Journal of Oceanography, Vol. 62, pp. 551 to 558, 2006

Ecosystem Shift Resulting from Loss of Eelgrass and Other Submerged Aquatic Vegetation in Two Estuarine Lagoons, Lake Nakaumi and Lake Shinji, Japan

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(Received 11 October 2005; in revised form 10 February 2006; accepted 12 April 2006)

***Zostera marina* L. was intensively harvested until the early 1950s in Lake Nakaumi, a eutrophic estuarine lagoon. We have estimated the amount of nitrogen (N) and phosphorus (P) removed from the lagoon through *Z. marina* harvesting. Lake Nakaumi lies in Tottori and Shimane prefectures, and the annual harvest of *Z. marina* in the late 1940s in Tottori was recorded as at least 56,250 t wet weight. The nutrient content of 56,250 t of *Z. marina* was calculated to be 61.9 t of N and 12.9 t of P, which is equivalent to 5.3% and 11%, respectively, of present annual nutrient loads to the lake. The nutrients formerly used by *Z. marina* were likely used by phytoplankton after the *Z. marina* started to decline in the mid-1950s at Lake Nakaumi. This shift in the chief primary producer, from benthic macrophytes to phytoplankton, caused a subsequent shift in secondary producers. Benthic fish and crustacean populations decreased and the non-commercial filter-feeding bivalve, *Musculus senhausia*, increased in Lake Nakaumi after the decline of seagrass beds. This affected the local economy, inducing not only eutrophication but also the collapse of local fisheries. On the other hand, at adjacent Lake Shinji, loss of submerged aquatic vegetation induced an increase of the commercial filter-feeding bivalve, *Corbicula japonica*, which doubled the fishery yield in the lake.**

Keywords:
· Eelgrass harvesting,
· *Zostera marina*,
· 2,4-D,
· seagrass,
· SAV,
· *Musculista senhausia*,
· *Corbicula japonica*.

1. Introduction

Submerged aquatic vegetation (SAV) includes both marine and freshwater rooted vegetation that grows underwater in shallow zones where light penetrates. SAV improves water quality by filtering nutrients and contaminants from the water, stabilizing sediments, and damping wave action. It also provides food and shelter for waterfowl, fish, and shellfish (Kemp *et al*., 2004).

Both natural and human-induced disturbances have decreased SAV populations. All SAV species in Chesapeake Bay, USA, declined dramatically in the late 1960s and 1970s (Orth and Moore, 1983), the decline being correlated with increasing nutrient and sediment inputs from development of the surrounding watershed (Kemp *et al*., 1983). The most severe naturally occurring change affecting seagrasses occurred in the 1930s, when almost the entire North Atlantic population of eelgrass (*Zostera marina* L.) was destroyed by a wasting disease (Rasmussen, 1977).

In Japan, *Z. marina* beds began to diminish around 1950 (Aioi *et al*., 2001). Quantitative data regarding the timing, causes, and extent of the loss of eelgrass beds have not been recorded for all of Japan. *Z. marina* was commonly used as a green mulch and fertilizer in Japan until the 1950s (Aioi, 2004). Before the decline of the beds, harvesting of *Z. marina* probably protected these habitats from eutrophication because it removed the nitrogen (N) and phosphorus (P) contained in the

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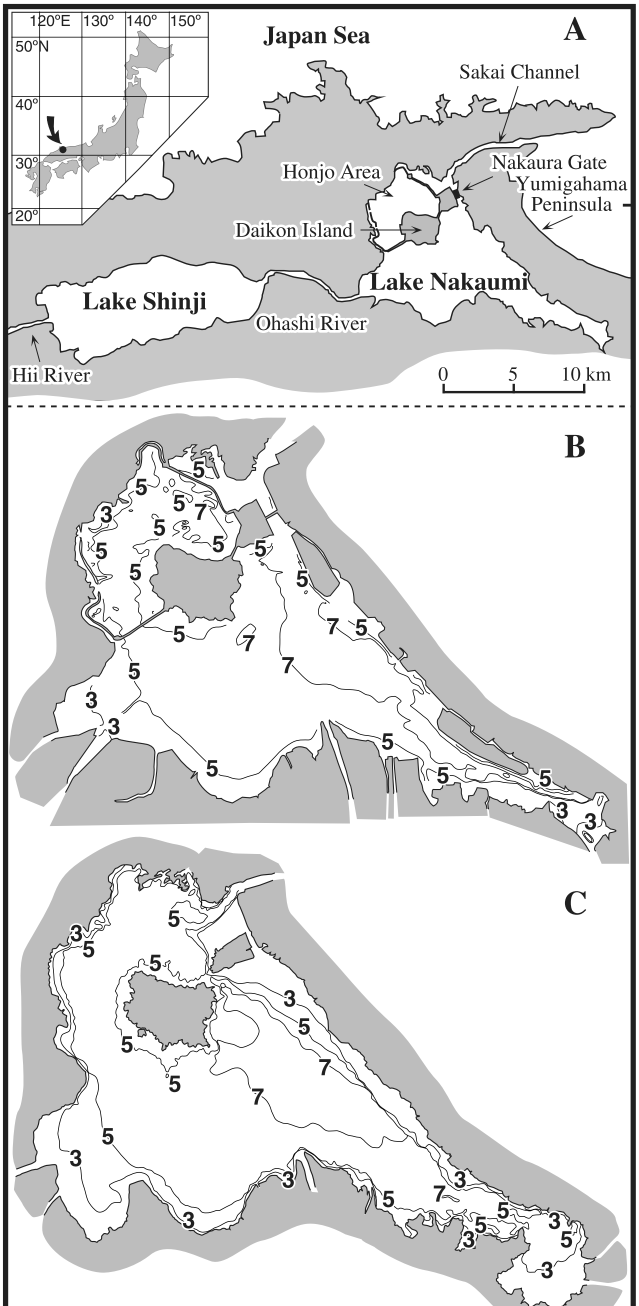

