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Lake Biwa watershed transformation and the changed water environments

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Introduction

Lake Biwa is the largest and oldest lake in Japan, located in the heart of Shiga Prefecture. The lake is estimated to have originated some 4 million years ago and is one of the most ancient in the world. It has developed a rich lake ecosystem, including over 50 indigenous species. For tens of thousands of years, humans have been a part of that ecosystem. Endowed with the bountiful resource values of the lake, they have also developed a distinctive lake-community culture including that of wary respect for the occasional dangers it presents, such as floods.

The Lake Biwa Comprehensive Development Plan (LBCDP) was launched in 1972 as a national program based on a special measures act of the Diet, and concluded in March 1997. The primary objectives of the plan were to develop additional water resources for the downstream Osaka–Kobe (Hanshin) Region and to reduce the threat of floods in the lakeshore areas, while preserving the natural environment of the lake and restoring a water quality that was rapidly showing the effects of pollution. The plan succeeded in providing more effective utilization of the water resources and in significantly reducing flood damage. Today, Lake Biwa has become a vital water resource for the Keihanshin (Kyoto–Osaka–Kobe) Region (Table 1). The lake also has become a favorite recreational site for the region.

Another important aspect of the LBCDP, however, was the development of the Lake Biwa watershed. Over the 25 years of the LBCDP implementation, the lake watershed has undergone tremendous transformation due to urbanization and industrialization. Despite the introduction of significant structural and non-structural environmental control measures, the water quality and ecosystem integrity of the lake began to deteriorate. The transformation of the watershed and coastal zone for housing, industrial and recreational development has resulted in the loss of paddy fields and wetlands, together with the degradation of the upland forest areas. Despite some signs of improvement in the nutrient concentration level, as a result of the gradually expanding sewerage networks, achievements have been considerably less in the areas of restoration of the natural self-purification capacity lost through the transformed land uses, and the conversion of forestlands and wetlands to facilitate development activities. Consequently, during the last phase of the LBCDP, the prefectural government of Shiga began to consider how to ensure the comprehensive conservation in the post-LBCDP era.

In March 1997, Shiga Prefecture compiled the results of the deliberations of a national council established for the purpose, and they prepared a proposal for the national authorities, resulting in the Lake Biwa Comprehensive Conservation Plan, or LBCCP, dubbed the "Mother Lake 21". The plan emphasizes that the ultimate solution to the problems facing Lake Biwa lies in the restoration of the natural and ecosystem capacities of the coastal zone and the watershed while pursuing the revival of an environmental culture to allow such re-transforma-

Table 1. Population served by Lake Biwa water, 1994.

Prefecture	Population within jurisdiction	Population served by Lake Biwa	Dependency on Lake Biwa water (%)
Shiga Pref.	1,300,000	1,000,000	79
Kyoto Pref.	2,600,000	1,790,000	69
Osaka Pref.	8,720,000	8,530,000	98
Hyogo Pref.	5,470,000	2,610,000	48

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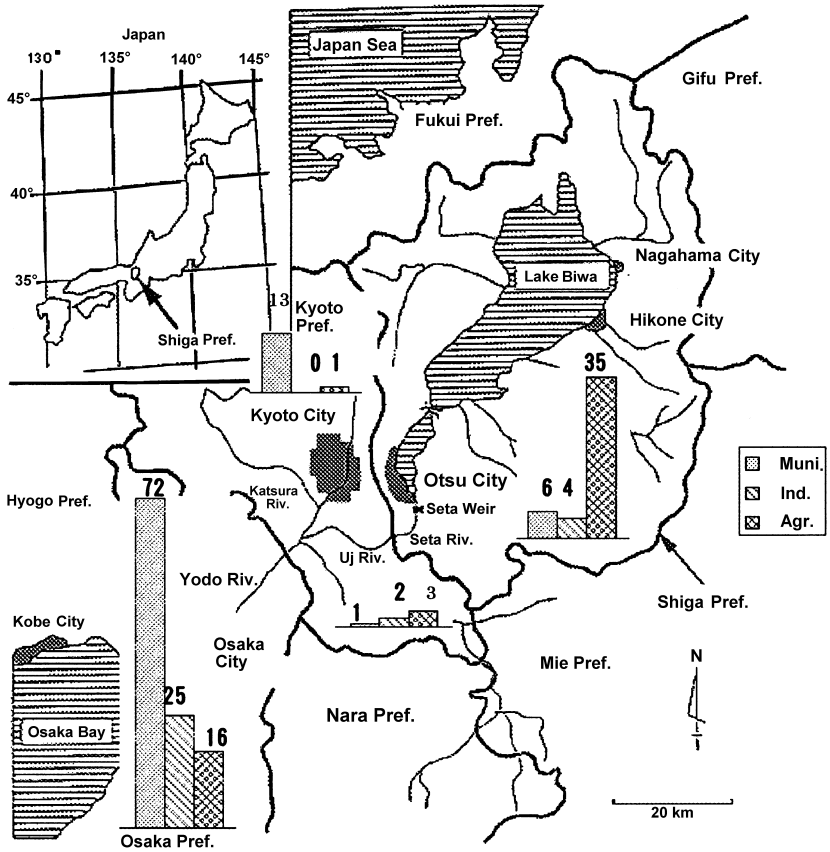

Fig. 1. Downstream demand for water (m^3/s, as of late 1990s).

tion to occur. The present paper gives an overview of the transformation that has taken place in the Lake Biwa watershed and of its impacts on the lake, which led to the formulation of the LBCCP.

The Lake Biwa–Yodo River water system

Lake Biwa is Japan's largest freshwater lake, both in terms of surface area (674 km^2) and volume (27.5×10^9 m^3). It receives water from some 120 rivers (over 400 if small streams are included) in its catchment basin, which is only five times the area of the lake itself. It has only one exiting river at the southern end – the Seta River. The Seta River (called the Uji River in Kyoto Prefecture) is joined by the Katsura and Kizu Rivers some 30 km downstream of the lake to become the Yodo River (Fig. 1). The flow contributions to the Yodo River from the Uji, Kizu and Katsura Rivers are, respectively, 64.2%, 18.0%, and 15.0%. The official designation of the entire Yodo–Uji and Lake Biwa water bodies is the Yodo River system. Its annual average flow, its high flow and its low flow are, respectively, 177.6 m^3/s, 226.8 m^3/s, and 117.0 m^3/s. The ratio of high to low flows, 0.52, is the highest among the major river systems in Japan, making the Yodo River a very stable source of water.

