most studies of the benthic algal community in the littoral zone of Lake Biwa have been conducted in the stony zone (Saijo et al. 1966; Negoro et al. 1966; Nozaki et al. 1998; Nozaki 1999, 2001; Nozaki and Mitsuhashi 2000; Nozaki and Mitamura 2002) and the macrophytic (reed) zone (Negoro et al. 1966; Higashi et al. 1981; Tanimizu et al. 1981; Kusakabe 1988; Mitamura and Tachibana 1999). There is only one report of the flora of diatoms in the sand-beach zone of Lake Biwa (Tuji 1995). Thus, there is very little information on the dynamics of benthic algae in the sand-beach zone. In the present study, the temporal changes in benthic algal biomass and dominant species were investigated to better understand the characteristics of the distribution of benthic algal communities in the sand-beach zone of Lake Biwa.

Methods

This study was carried out in a littoral sand-beach zone (35°15′35″N, 136°13′7″E) located in Hikone City on the eastern side of the north basin of Lake Biwa (35°00′–35°30′N, 135°50′–136°20′E). Two sampling stations were set up; Station 1 faced open water in an offshore direction, and Station 2 was in a zone protected by a breakwater. Surveys were conducted 14 times from December 22, 1999 to September 6, 2000.

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Benthic algae on sandy sediments were collected three times from the shore line (0 cm) and at depths of 30 and 50 cm on offshore transects at both stations. Sampling procedures were as follows: upturned glass petri dishes (9 cm in inner diameter and 1 cm in depth) were gently pushed into the sandy sediments at each sampling point, steel spatulas were slipped under the dishes, the sandy sediments caught between the dish and the spatula were gently withdrawn from the bottom, the collected sediments were transferred from the dish to a polyethylene bottle (250 ml) with a spoon, and all samples were kept in an ice-box and brought back to the laboratory.

Each sample was flushed into glass beakers (1 L) from the bottles with distilled water. The benthic algae were separated and released from the sandy sediments by stirring with a glass rod. The suspension of algae was poured into polyethylene bottles (2 L) and the stirring of algae from the sediments continued until there was a full 2 L of suspended sample in each bottle. A portion of each sample suspension was filtered onto glass-fiber filters (Advantec GF-75, Toyo-roshi, Tokyo, Japan) precombusted at 450°C for 2 h. Chlorophyll-*a* on the filters was measured by the method of UNESCO (SCOR/UNESCO 1966) using 90% acetone as extraction solvent. Benthic algal samples were preserved with borate-buffered neutral formalin (5%). Algal cells were counted under a microscope using a plankton-counting chamber (Matsunami S 6117, Matsunami Glass, Osaka, Japan).

Results and discussion

Temporal changes in the chlorophyll-*a* amounts of the benthic algal communities per unit area of the sandy sediments are shown in Fig. 1. Although chlorophyll-*a* amounts were very low at all sampling points of both stations from December 1999 to April 2000, they rapidly increased from late April to June, especially at 30- and 50-cm depths at Station 2, where they reached 40–60 mg chl. *a* m^{-2}. The sandy sediments were colored bright green, apparently due to the propagation of benthic algae. Microscopic observation mainly revealed two genera of filamentous green algae, *Oedogonium* sp. and *Spirogyra* sp., and a filamentous diatom, *Melosira varians*. Figure 2 shows the seasonal changes in cell numbers of the three major taxa at a depth of 50 cm at both stations. Marked increases in *Oedogonium* sp. and *Spirogyra* sp. in May at Station 2 corresponded to the increase in chlorophyll-*a*. Figure 3 shows the cell numbers of the three taxa at 0-, 30-, and 50-cm depths at both stations on May 8, when the filamentous green algal community was well developed. Cell numbers of *Oedogonium* and *Spirogyra* at 30- and 50-cm depths at Station 2 were higher than those at deeper points at Stations 1 and 2 (one-way ANOVA *Oedogonium* $F = 46.4$, $P < 0.01$; *Spirogyra* $F = 3.39$, $P < 0.05$). Chlorophyll-*a* amounts at 30- and 50-cm depths at Station 2 were also significantly higher than at 0 cm at Station 2 and at 0-, 30-, and 50-cm depths at Station 1 on May 8 (one-way ANOVA $F = 13.4$, $P < 0.01$). Cell numbers of filamentous green algae and benthic algal chlorophyll-*a* amounts at 30- and 50-cm depths at Station 2, protected by a breakwater, were higher than those of Station 1. This fact suggests that biomass accumulation of benthic algal communities is strongly controlled by wave disturbance.

