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Development of a Filamentous Green Algal Community in the Littoral Zone of Lake Biwa: a Mini-review

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The development of a benthic filamentous green algal community formed by *Spirogyra* sp. in early summer has been observed in the littoral zones in the north basin of Lake Biwa since the 1980s. The development of a *Spirogyra* sp. community may have an effect on the increase in the biomass of the benthic algal community in early summer and on the alterations in seasonal fluctuation patterns of the biomass. In this mini-review, the causes underlying the development of the *Spirogyra* sp. community are discussed on the basis of studies in the seasonal fluctuations of benthic algal communities in littoral stony zones carried out in 1963-1964, 1995-1996 and 2000-2001, especially those focusing on the nutrient concentration (NO_3^--N). NO_3^--N concentrations in June were higher than 100 μg L^{-1} in 1995 and 2000 in contrast to a concentration in June 1964 of only 20 μg L^{-1}. These results show that NO_3^--N concentrations throughout in 1963-1964 period were considerably lower than those in 1995-1996 and 2000-2001, suggesting that the NO_3^--N concentration may have served as a limiting factor on *Spirogyra* sp. growth in 1963. NO_3^--N concentrations in the pelagic zone in the north basin of Lake Biwa have clearly increased from the 1950s under the impact of economic growth and the increasing population in the watershed. The development of the *Spirogyra* sp. community seems to be the result of a heady increase in the nutrient supply from human activities.

Key words : filamentous green algae, human activity, lake biwa, littoral zone, nutrient, *Spirogyra* sp.

INTRODUCTION

The development of the *Spirogyra* sp. community in the littoral zone in the north basin of Lake Biwa since the early 1980s has been reported by Watanabe *et al.* (unpublished data from the Internal Report of The Lake Biwa Institute), Matsuoka *et al.* (1995), Nagoshi (1999), Nozaki (1999, 2001), Nozaki and Mitamura (2002) and Nozaki *et al.* (2003). The effects of the *Spirogyra* sp. community on the littoral zone ecosystem of Lake Biwa have been studied on diurnal changes in dissolved oxygen concentrations (Nozaki *et al.*, 1998), accumulations of nutrients converted into algal biomass (Nozaki and Mitsuhashi, 2000), and the primary production process of a benthic algal community (Nozaki, 1999, 2001). However, the reasons for the propagation of *Spirogyra* sp. in recent years have not been sufficiently investigated (Nozaki *et al.*, 2003). In this mini-review, the underlying causes of *Spirogyra* sp. community development are discussed based on studies of seasonal fluctuations in benthic algal communities in the littoral stony zones carried out in 1963-1964, 1995-1996, and 2000-2001.

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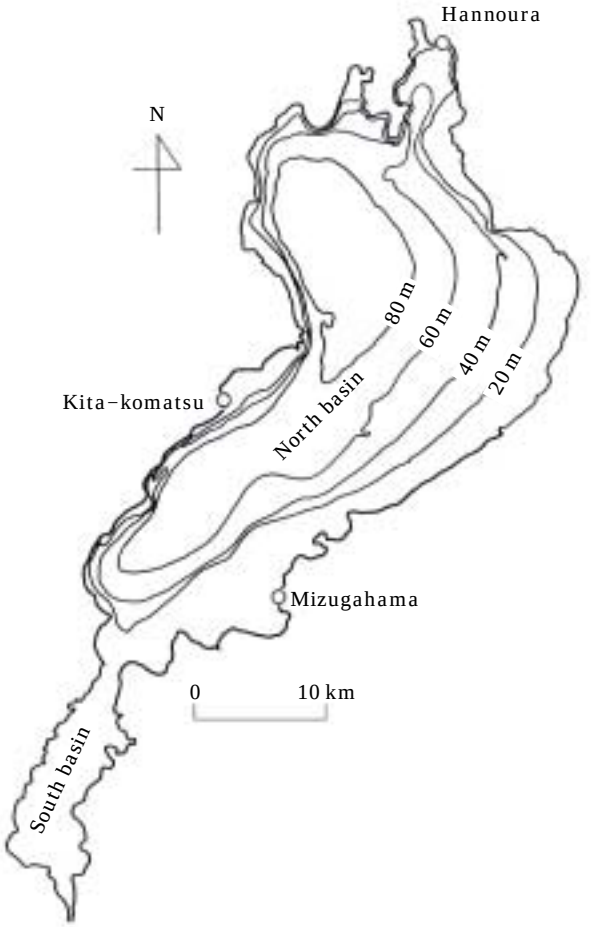

Fig. 1. Lake Biwa (35°00′–35°30′N, 135°50′–136°20′) and locations of study sites.