The Lake Biwa–Yodo River system is of overriding importance in Kansai, the general designation of the western half of Japan. The water from this system is supplied to such large cities as Kyoto, Osaka, and Kobe, to the industries in the Osaka Bay area, the urban and semi-urban areas, as well as the extensive paddy agriculture fields in the lake catchment area. A complex web of water supply and wastewater networks, which support the region's high level of municipal, industrial and agricultural activities, characterizes the region. This great metropolitan complex within the Keihanshin region has been almost totally dependent on the Yodo River, or largely on Lake Biwa, for its water resource needs. The water resource capacity had to be gradually increased to meet the growing demands.

The mountain ranges around Lake Biwa and the tributaries of the Yodo River are mostly covered with dense forests. They function as a natural reservoir as well as a gigantic filter producing high quality raw water to replenish Lake Biwa and the Yodo River. There are, however, 12 dams (including some under construction, but excluding agricultural irrigation dams) in the watershed for the integrated management of water resources, to make up for the fluctuations in precipitation. The Yodo River main watercourse serves most of the downstream needs. Waste water is collected by the sewerage networks, treated, and discharged back into the Biwa–Yodo watercourse or directly into Osaka Bay. The water systems of Lake Biwa, the Yodo River, and Osaka Bay are all within a compact geographical area of less than 10,000 km^2. The direct distance from the northernmost tip of the Lake Biwa watershed to the southern opening of the Osaka Bay estuary is less than 200 km.

The Lake Biwa Comprehensive Development Project (LBCDP)

Lake Biwa provides water supplies for municipal, industrial and agricultural purposes amounting, respectively, to 6.6 million tons/day, 1.2 million tons/day and 23.6 million tons/day. It serves as many as 14 million people living in the Keihanshin area, including Shiga. The pollution of the lake has therefore been of serious concern not only for those living around it but also for those receiving water from Yodo River. The demand for water, particularly for industrial uses in the downstream Yodo River and the Osaka Bay area, began to increase sharply as the country entered an era of economic growth a decade or so after World War II. Exploitation of the groundwater soon became constrained due to competition between industrial establishments and due to land subsidence caused by the overuse of the water. Industries were then forced to look for alternative sources of water. Domestic water supply needs also began to increase in the Yodo River area after suburban cities joined Osaka in requiring access to the Yodo River water. The water situation in the downstream Yodo River culminated in the inception of a large-scale water resource development – the LBCDP (Fig. 2).

The primary goal of the LBCDP was to allow the lake to be converted into a 'man-made' reservoir (via a financial arrangement with the national government), which would generate additional water resources amounting to a maximum of 40 m^3/s at times of drought, in order to meet the ever-increasing downstream needs in the early 1970s. Flood control was an added function achieved through the installation of intricate flow control facilities around the lake. The LBCDP, however, had another major

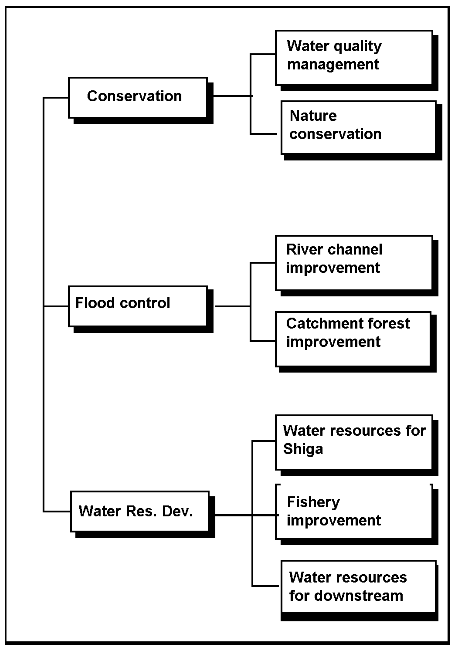

Fig. 2. Basic framework of the LBCDP.

objective – the development of regional infrastructure systems for the Shiga Prefecture – which was included as a compensatory measure for the prefecture so as to reach agreement on the scheme of water resource development for the downstream. The compensatory measures included a wide range of lakeshore and watershed infrastructural development projects, such as the construction of roads, a park, water supplies, sewerage, and many other facilities. These provisions would improve the development potential of the then rural and economically disadvantaged Shiga Prefecture, allowing people, industries, and commercial establishments to relocate to the prefecture from the already densely developed downstream regions.

When the LBCDP was inaugurated in 1972, it was to be completed within 10 years, at the end of the 1981 fiscal year. Due to the economic slowdown in the 1970s, the project period was extended for another 10 years, changing the target date of completion to the end of the 1991 fiscal year. Shiga Prefecture insisted that not all of the regional infrastructure projects could be completed by the termination of the period so another 5-year extension was agreed upon. The final date of completion therefore became the end of the 1997 fiscal year, making the LBCDP a 25-year national project.

As a result of the LBCDP, however, the area surrounding Lake Biwa has been increasingly urbanized. The Lake Biwa system is now strongly human-dominated. These developments have resulted in major ecosystem changes in the lake, including littoral conversion, the disappearance of some of the connecting lagoons, called 'Naiko', the channelization and control of stream flows, and the segmentation of coastal wetlands and shores, as described herein in the section titled '*Watershed transformation over the past few decades*'.

The rapid rate of water quality deterioration, which occurred in the 1970s, called for a greater emphasis on environmental components in the 1982 revision of the project. In 1982, a substantial level of funding was directed towards environmental protection and pollution control, e.g. from an annual expenditure of 10 billion yen/year for a sewerage and night soil treatment system during the 1972–1981 period, to 26 billion yen/year during the 1982–1991 period (Fig. 3). The funds were also made available for constructing dairy waste treatment facilities, rural sewerage facilities, refuse disposal facilities, and for upgrading the lake water quality surveillance and monitoring system.