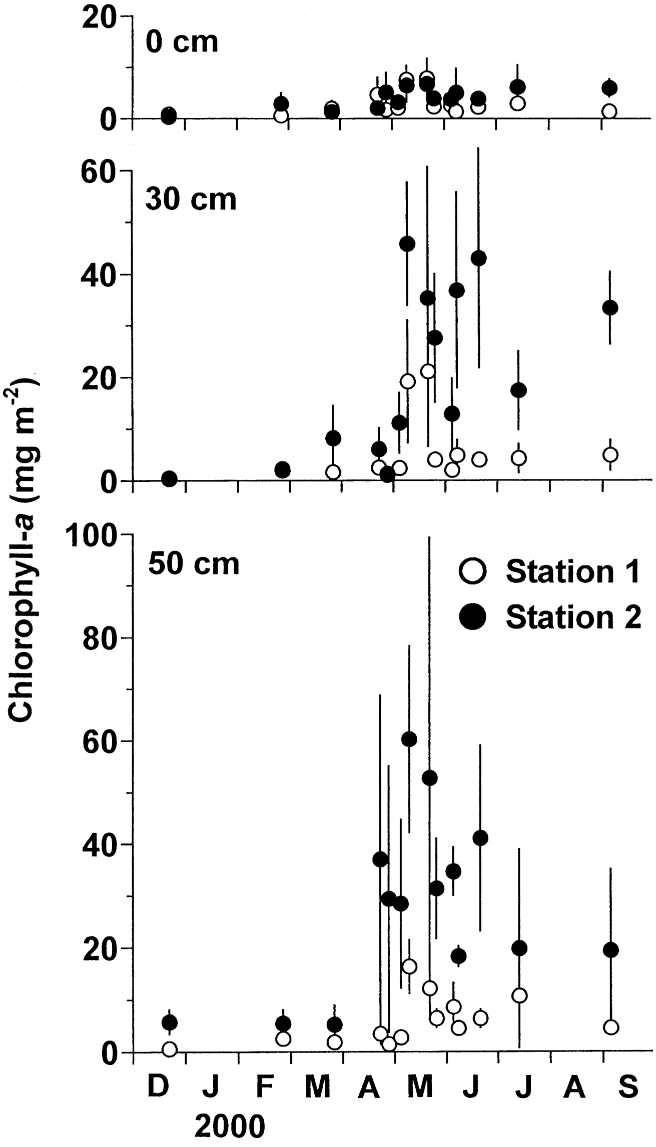

Fig. 1. Seasonal variations of chlorophyll-*a* (mean ± SD, $n = 3$) of benthic algal communities per unit area of the sandy sediments at depths of 0, 30, and 50 cm at Stations 1 and 2

Saijo et al. (1966) investigated benthic algal communities dominated mainly by diatoms throughout the year in 1963–1964 in a littoral stony zone in the north basin of Lake Biwa and found a maximum biomass in February and a minimum in July to August. On the other hand, Nozaki (2001) investigated the chlorophyll-*a* of benthic algal communities formed on stones in a stony zone in the north basin of Lake Biwa from 1995–1996. The maximum values were obtained in June and July when a filamentous green alga, *Spirogyra* sp., appeared in abundance. Therefore, the maximum benthic algal biomass in the stony zone of Lake Biwa was

