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Recent drastic changes in Lake Biwa bio-communities, with special attention to exploitation of the littoral zone

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Abstract: A change for the worse in water quality in Lake Biwa has led to musty odor of tap water, freshwater red tide and other water blooms by sudden propagations of nuisance planktonic algae since 1970. Further, some endemic and commercially important species of fish and molluscs decreased drastically in the last 10–30 years. These events seemed to be closely related to drainage of many small lakes channeled to Lake Biwa as part of an agricultural policy after World War II, and to senseless exploitation of the littoral zone in the 1970s and 1980s as a link in the Comprehensive Development Project of Lake Biwa. Simplification of its littoral zone has led to a deterioration in its ecosystem through physical destruction of spawning habitats and increase in eutrophication.

1. Introduction

Lake Biwa is one of the ancient lakes in the world with a record of five million years in its history (Horie 1984). The lake has been characterized by shore lines with diverse shapes, littoral areas with muddy, sandy, pebbly and rocky zones and with a pelagic zone spatially large and stable before World War II. With such a background, the structure and function of bio-communities have been highly diversified in the lake. As a result, more than one thousand species including ca. fifty endemic species of molluscs, fish, planktonic algae and aquatic plants have coexisted there. Thus, Lake Biwa is one of the special properties of the world from a biological viewpoint. Further, it has played important roles in fisheries, water resources, a place of sentiments and creation of local cultures (Nakanishi 1993).

However, recently, it has become difficult to keep these values of Lake Biwa because of 1) a change for the worse in water quality through industrialization, modern modes of human life, population increase and senseless exploitation, 2) physical destruction of the littoral zone which is important for habitats and spectacular vistas, and 3) invasion and introduction of alien plants and animals.

In the present study, we focus on the drastic changes in bio-communities which have occurred in Lake Biwa in the last 25–30 years, giving special attention to exploitation of the littoral zone.

2. Morphometry of Lake Biwa and shape changes

Lake Biwa is located in the center of Honshu Island in Japan at an altitude of 85 m. The lake is divided into two basins: the north basin and south basin (Figure 1). The former is ca. 620 km^2 in surface area and 104 m in maximum depth (mean depth, 44 m), and the latter is 57 km^2 in surface area and 8 m in maximum depth (mean depth, 2.8 m).

There were more than thirty small lakes or swamps which drain into Lake Biwa (Figure 1). These lakes or swamps played important roles in water purification and spawning of cyprinid fish. Most of them, however, were lost by drainage as a link in the agricultural policy after World War II.

Further, a great part of shoreline of the lake has been changed and simplified artificially by the Comprehensive Development Project of Lake Biwa proclaimed in 1971 (cf. Figure 1). The area which was lost by drainage and reclamation exceeds 20% of the whole littoral area.

Loss of small lake-swamp areas and shape change in the shoreline gave rise to a decrease in the reed

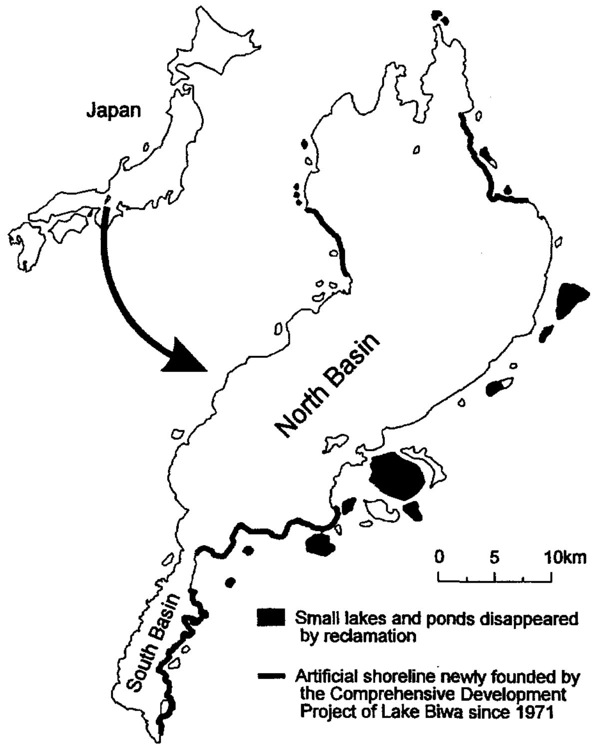

Figure 1. Map of Lake Biwa showing small lakes and ponds channeled to Lake Biwa and recent artificial shorelines newly founded (Kurata, 1983, modified).

community and submerged macrophyte zones which play important roles in water purification through physical, chemical and biological processes and in spawning of fish. The area of the reed community in 1990 (120 ha) was half that in 1953 (260 ha). Also the submerged macrophyte zone decreased drastically (Figure 2). Because of the functions of aquatic plant areas, such a sharp decrease in the reed community and submerged macrophytes zones would seem to be one of causes of deterioration in water quality and decrease in cyprinid fish populations.