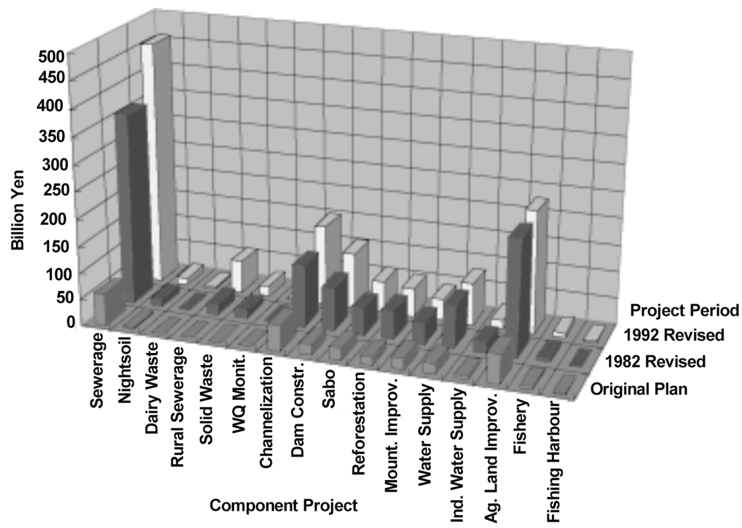

Fig. 3. Component project budget of the LBCDP.

Nutrient control and lake water quality

Land-based nutrient loading and its control

Land-based pollution originates from point sources (industries, commercial establishments, households, etc.) as well as from non-point sources (aerosols in precipitation, contaminants in urban storm runoffs, forest and field runoffs and irrigation return flows, etc.) Control of such pollution is of primary concern for reducing the nutrient inputs into the lake.

Since the post-war industrialization policy in Japan encouraged heavy industries to locate along the Pacific coast port cities, the inland Lake Biwa region was left free from any significant industrial pollution. Nonetheless, some large industries, such as textile mills and electronic manufacturing firms, found the lake basin area attractive for their water-intensive operations, thus making the control of industrial pollution a top priority in the early years of lake pollution control. The Water Pollution Control Law enacted in 1970, which included stringent punitive provisions for offenders, was an effective policy tool for the regulatory agencies, though the slowing down of the Japanese economy in the mid-1970s also helped reduce the intensity of industrial activities in the region. Today, the industrial pollution loads, in terms of COD, TN, and TP, are 22.4%, 17.4%, and 29.0%, respectively (Fig. 4).

The rapid development in the Lake Biwa basin prior to 1970 resulted in an increased level of eutrophication. Specifically, the loads of TP and TN to the lake became greatly elevated. As a result, the lake suffered a major outbreak of the flagellate, *Uroglena americana* (freshwater red tides), in 1977 in the North Basin, and a bloom of cyanobacteria – *Anabaena* and *Microcystis* – in the South Basin in 1983. These blooms outraged the long-term Shiga residents as they consider Lake Biwa the most valuable spiritual and cultural asset of the prefecture. The citizens of Shiga Prefecture, particularly housewives, organized themselves immediately after the red-tide incident to pursue the movement to "use soap to save the lake", despite initial strong pressure from the detergent industry against the movement. Prompted by the occurrence of freshwater red tides and the consequent citizen outcry, the Shiga Prefecture enacted the Ordinance for the Prevention of Eutrophication in Lake Biwa in 1980. This Ordinance was effective in bringing about a reduction in the level of TP in the lake, particularly in the early 1980s. Figure 5 shows a reduction in TP of more than 10 µg/L in the South Basin after the implementation of the Ordinance and a gradual reduction in the North Basin. This experience has been instrumental in ensuring that the Shiga residents continue to be actively involved in the citizen-initiated activities controlling land-based sources of pollution.

The municipal waste water (waste water from commercial establishments, public buildings, small industries and general households) has been another major source of lake pollution. More than one-third of the TP and more than a quarter of TN and COD loads are attributed to this source of input. Three major categories of sewerage systems, aside from the public sewerage in the City of Otsu that has been operating since the mid-1960s, have been instituted in the Lake Biwa basin (Figs. 6 and 7). They are:

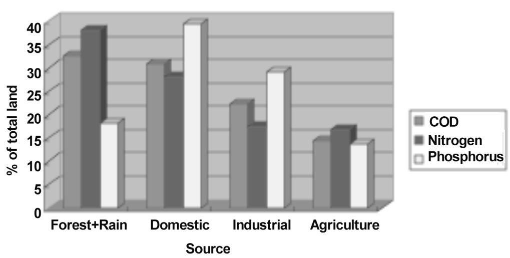

Fig. 4. COD, TN, TP loads by source categories (as in 1999).

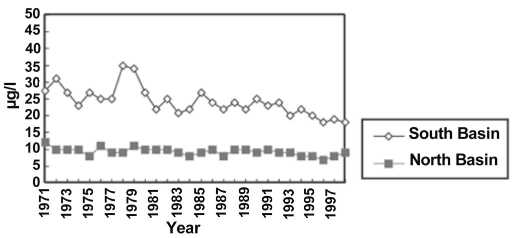

Fig. 5. Gradually decreasing TP concentrations.

the regional public sewerage program, which is catered for by four regional service districts, each with a large centralized treatment plant (57% population coverage as in 1998), the rural sewerage program consisting of some 200 individual community service systems (12.3%), and the on-site treatment technologies servicing individual households not yet served by either of the above two programs (30.8%).

The categories of non-point sources of pollution in the Lake Biwa basin include: (1) precipitation directly onto the lake, and forest run-offs, (2) runoff from rice paddy and other agricultural fields, (3) industrial run-offs, and (4) urban runoffs. The control of runoff from urban and agriculture sources has already been tried at a limited scale. For example, the runoffs

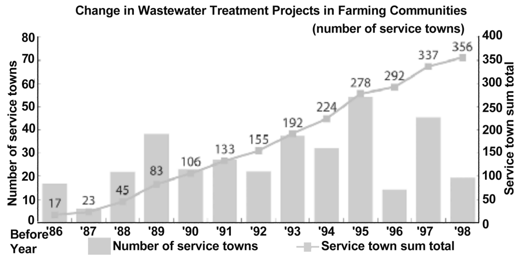

Fig. 7. The trend in number of agricultural community sewerage systems installed.