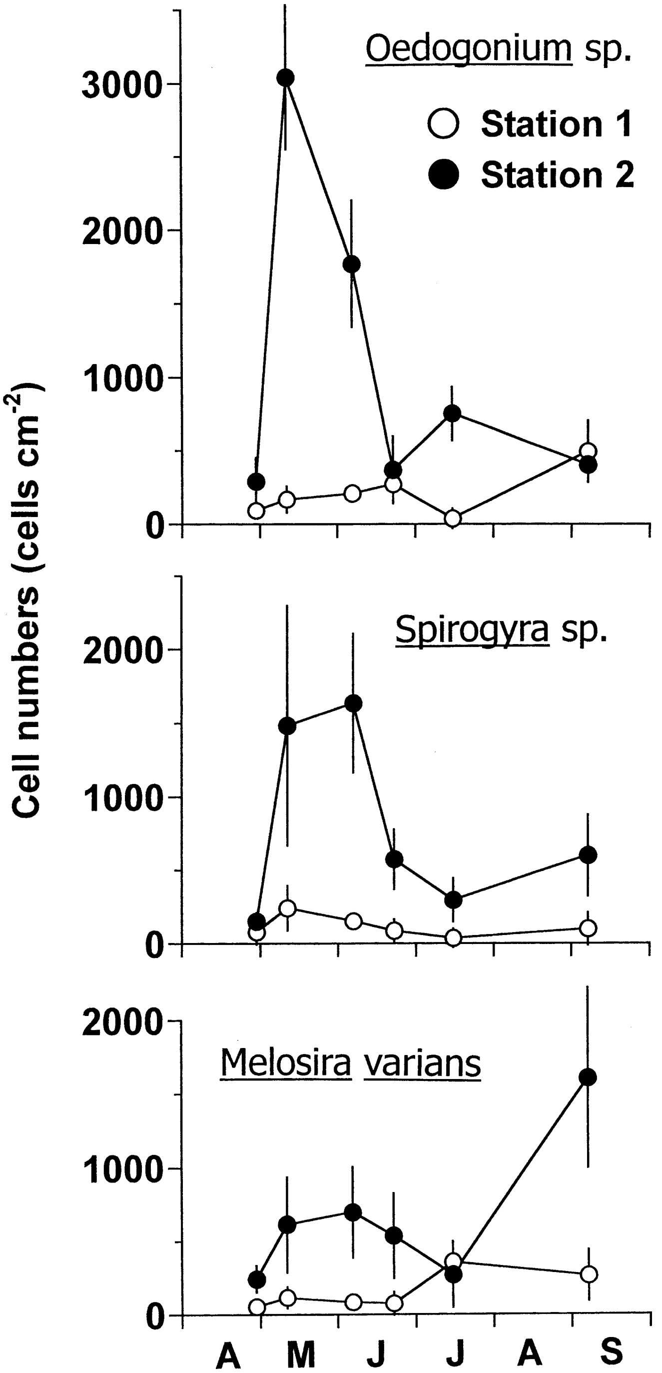

Fig. 2. Seasonal changes in the cell numbers (mean ± SD, $n = 3$) of filamentous green algae *Oedogonium* sp. and *Spirogyra* sp. and a filamentous diatom *Melosira varians* at a depth of 50 cm at Stations 1 and 2