3. Changes in phytoplankton communities

Serious events have occurred due to sudden propagation of certain planktonic algae since 1970 (Figure 3). In 1970, a musty odor of tap water in Kyoto City where water is supplied from Lake Biwa was noted in a local newspaper. Problems of musty odor of tap water have expanded not only to Kyoto City but also to Osaka and Otsu cities in the 1970s, which all draw supplies from Lake Biwa. Occurrence of musty odor is closely related to propagation of some planktonic algae in the eutrophic south basin of Lake Biwa. The algae related to musty odor have changed successively from a diatom, *Synedra rumpens* to blue-greens, *Oscillatoria* spp. through to *Phormidium mucicola* and *Anabaena macrospora. Uroglena americana* (Chrysophyceae) propagated suddenly in both basins in 1977 and changed the surface water to a dark brown color. We define this phenomenon as a freshwater red tide. The freshwater red tide has been observed every year mainly in May–June since 1977. Further, in the 1980s, *Anabaena macrospora, A. affinis, Microcystis aeruginosa* and *M. wesenbergii* which are nuisance blue-green algae became dominant or tended to increase from August to early September in the south basin of Lake Biwa (Figure 4) and have formed water blooms at some locations since 1985. On the contrary, a green alga, *Pediastrum biwae* and a diatom, *Melosira solida* which are endemic or rare species have decreased drastically in their abundance after around 1985 (Figure 5). Such a replacement of algal species has not been reported previously in Lake Biwa. In 1989, water color for the first time became dark in the most northern part of Lake Biwa. This was due to a sudden propagation of algal picoplankton consisting mainly of *Synechococcus* spp. (Ichise et al. 1991). From the viewpoint of algal succession, eutrophication has been in progress in Lake Biwa since 1970. However, Tezuka (1992) pointed out that eutrophication has not advanced during the last 24 years on the basis of annual changes in physical and chemical variables

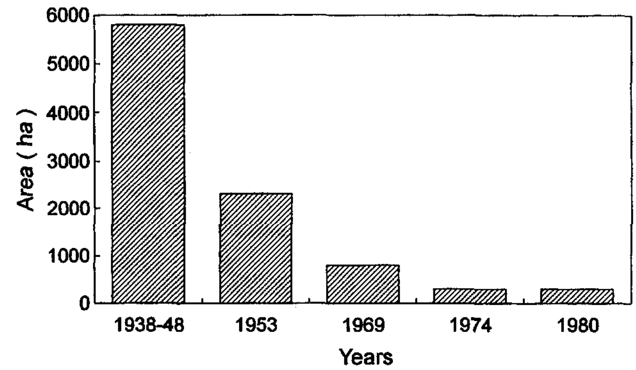

Figure 2. Change in submerged macrophyte area in the south basin of Lake Biwa (Suzuki, 1988).

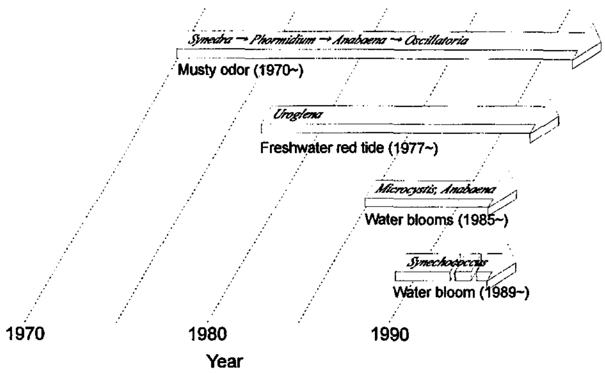

Figure 3. Socially important events due to propagations of nuisance planktomc algae in Lake Biwa over the last 25 years.

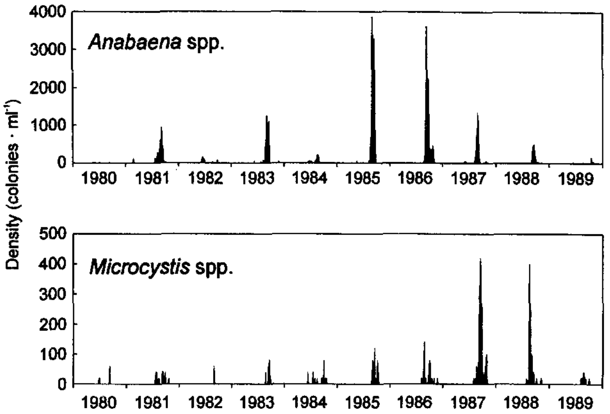

Figure 4. Annual changes in densities of *Anabaena* spp. and *Microcystis* spp. (data provided by Shiga Pref. Inst. Pub. Hlth. and Environ. Sci.).