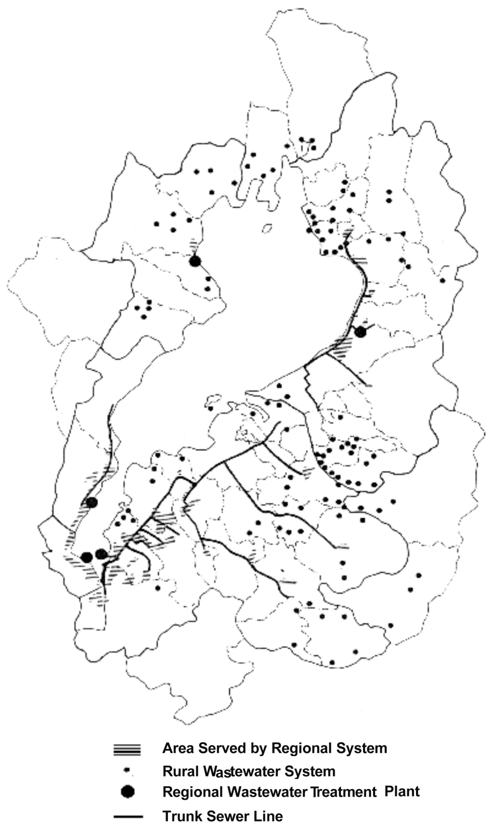

Fig. 6. Wastewater systems in the Lake Biwa watershed.

from rice paddies during periods of low flow or no precipitation are treated using a combination of structural approaches (e.g. use of irrigation water recycling system) and non-structural approaches (promotion of agricultural best management practices (BMPs), which, together with education and information dissemination programs, entail the introduction of management practices proven to be most desirable in terms of reducing wasteful use of water, fertilizer and pesticides). As the water resource and regional development objectives have been met through the LBCDP, the Shiga Prefectural government, together with the central government and downstream governments, is now attempting to conserve the Lake Biwa environment via the control of non-point pollution and the enhancement of ecological integrity.

Change in lake water quality

The quality of the water in Lake Biwa has not improved much over the past few decades. While the concentration of TP has shown slight improvement in recent years (Fig. 5), the COD and TN concentrations have been, if anything, creeping upwards (Figs. 8 and 9). The expansion of economic growth and the increase in population are expected to prevail for some decades ahead; therefore the pollution pressure within the watershed is liable to increase. Thus, the reduction in the influent point-source pollution load will continue to be a priority issue. However, the institutional and managerial measures most suitable for the Lake Biwa non-point sources control have not yet clearly emerged.

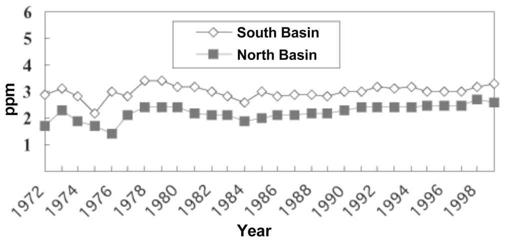

Fig. 8. Steadily increasing COD.

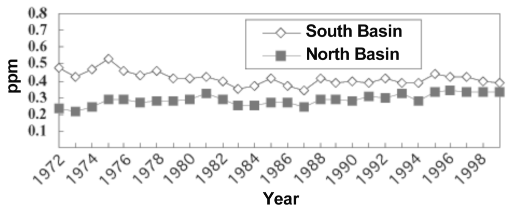

Fig. 9. TN concentrations have shown a slightly decreasing trend since 1996.

Even more troublesome are the precipitation-borne contaminants that result from the densely laid network of highways and urban roads, from the application of chemicals on farmlands, as well as from the long-distance transport of air pollutants from outside the watershed, even from across the East Asian seas. There is an urgent need to accelerate the move towards the development of a sound water and material cycle that would allow greater reliance on the self-purification capacity of the natural ecosystem.

Watershed transformation over the past few decades

Transformation of the littoral zone and aquatic vegetation

The rate of population increase in Shiga Prefecture in the past few decades has been one of the highest in the nation, and the agricultural land has been steadily converted for urban development. In the post-World War II era, much of the littoral area and many attached lagoons, or 'Naiko', around the lake were reclaimed, mainly for increasing paddy fields. The 2900 ha of Naiko area in the early 1940s has been reduced to 425 ha (15%) today. By the time the reclamation projects were legally brought to a halt in 1972, 11 out of 33 attached lakes had been totally or in part reclaimed, resulting in the disappearance of 75.8% of their combined surface area. The coastal area around the lake, however, was developed during the LBCDP era mainly for recreational and commercial purposes. The reed bed area has also been reduced from 260 ha in 1953 to 120 ha in 1990 (Fig. 10). The loss of littoral area (Fig. 11) due to filling and the construction of flood levies and embankments has caused a lowering of the natural purification capacity. The conversion of the littoral zone and the development of the coastal zone have not only led to the disappearance of large areas of aquatic plants in the lake, but have also extensively impacted on fish production and water quality. In fact, many recent changes in the lake biota and the deteriorating water quality conditions may be traced to the conversion of the littoral area and the development of the coastal zone (Kira 1988, Nakanishi & Sekino 1996).

In addition to the changes in the vegetation coverage, the dominant macrophytes have also undergone major shifts. Two introduced species – *Elodea nuttallii* and *Egeria densa* – became dominant. *Elodea nuttallii*, a native in North America, was first found in November 1961 at the Shiozu Bay, which is located at the northern end of the lake. This species was able to outcompete other species of submerged macrophytes using the fragmentation of its shoots to colonize other parts of the littoral zones. The increased level of eutrophication in Lake Biwa may have been the reason for the leveling off in the growth and colonization of this species. The other species, *Egeria densa*, which is a native species of South America, was first found in the lake in 1969 and became dominant in 1974. It has now been found along all shorelines of the lake, including the western shore, constituting about 6% of the total area of submerged macrophytes, with a biomass reaching 410 g/m.