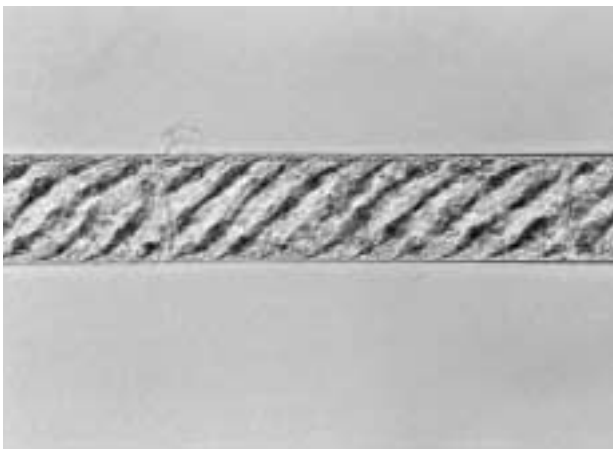

Fig. 2. Microscopic photographs showing that the dominant type of *Spirogyra* sp. in the littoral zone in the north basin of Lake Biwa (×400). This sample collected from a littoral zone (Mizugahama).

SPIROGYRA IN LAKE BIWA AND ITS SEASONAL FLUCTUATIONS

Locations of the study sites are shown in Figure 1. The depths of each study site were 50 cm at Hannoura, 70 cm (range 30–160 cm) at Kita-komatsu, and 50 cm (range 1–90 cm) at Mizugahama. The bottoms of those study sites were covered with gravel (diameter 10–20 cm). The water depth changed with varying water level of Lake Biwa. Figure 2 shows the dominant type of *Spirogyra* sp. Since neither conjugation nor zygotes of this alga have been observed either in the field or under laboratory culture conditions (Nozaki and Mitamura, 2002), the exact species remains unknown. The thickness of a flourishing community has reached as high as 10–20 cm.

Seasonal fluctuations in the biomass of benthic algal communities expressed as chlorophyll-*a* amounts and cell numbers of *Spirogyra* sp. in

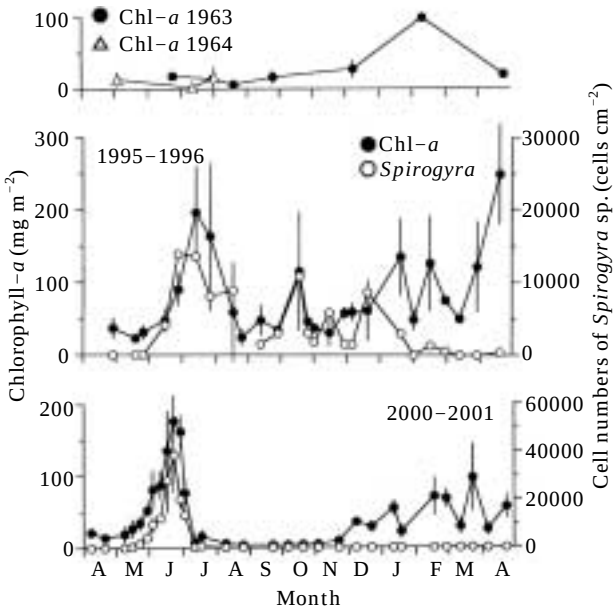

Fig. 3. Seasonal fluctuations in chlorophyll-*a* amounts in benthic algal communities and cell numbers of *Spirogyra* sp. in the littoral zones of Lake Biwa investigated in 1963–1964 (Hannoura, Saijo *et al.* 1966), 1995–1996 (Kita-komatsu, Nozaki, 1999, 2001), and 2000–2001 (Mizugahama, Nozaki and Mitamura 2002; Nozaki unpublished data). Error bars show the standard deviation (n = 3). Cell numbers of *Spirogyra* sp. were not counted in 1963–1964. Chlorophyll-*a* amounts determined by pheophytin method in 1963–1964, and by Lorenzen method after 1995.