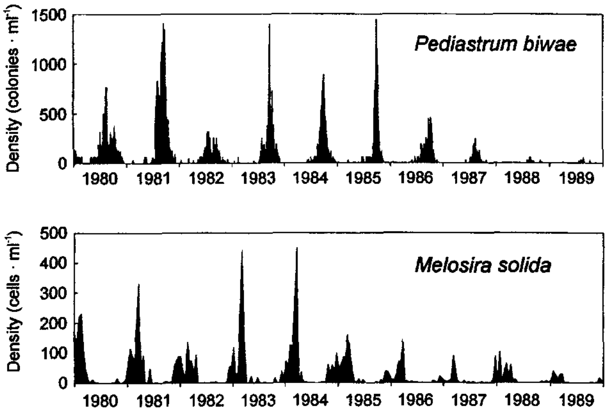

Figure 5. Annual changes in densities of *Pediastrum biwae* and *Melosira solida* (data provided by Shiga Pref. Inst. Pub. Hlth. and Environ. Sci).

such as transparency, minimum dissolved oxygen concentration in the bottom layer and total phosphorus concentration. As pointed out by Tezuka (1992), year-to-year changes in total nitrogen and phosphorus concentrations in both basins were mostly stable over the last 23 years (Figure 6). These facts suggest that the drastic changes in algal composition during the last 25 years cannot be explained by the traditional indicators for eutrophication. More comprehensive consideration is required.

4. Population decrease in some endemic fish and molluscs

Judging from annual yield of fish and molluscs, some of the endemic and commercially important fish and molluscs seem to be decreasing drastically in their abundance. As typical examples, we can list *Carassius carrassius grandoculis*, one of crusian carps, *Chaenogobius isaza*, a goby (Figure 7), and *Corbicula sandi* and *Hyriopsis schlegeli*, molluscs

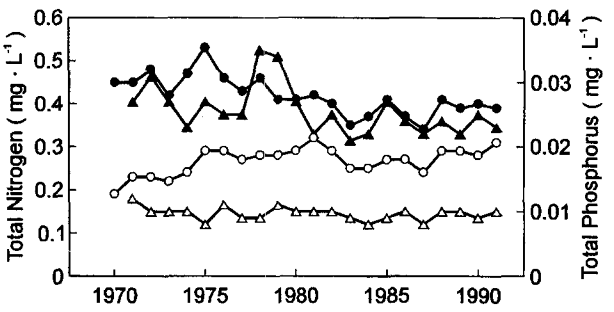

Figure 6. Annual changes in annual mean total nitrogen (TN) and total phosphorus (TP) concentrations in the north and south basins of Lake Biwa (Shiga Pref., 1992). ●, TN in the south basin; ▲, TP in the south basin; ○, TN in the north basin; △, TP in the north basin.

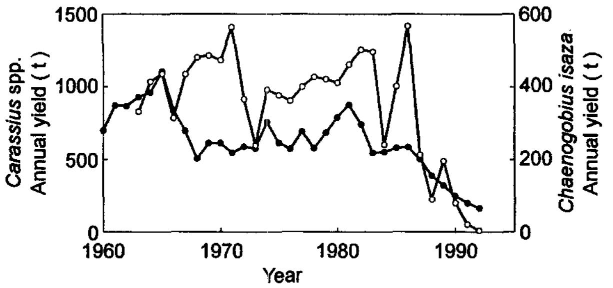

Figure 7. Changes in annual yield of *Carassius* spp. (●) and *Chaenogobius isaza* (○) (Kinki Noseikyoku Shiga Tokei Joho Jimusho, 1960-1993), Lake Biwa.

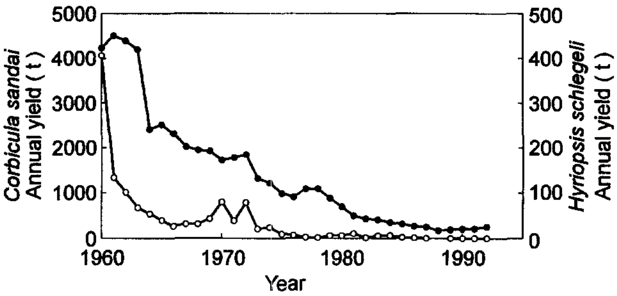

Figure 8. Changes in annual yield of *Corbicula sandai* (●) and *Hyriopsis schlegeli* (○) (Kinki Noseikyoku Shiga Tokei Joho Jimusho, 1960–1993), Lake Biwa.