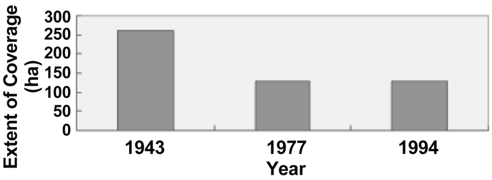

Fig. 10. Drastically reduced area covered by reed bed.

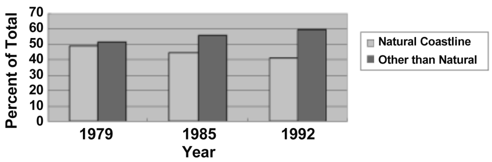

Fig. 11. Transformation of the natural coastline to artificial coastline.

Land use transformation in the Lake Biwa watershed

The coastal land of Lake Biwa has undergone a significant transformation since World War II, as described in the previous section. A dramatic land-use transformation also took place in connection with the implementation of the LBCDP. In addition to the reduction in coastal wetland described earlier, the watershed forestland, including the riparian forests, has also been reduced due to urban encroachment (Fig. 12). The deteriorating quality of management of Japan's manicured forests, due to a dwindling and aging forestry labor force, makes the situation worse. Furthermore, the prefecture's farmland decreased by 21.4%, from 72,687 ha to 57,146 ha, between 1975 and 1998 (Fig. 13), because of conversions to housing areas (42.7%), industrial estates (12.3%), designated farm roads (9.8%), or roads and railroads (9.4%). The rice fields that cover 92% of the prefecture's farmland have also been extensively rearranged. Small, irregular plots have been reshaped into large rectangular units to allow the use of heavy planting and harvesting machinery. The traditional gravity-fed channels that were used for both irrigation and drainage have been replaced with separate piped irrigation networks and straight concrete drainage channels. Other causes of land-use transformation due to the LBCDP include, for example, the widening of roads for the construction of large trunk sewers, and the construction of lakeshore parks and embankment-motorway around the lake for recreational and flood control purposes.

These land-use changes have provided material satisfaction and a convenient lifestyle, but they have also led to the destruction of natural environments as well as the physical and psychological alienation of humans from nature.

The change in lake water environments

Impact of the altered precipitation pattern

One of the most critical climatological factors affecting the limnological condition of Lake Biwa is the amount of snow received by the watershed, which is strongly affected by the strength and position of the Siberia High. The water from the melting snow in early spring carries a substantial amount of dissolved oxygen to the bottom of the North Basin, which determines the initial DO concentration each year in the hypolimnion of the lake, prior to the onset of the thermal stratification in May. There has been a clearly decreasing trend in the amount of precipitation (Fig. 14) and snow falling in the Lake Biwa region during the last few decades, leading to a reduction in the supply of oxygen and an increase in the hypolimnic water temperature (Kumagai & Fushimi 1995). The DO concentration in the hypolimnion decreased gradually from the 1960s to the 1980s, but it began to recover unexpectedly in the early 1990s. The apparent oxygen consumption rate began to decrease in the benthic boundary layer, leading again to a decreasing trend in DO concentration. Nonetheless, as Lake Biwa becomes more eutrophic, an increasing amount of organic matter will settle in the hypolimnion, and the DO consumption by organic degradation is expected to increase. The potential impacts from reduced snowfall, as per the effects of global warming, could therefore significantly affect the hypolimnetic environments in Lake Biwa.

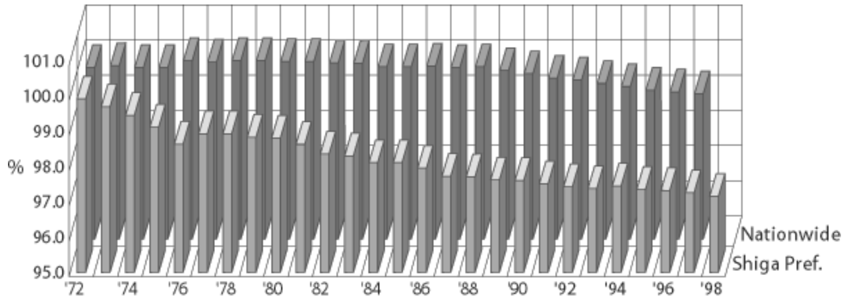

Fig. 12. Rate of forest land conversion: Lake Biwa (Shiga Pref.) vs nationwide average.

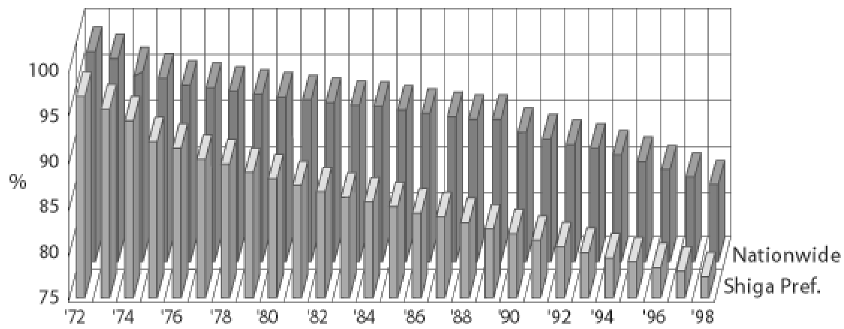

Fig. 13. Rate of agricultural land conversion: Lake Biwa (Shiga Pref.) vs nationwide average.

Change in fish population

Lake Biwa has more than 60 fish species and 40 shellfish species. The total production of fish in the 1990s has been stable, at a level of slightly more than 4000 tons/year, but the fish yield has been decreasing consistently and the species harvested from Lake Biwa also differ greatly from year to year. The fish yield from species such as the only salmon species in Lake Biwa, *Oncohynchus rhodurus*, a crucian carp, *Carassius auratus* and a goby, *Chaenogobius isaza,* has been drastically reduced in the last 10 years, though with a dramatic increase in 1996 for unknown reasons, while the yield of ayu, *Plecoglossus altivelis*, a major source of income for the fishermen in the Lake Biwa area, has been increasing since 1974 and now represents up to 60% of the total fish harvest from the lake.