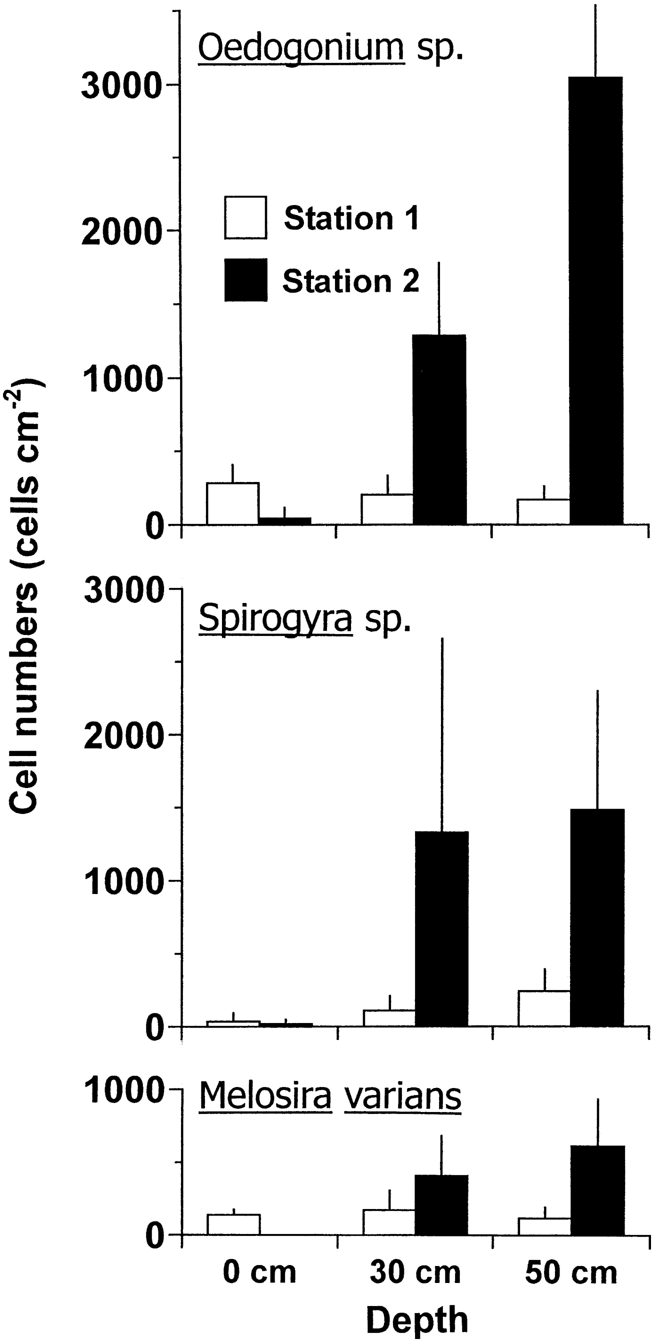

Fig. 3. Depth distributions of cell numbers (mean ± SD, $n = 3$) of filamentous green algae *Oedogonium* sp. and *Spirogyra* sp. and a filamentous diatom *Melosira varians* at Stations 1 and 2 on May 8, 2000

attributed to the appearance of *Spirogyra* sp. in recent years (Nozaki 1999, 2001; Nozaki and Mitsuhashi 2000; Nozaki and Mitamura 2002). In the present study, the chlorophyll-*a* amounts in benthic algal communities increased from May to June, simultaneously with the propagation of the filamentous green algae *Oedogonium* sp. and *Spirogyra* sp. Thus, the biomass increase is considered to result from the propagation of filamentous green algae. The development of filamentous green algae may have an effect on the increase in the biomass of the benthic algal community in early summer and on the alteration of seasonal patterns of biomass in the stony and sand-beach zone of Lake Biwa.

The development of the filamentous green algal community in early summer has been observed in the littoral zone in the north basin of Lake Biwa since the early 1980s (Dr. Y. Watanabe et al., unpublished data from the Internal Report of The Lake Biwa Institute 1983; Nagoshi 1999).

Propagation of filamentous green algae in the littoral zone of the lake has often been regarded as a biological indicator of changes in water quality caused by human impacts. A decline in dissolved inorganic and organic carbon concentrations with lake acidification (e.g. Turner et al. 1995a,b; Graham et al. 1996; Vinebrooke et al. 2003) and an increase in nutrient supply from the watershed (e.g. Lorenz and Herdendorf 1982; Neil and Jackson 1982; Painter and Kamaitis 1987; Jackson 1988; Pieczyńska et al. 1988; Planas et al. 1996; Parker and Maberly 2000) have been reported as factors contributing to the development of filamentous green algae. In the case of Lake Biwa, the propagation of filamentous green algae seems to reflect the increase in nutrient supply. Although the external phosphorus loading in Lake Biwa has been high enough to bring about its rapid eutrophication with reference to the prediction model of Vollenweider (1976), parameters indicating trophic status such as transparency, minimum dissolved oxygen, total phosphorus, and the biomass and productivity of the phytoplankton community in the pelagic zone were almost constant over the past 40 years (Tezuka 1992; Nakanishi et al. 2001). However, seasonal patterns in the dominant species of phytoplankton have changed drastically in recent years (Nakanishi and Sekino 1996; Ichise et al. 1999; Nakanishi et al. 2001). Thus, the biological characteristics of Lake Biwa have changed qualitatively. The human impacts on the lake ecosystem first exert their influence in the littoral zone rather than in the pelagic zone (Nakanishi and Sekino 1996). The propagation of a common green filamentous alga, *Cladophora glomerata*, in the littoral zone of Lake Winderemere (Cumbria, United Kingdom) was rapidly decreased by phosphate stripping at a sewage treatment plant (Parker and Maberly 2000). We believe that the development of the filamentous green algal community in the littoral zone of Lake Biwa is a result of eutrophication.

Epiphytic algal chlorophyll-*a* amounts in the macrophyte zones of Lake Biwa ranged from 1–17 $\mathrm{mg\,m^{-2}}$ in July (Mitamura and Tachibana 1999). The benthic algal chlororphyll-*a* amounts in the sand-beach zone in July obtained from the present study were roughly equal to those in the macrophyte zone (see Fig. 1). Furthermore, area of the sand-beach zone accounted for about 70% of the whole littoral area in the north basin of Lake Biwa. Primary production of the benthic algal community in the sand-beach zone may contribute to the overall lake metabolism through the food web of Lake Biwa; however, there is little ecological information regarding sand-beach zones. We should pay increased attention to sand-beach zones to fully understand ecosystem function in Lake Biwa.

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