1963–1964, 1995–1996 and 2000–2001 are shown in Figure 3. Chlorophyll–*a* amounts of benthic algal communities dominated mainly by diatoms throughout the 1963–1964 periods were found to reach their maximum value in February and their minimum from July to August (Saijo *et al*., 1966). Although *Spirogyra* sp. has been observed in summer, the alga failed to propagate (Negoro *et al*., 1966). On the other hand, Chlorophyll–*a* amounts in 1995–1996 and 2000–2001 increased from June to July and in winter, and the increase in the benthic algal biomass in summer was synchronous with the propagation of *Spirogyra* sp. (Nozaki, 1999, 2001; Nozaki and Mitamura, 2002). The *Spirogyra* sp. community begins to propagate in late May, and its biomass reaches a maximum from June to mid–July. The highest photosynthesis rate of the *Spirogyra* sp. in Lake Biwa was obtained at 35°C (Nozaki and Mitamura, 2002). Thus, the optimum season for the growth of the *Spirogyra* sp. seems to be summer. The results of these studies suggest that the development of a *Spirogyra* sp. community may have an effect on the increase in the biomass of the benthic algal community in summer season and on the alterations in seasonal fluctuation patterns of the biomass in the littoral zone in the north basin of Lake Biwa.

FACTORS INFLUENCING THE DEVELOPMENT OF A SPIROGYRA COMMUNITY

The community of a *Spirogyra* sp. in Lake Biwa rapidly decreased in late July (*cf*. Fig. 3). The daytime water temperature in late July–August in the north basin of the lake reached 30–33°C in the littoral zone (Nozaki, 1999; Nozaki and Mitamura, 2002). Graham *et al*. (1995) reported that the optimum water temperature affecting the photosynthesis rate of *Spirogyra* sp. collected from Lake Surrey (USA) was 20–25°C, and that the rate rapidly declined at 30–35°C. This result suggests that water temperature is an important factor in the summer decline of *Spirogyra* sp. in Lake Surrey. However, the optimum water temperature of the photosynthesis rate of *Spirogyra* sp. in Lake Biwa is 35°C, suggesting that the summer water temperature is not likely to constitute a direct regulating factor on the photosynthesis.

The propagation of filamentous green algae such as *Cladophora glomerata*, *Mougeotia* sp., *Oedogonium* sp. and/or *Spirogyra* sp. in the littoral zone of Lakes has often been regarded as a biological indicator of changes in water quality due to human activity. A decline in dissolved inorganic and organic carbon concentrations due to lake acidification (Turner *et al*., 1995; Graham *et al*., 1996; Vinebrooke *et al*., 2003), and an increase in the nutrient supply from a watershed (Neil and Jackson, 1982; Pieczynska *et al*., 1988; Parker and Maberly, 2000) have been reported as factors contributing to the development of a filamentous green algal community. In the case of Lake Biwa, the propagation of *Spirogyra* sp. seems to reflect on increase in the nutrient supply. Therefore, we examined the nutrient supply as a factor influencing the development of a community of *Spirogyra* sp. on the basis of seasonal variations in the concentrations of nitrate nitrogen (NO_3^-–N), because the concentration of phosphate (PO_4^{3-}–P) were usually below the limit of detection ($< 3\ \mu g\ L^{-1}$) in the north basin of Lake Biwa (Tezuka, 1984; Nozaki, 1999).