The decreasing fish population in Lake Biwa may be primarily due to habitat alterations, a reduction in suitable spawning sites, over-fishing, and insufficient prey. Nakanishi & Sekino (1996) indicated that the reductions in the *Carassius carrassius grandoculis* and *Chanenogobius isaza* populations are mainly attributed to the deterioration of the spawning sites, as a result of the development of the littoral zone and coastal area of the lake, which extensively altered the littoral environments. Also, the introduced fish species, i.e. large-mouth bass (*Micropterus salmoidea salmoides*) and bluegill sunfish (*Lepomis macrochirus*), are driving these indigenous species into collapse or extinction. The reduction in the population of the salmon, *Oncohynchus rhodurus*, could be due to the increased levels of eutrophication and the construction of dams and weirs on streams, which prevent the salmon from spawning in the river upstream. Commercially important shellfish species, including *Corbicula sandai*, are now maintained through artificial stocking.

Incidents of mass die-off of ayu in Lake Biwa

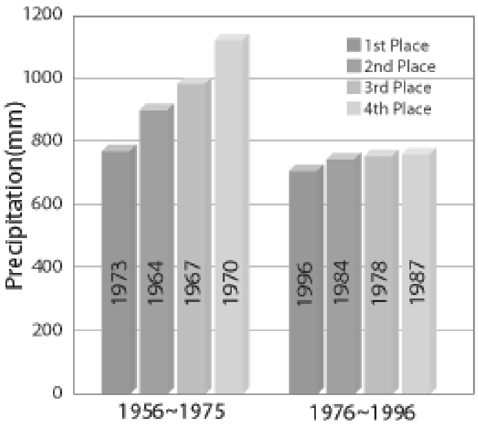

Fig. 14. Lowest precipitation records in the Lake Biwa–Yodo River region.

have been seen occasionally since 1983. According to the studies conducted by the Shiga Prefectural Fisheries Station (Satoi 1995), Vibriosis, or infection by *Vibrioanguillarum (A)* was identified as a major cause. The estimated scale of fish die-off and the percentage of fish infected during these incidents were estimated at 300 million fish and 98% of fish sampled in 1983, 400 million and 88% in 1989, 160 million and 93% in 1990, 100 million and 90% in 1992, 70 million and 87% in 1993, and 6 million and 100% in 1994. Some of the more recent die-off incidents, however, have been found to be due to infection by *Favobacterium psychrophilim*.

Change in phytoplankton species

Lake Biwa has more than 90 species of algae, including 12 species of Cyanophyceae, 41 of Chlorophyceae, 6 of Chrysophyceae, 22 of Bacillariophyceae and 2 Dinophyceae. The seasonal changes in the dominant species since 1965 in the North Basin are as follows: *Melosira solida* (November–April), *Asterionella formosa* (May), and *Staurastrum dorsidentiferum, Closterium aciculare* and/or *Pediastrum biwae* (June–October). In some years, *Staurastrum dorsidentiferum* and *Closterium aciculare* are occasionally abundant between October and January. The increase of these species is often associated with the decrease of *Melosira solida*. The yearly pattern of seasonal changes in the South Basin is more variable. The dominant species include *Pediastrum biwae, Staurastrum dorsidentiferum, Closterium aciculare* and *Melosira granulata*.

A major outbreak of the flagellate, *Uroglena americana*, was noted in 1977 in the North Basin. This bloom gave the lake a reddish-brown color and foul smell, and was referred to locally as ‘freshwater red tide’. Such blooms have been seen each year since 1977, with the exception of 1986 (Fig. 15). This red tide phenomenon usually appears at the end of April and the beginning of June each year, when the water temperature reaches somewhere between 15 and 20 °C. The occurrence of the red tide was the beginning of a major change in the species composition of phytoplankton in Lake Biwa.

In September 1983, the cyanobacteria, *Anabaena* and *Microcystis*, became dominant in a bloom condition. Since then the blooms have occurred every year, except 1984 (Fig. 15). However, it is now found more frequently along the eastern shore of the South Basin. The *Microcystis* bloom was found for the first time in the North Basin in late summer 1994, the record drought year for Lake Biwa and for most of the western part of Japan.

Dramatic declines in an endemic diatom species, *Melosira solida* (Fig. 16), and an endemic green alga *Pediastrum biwae*, have been reported (Nakanishi & Sekino 1996), and this phenomenon is suspected to be due to a sudden propagation of algal picoplankton consisting

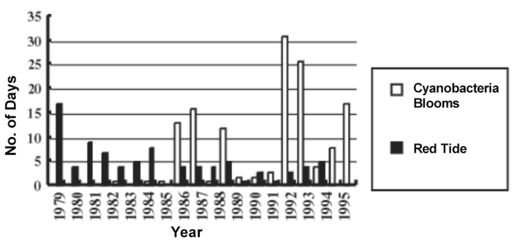

Fig. 15. The incidences of cyanobacteria blooms have surpassed those of red tide.

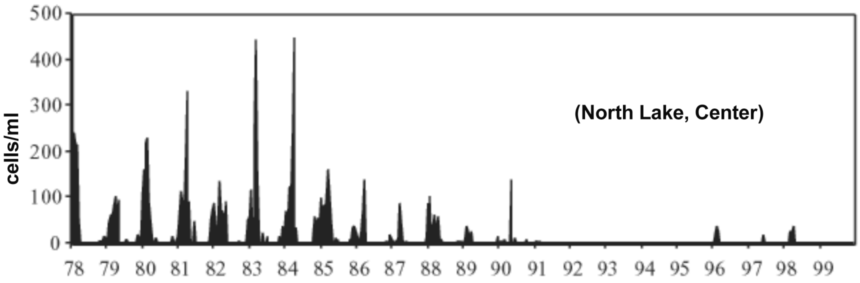

Fig. 16. Dramatic decline in the density of *Melosira solida* (data provided by S. Ichise 2001, personal communication).

mainly of *Synechococcus* spp. The sighting of large-scale *Synechococcus* blooms was first reported for the North Basin during 1989–1991. This group of cyanobacteria are prokaryotic (0.4–1.5 µm) rod-shaped organisms with cell numbers reaching a maximum of 10^6 cells/mL, and the build-up of the bloom is due to the fast growth of the species; it is later destroyed by heterotrophic nanoflagellates and bacteriolysis by cyanophages (Maeda 1993).