(Figure 8). *C. carrassius grandoculis* inhabits the middle to bottom layer of the offshore area and feeds mainly on zooplankters. In the spawning season (May–June), this fish moves to the shore to spawn on macrophytes and submerged willow roots or other floating material. Littoral zones where reed communities, submerged macrophytes or other vegetation are well developed are essential for the life cycle of these cyprinid fishes.

C. isaza inhabits the bottom at depths greater than 30 m. In the spawning season, April to June, however, it moves to gravel shores and deposits eggs under small stones (Tokui and Kawanabe 1984). Recently, the gravel in the littoral zone is being covered with filamentous algae such as *Spirogyra* and *Cladophora*, thereby causing a deterioration in the spawning sites. Further, conditions for survival of *C. isaza* may have been influenced by depletion of dissolved oxygen near the bottom during the stagnation period (cf. Kumagai and Fushimi 1995).

The annual yield of *Corbicula sandi*, a mussel, has been decreasing for the last 40 years. The yield in 1992 was 4% of that in 1955 (Figure 8). This fact suggests that its population size has decreased greatly. This mussel inhabits sandy or sandy-mud substratum and shallow areas less than 10 m deep. According to Mori (1984), the distribution of *C. sandai* has been limited due to a rapid progress in eutrophication since 1971. In addition to habitat deterioration by eutrophication, its habitat also has become physically unstable due to frequent inflows of earth and sand through morphological changes in rivers and shorelines. Annual yield of *H. schlegeli*, which is another endemic mussel used for freshwater pearl production, is also declining sharply (Figure 8).

Because of the complicated life histories of fish and mussels, it is very difficult to find the exact processes causing decrease in their population sizes. As a whole, however, there is little doubt that the changes in bio-communities in Lake Biwa are related closely to human activities.

5. Discussion

Possible causes of changes in the bio-community occurring recently in Lake Biwa seem to be as follows; 1) eutrophication due to population increase, changes in modes of human life and agriculture, industrialization and exploitation, 2) toxic pollution by industrial and agricultural chemicals, 3) physical destruction of habitat by senseless exploitation of shorelines and the catchment area, 4) competition for the habitat and/or food between native and alien organisms and 5) over-fishing.

For the phytoplankton community, nuisance blue-green algae such as *Anabaena* spp. and *Microcystis* spp. became dominant after 1985 and at the same time endemic or rare species such as *Pediastrum biwae* and *Melosira solida* decreased drastically (see Figures 4 and 5). Endemic species, *Carassius carrassius grandoculis* and *Chaenogobius isaza* in the fish community began to decrease in their population size around 1985 (see Figure 7). Endemic molluscs, *Corbicula sandai* and *Hyriopsis schlegeli* have decreased since 1960. There is a difference in the habitat used between phytoplankton-fish and molluscs; the former inhabits the water layer and the latter the bottom sediments shallower than 10 m deep. Thus, in Lake Biwa, it is considered that the bottom enviromment as molluscan habitat has become worse earlier than did the water. Though over-fishing is considered as one of causes of population decrease in molluscs, it has not been reported.