Figure 4 shows seasonal variations in the concentrations of NO_3^-–N in the littoral zones of Lake Biwa surveyed in 1963–1964, 1995–1996 and 2000–2001. NO_3^-–N concentrations in winter were generally higher than in other seasons. The concentrations in 1995–1996 and 2000–2001

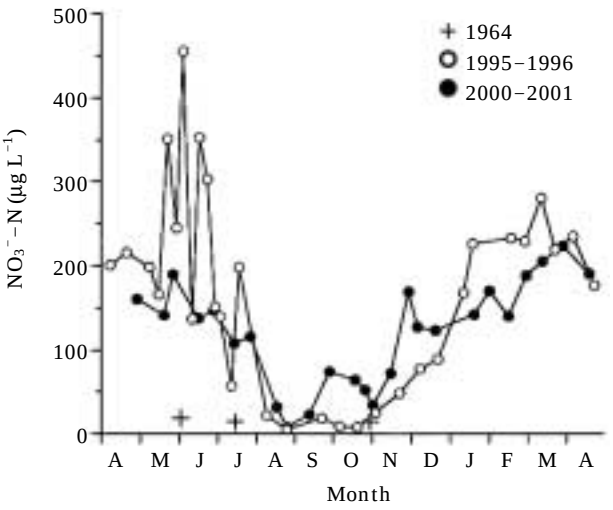

Fig. 4. Seasonal variations in concentrations of nitrate nitrogen (NO_3^-–N) in the littoral zones of Lake Biwa investigated in 1964 (Fujinaga *et al*., 1966), 1995–1996 (Nozaki, 1999) and 2000–2001 (Nozaki, unpublished data).

decreased rapidly from July and by August had declined to less than 10 μg L^{-1}. The seasonal patterns and concentrations of nutrients in the littoral zone of Lake Biwa were similar to those in the pelagic zone (Nozaki, 1999). Remarkably low concentrations of NO_3^-–N in summer are well known in the surface layer of the pelagic zone in the north basin of Lake Biwa (Tezuka, 1984). Thus, the growth of aquatic plants such as algae seems to be regulated in summer by low concentrations of NO_3^-–N. Those concentrations in June were higher than 100 μg L^{-1} in 1995 and 2000, whereas the concentration in June 1964 was only 20 μg L^{-1}. These results indicate that the NO_3^-–N concentrations throughout the 1963–1964 periods were considerably lower than those in 1995–1996 and 2000–2001, suggesting that the NO_3^-–N concentration may have served as a limiting factor on *Spirogyra* sp. growth in June 1963. Yamada and Nakanishi (1999) reported that NO_3^-–N concentrations in the pelagic zone in the north basin of Lake Biwa have clearly increased since the 1950s due to economic growth and an increasing population in the watershed. Thus, the development of a *Spirogyra* sp. community in the littoral zone in the north basin of Lake Biwa seems to be the result of an increase in the nutrient supply from human activities.

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＜**국문적요**＞

Biwa호 연안대에서 사상성 녹조류 군집의 발달

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1980년대 이래로 Biwa호 북측 지역 연안대에서 초여름 동안 *Spirozyra*에 의해 조성된 저서 사상성 부착녹조류 군집의 발달이 관찰되어 왔다. 이들의 발달은 초여름 저서 조류 군집의 생물량 증가와 생물량의 계적적 변동 양상에 영향을 미친 것으로 판단된다. 본 논문에서는 *Spirozyra* 군집 발달의 원인을 1963–64년, 1995–96년, 2001–02년 동안 수행된 연구 결과(특히, 영양염, NO_3^-–N)에 기초하여 고찰하였다. 6월 동안의 NO_3^-–N의 농도는 1964년 6월에 20 μg L^{-1}에 비교할 때 1995년과 2002년은 100 μg L^{-1} 이상이었다. 이 결과는 NO_3^-–N가 1963년도에 *Spirogyra* 성장에 대해 제한요인으로 작용하였음을 시사한다. Biwa호 북측 지역 개방수역에서 NO_3^-–N의 농도는 1950년대 이후 유역에서의 인구증가와 경제성장의 영향으로 뚜렷하게 증가하였다. 따라서 Biwa호에서 *Spirogyra* 군집의 발달은 인간활동에 의한 영양염 공급의 증가의 결과로 추정된다.