While the long-term trend of phytoplankton in the North Basin of Lake Biwa has been more or less constant in terms of chlorophyll *a*, there has been a clear trend of increasing numbers of total phytoplankton cell counts since 1995, as shown in Fig. 17. Furthermore, there has also been a marked change in the species composition and the dominant species, and a rather alarming trend of increase in the frequency of cyanobacterial blooms and the associated increase in their cell count and total biomass (S. Ichise 2001, personal communication).

Changes in the zooplankton dynamics

In an earlier report (Nakanishi 1984), 7 species of Copepoda, 18 of Cladocera, 80 of Rotifera and 14 of Protozoa were reported for Lake Biwa, but the identified number of species has now grown to over 200 (S. Ichise 2001, personal communication). The frequently occurring species in the North Basin include the copepods, *Mesocyclops leuckarti, Cyclops vicinus,* the cyclopoids, *Mesocyclops* and *Cyclops,* and the cladoceras, *Daphnia biwaensis, Daphnia longispina* and *Bosmina longirostris*, and the rotifers, *Eodiaptomus japonicus*, a dominant and endemic species found in lakes and ponds in southern Japan, and *Kellicottia longispina*. The

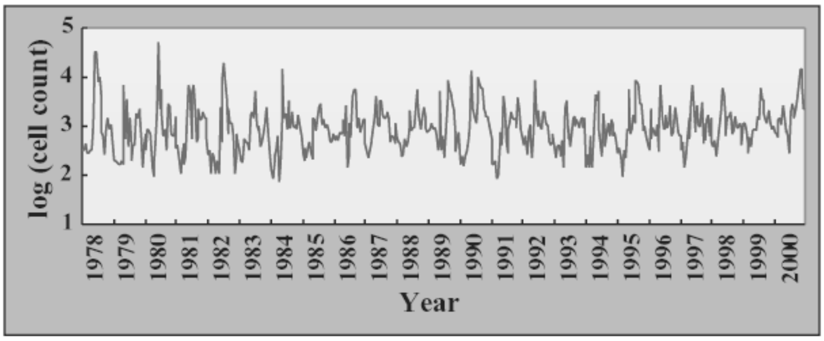

Fig. 17. Change in the total number of phytoplankton species (data provided by S. Ichise 2001, personal communication).

most common species in the South Basin are crustaceans, *Bosminopsis deitersi* and *Chydorus sphaericus*, and the rotifers, *Synchaeta stylata, Polyarthra vulgaris* and *Keratella cochlearis*. Although there are reports of long-term trend data and episodic observations made on Lake Biwa zooplankton in the past, the overall extent of change in the food-chain dynamics involving autotrophic algae and heterotrophic planktonic organisms in Lake Biwa is still not very clear. Recent studies on the subject, such as that reported by URABE et al. (1996), are expected to shed some light on this important subject.

In the pelagic systems, zooplankton play various roles in community organization and material flow, which are coupled with each other, although not perfectly. One study (URABE et al. 1995) indicated that zooplankton grazing in Lake Biwa is a major loss process in the elimination of seston from the epilimnion from summer to fall. This indicates that the zooplankton consumption can promote phosphorus (P) limitation for phytoplankton by fixing a large fraction of the P in the system into their mass, and by recycling a substantial amount of the N to a dissolved form.

The preferred prey of ayu (*Plecoglossus altivelis*), a commercially valued freshwater fish in Lake Biwa, is *Daphnia galeata*, which is also an efficient predator preying on phytoplankton species. The recent report indicated that the selective feeding by ayu fish on *Daphnia galeata* may result in a predatory effect, in which the phytoplankton population increases in summer in the epilimnion as a result of the reduced numbers of *Daphnia* (ANONYMOUS 1997). Since ayu is an important commercial fish, the increase in the ayu population in the lake, and its selective feeding, will greatly impact the zooplankton community in the North Basin and can cause a significant increase in phytoplankton biomass.

Changing benthic conditions

Lake Biwa has 152 identified benthic animal species including insect larvae, mollusks, tubificids and chironomids. The first two are found in large numbers in Lake Biwa while the latter two are generally small in number. Crustaceans and insect larvae are bottom inhabitants and are a major part of the epifauna. Shrimps and prawns are mostly found in areas with submerged aquatic plants. Since the shallow littoral zone of Lake Biwa is composed of several different substrates and provides a variety of habitats to benthic animals, insect larvae and rudineans dominate in this zone. The substratum in the profundal region is uniform with no substantial growth of aquatic plants, and species such as oligochaetes are found in large numbers (58%) in this region (OHTAKA & NISHINO 1995).

There are 44 species of mollusks in Lake Biwa. Of these species, Asian clam, *Corbicula sandai*, is the most important species in terms of economic value in Lake Biwa. The young *Corbicula* prefers the sandy substrates and primarily lives at depths of between 2 and 8 m. The adults feed on sandy or sandy mud substrates up to depths of 40 m (HARADA & NISHINO 1995). This species is endemic and is widely distributed in the lake. Habitat alterations, increased eutrophication, and over-fishing of this species have resulted in a major reduction in its yield. The catch of the species has plummeted from a peak of 4225 tons/year in 1969 to less than 400 tons/year in early 1990s, but it recovered to 1319 tons/year in 1995 (TAKAHASHI et al. 1999).