On the other hand, the major events in phytoplankton and fish communities mentioned above occurred in 1985. Phytoplankton composition is influenced mainly by nutrient concentration, its ratios and biological competition. Annual mean concentrations of total nitrogen and phosphorus were not significantly different before and after 1985 in both basins (see Figure 6). This fact suggests that macronutrients were not so effective for changing algal composition. As pointed out by Ishida (1987), dissolved ferric iron available for algae and the vitamin B group seem to be related to change in algal composition in Lake Biwa. It is thought that organic matter such as humic acid and fluvic acid as chelates of ferric iron increased and the production of the vitamin B group was enhanced with progress in eutrophication. Decrease in fish population size is related mainly to habitat deterioration, decrease in food, over-fishing and decrease in spawning areas. It is very difficult to explain the decrease in population size of *Carassius carassius grandoculis* from the viewpoint of a change for the worse in its habitat and decrease in food. Regarding its habitat, the bottom layer is surely becoming worse by depletion of dissolved oxygen (Kumagai and Fushimi 1995). As a result, this habitat became spatially reduced and also was restricted in the middle layer. Zooplankton, especially the cladoceran community used as food were variable from year to year for the last 24 years. Thus, it is difficult to find a relationship between change in the fish population and zooplankton. Overfishing may be a possible cause, though there are no data available. There are a few native predators such as Biwa salmon (*Onchorhynchus rhodurus*), Hasu fish (*Opsariichthys uncirostris*) and catfish (*Parasilurus lithophilus, P. biwaensis*), but there is no information on increases in their population size for the last 24 years. Alien fish such as bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) were introduced Lake Biwa in the 1980s. The effect of these exotic predators on the *C. carrassius grandoculis* population seems to be minor as far as is indicated by their stomach contents (Suzuki, Norio, personal comm.). Deterioration of spawning areas is the most probable cause of decrease in the *C. carrassius grandoculis* population. Senseless exploitation of the littoral zone in the 1980s as a link in the Comprehensive Development Project of Lake Biwa destroyed natural physico-chemical properties of littoral zone and macrophytes zone. As a result, it accelerated decrease in the spawning areas for the fish. The importance of spawning habitat for fish stock maintenance is supported in the case of the sweetfish (*Plecoglossus altivelis*). Annual yield of sweetfish did not decrease and instead tended to increase over the last 23 years (Figure 9). This is due

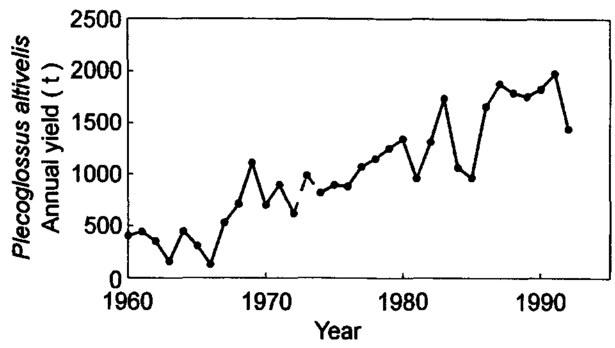

Figure 9. Changes in annual yield of *Plecoglossus altivelis* (Kinki Noseikyoku Shiga Tokei Joho Jumusho, 1960-1993), Lake Biwa.

to construction of artificial streams fully functioning as spawning habitat. As mentioned before, the decrease in the *Chaenogobius isaza* population seems to be closely related to deterioration in spawning areas and the bottom habitat through eutrophication.

Exploitation of the littoral zone for the purposes of the food control and park construction in Lake Biwa has been attended usually with modification of the shoreline. The shoreline is covered with concrete or paved with stones. These structures block the biological and chemical exchanges between water and land. Further, they simplify physically habitats of the littoral zone. Thus, the exploitation seems to lead to decrease in biodiversity of lakes through severe changes in physico-chemical properties of the littoral zone, or through physical destruction of habitats and eutrophication (Figure 10).

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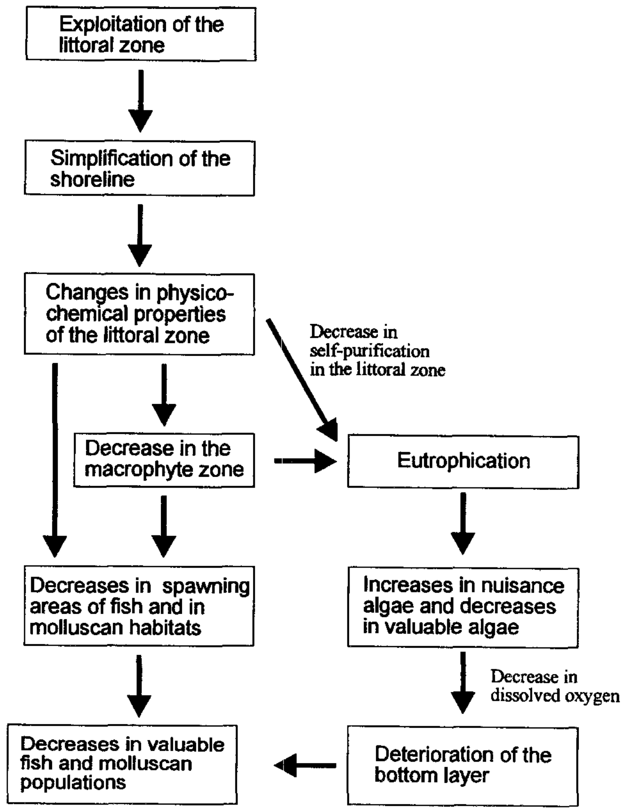

Figure 10. An outline of the steps in exploitation of the littoral zone which have strong negative effects on the bio-comunities of Lake Biwa.

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