Indications of rather drastic changes in the distribution and densities of benthic animals taking place over the past few decades in the profundal bottom of Lake Biwa have been reported (e.g. NISHINO & HARADA 2001). The total disappearance of an endemic leech, *Ancyrobdella biwae*, first found in 1915 at a depth of 80 m in the North Lake, is a well-established fact among Lake Biwa scientists. On the other hand, the recent discovery (in 1992) (NISHINO et al. 1998) of a dense mat of sulfur-oxidizing and sheath-forming filamentous bacteria, *Thioploca* spp., was a surprise as it was only the fourth reported sighting in the world of such a dense mat in lakes. The sighting is consistent with observation on the increasing accumulation of organic matter due to eutrophication, together with the decreasing concentration of DO, due to the afore-mentioned decrease in winter precipitation.

The Lake Biwa comprehensive conservation plan

The efforts to develop a conservation plan for the lake ecosystem began in 1995. The original idea of the Prefectural government was to solicit the central and downstream governments to maintain the LBCDP framework for another 10 years or so, in order to be able to continue investing in environmental conservation projects. Neither the central government nor the downstream governments were willing to go along with such an idea, because it was not clear how much restoration of ecological integrity and how much improvement of the lake water quality were to be considered adequate, or how much more cost they would be expected to bear in the implementation of what later turned out to be the LBCCP (Fig. 18).

After 4 years of preparatory studies and deliberations by the officially commissioned expert panel, a plan has been developed for the comprehensive conservation measures of Lake Biwa, which consists of (1) maintaining water quality, (2) improving the recharge capacity of the soil and (3) preserving the natural environment and scenic landscapes, together with the measures needed to promote these activities: participation and practice, exchange and information access, and research. The issues contained in the three primary conservation domains are interrelated in a complex manner. This complexity stems from the wide range of targeted phenomena, as well as the diversity of causal factors and their interactions. It is further compounded by the impacts of the lifestyles of the people who enjoy Lake Biwa. The first order of business stipulated in the plan was for all those with a stake in the lake to develop a multi-tiered collaboration between various entities. The prefectural government will continuously evaluate the results of this activity to ensure its constant improvement.

The plan will run for 22 years, from April 1999 to March 2020, and will comprise two stages, the first lasting from 1999 to 2010, and the second covering the decade from 2010 to 2020. By the end of 2020, the plan aims to

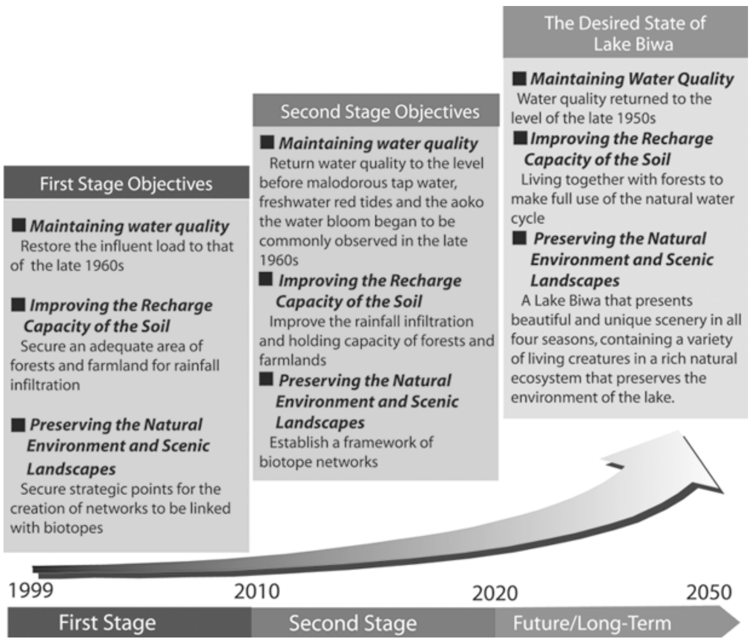

Fig. 18. A general conceptual sketch of the LBCCP.

have the lake in a suitable condition to leave to future generations, and the achievement of the 50-year long-term vision (ca. 2050) will be well under way. By concentrating on continuously updating existing measures and implementing them in a consistent manner, in the 12-year first stage, the plan aims to (1) seek to coordinate different policy measures, and (2) carry out continuous surveying and monitoring while new policies and measures are formulated. Applying the knowledge and experience thus amassed, in the second stage, the plan aims to (3) further promote conservation measures while shifting the focus toward more forward-looking activities.

Because progress will only be evident in the long-term, and the future developments are difficult to predict, the plan must be flexible. In many senses, the best results produced by various measures in the earlier stages have to be incorporated into the plan and its execution in later stages. New technologies and other pertinent developments will also have to be properly accommodated.

Summary and conclusion

The Lake Biwa watershed has undergone tremendous transformation in the past few decades from what used to be an agricultural and rural region conducive to the survival of the lake and its surrounding environment to what is now a rapidly urbanizing and industrializing region attracting populations and industries from across the western part of Japan, particularly from the Osaka, Kyoto and Kobe areas. This transformation took place mostly over the past few decades, during which the Lake Biwa Comprehensive Development Project (LBCDP) was implemented. As this was a mega-scale regional project aimed at achieving water resource control, flood control, environmental conservation and economic infrastructure development, LBCDP implementation was accompanied by large-scale land-use changes, a loss of coastal wetlands, the introduction of highly mechanized irrigation systems over the vast paddy fields, and the loss of soil recharge capacity in the surrounding forests, each of which is likely to result in significant impacts on the integrity of the lake–watershed system. Despite enormous efforts made by the national and prefectural governments to control the pollution, particularly through the implementation of regional wastewater systems, the deteriorating trend of lake environments has not yet been reversed.

This large-scale transformation of the watershed is likely to continue for decades. Having realized the serious future implications of the resulting alteration of the lake ecosystem characteristics, the prefectural government, together with downstream and national governments, developed a comprehensive plan (the LBCCP) for the conservation of the lake environments over the next 50 years (ca 2050), with implementation, in the next two decades, of measures proven successful so far, as well as new measures for exploratory purposes. The proposed plan is expected to evolve over years of trial and error, and thus the role of science and scientific approach in lake management will become even more crucial for bringing the plan to success.

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