Fig. 1. A: Lake Nakaumi and the surrounding area at present. B: Bathymetry (m) and morphology of Lake Nakaumi in 1994. C: Bathymetry (m) and morphology of Lake Nakaumi in 1954.

Z. marina biomass from the marine ecosystem. Disappearance of the eelgrass beds resulted in a loss not only of nutrient control, but also of habitat and epiphytic food sources for those creatures that used the *Z. marina* beds (which possibly included commercial fish and shellfish). Thus, the loss of eelgrass beds should have caused economic losses associated with ecosystem degradation (Kahn and Kemp, 1985).

Eelgrass beds previously extended all along the shallow shoreline of Lake Nakaumi in southwestern Japan. The eelgrass was formerly harvested as fertilizer, but no *Z. marina* currently survives in Lake Nakaumi. If details regarding the eelgrass harvest are clarified, including the amount harvested annually, it may be possible to quantitatively evaluate the impact of the loss of eelgrass beds on water quality, habitat opportunity for animals, and human economics in Lake Nakaumi and its adjacent area. We studied the issue from the perspectives of natural science (including chemical analyses) as well as social science (we conducted interviews and collected statistics and historical documents). Lake Shinji, an adjacent oligohaline lagoon, has also been studied for comparison.

2. Materials and Methods

2.1 Study area

Lake Nakaumi (area 92.1 km^2, mean depth 5.4 m) and Lake Shinji (area 81.8 km^2, mean depth 4.5 m) are eutrophic coastal lagoons (Fig. 1A). Lake Nakaumi lies in both Tottori and Shimane Prefectures (the Yumigahama Peninsula is in Tottori Prefecture and the rest of the shoreline lies in Shimane Prefecture). Lake Shinji lies entirely in Shimane Prefecture. Seawater enters Lake Nakaumi through the Sakai Channel and the Nakaura gate, while oligohaline water from Lake Shinji is supplied by the Ohashi River. The combination makes Lake Nakaumi polyhaline. More than 70% of freshwater entering Lake Shinji is discharged by the Hii River. The average concentrations of nitrogen (N) and phosphorous (P) in the surface water of Lake Nakaumi are 444 and 44 μg L^{-1}, respectively; levels at Lake Shinji are 442 (TN) and 45 μg L^{-1} (TP) (Goto *et al.*, 2004). These amounts exceed the legal limits, which are 400 (TN) and 30 μg L^{-1} (TP) (Law Concerning Special Measures for Preservation of Lake Water Quality, Ministry of the Environment). Prefectures are responsible for lowering the TN and TP levels. The average chlorophyll *a* concentration in the surface water is 13.0 μg L^{-1} at Lake Nakaumi and 16.8 μg L^{-1} at Lake Shinji (Goto *et al.*, 2004). Monthly environmental monitoring of the lakes began in 1976 for chemical parameters (i.e., dissolved oxygen and nutrients) and in 1981 for phytoplankton and zooplankton.

2.2 Historical observations of eelgrass harvesting and the lake environment

We interviewed local inhabitants around Lake Nakaumi, who are now in their 70s and 80s. Ten lived in Shimane Prefecture and five in Tottori Prefecture. They had all harvested *Z. marina* for use as fertilizer. We asked about the duration, place, method, and amount of the harvest, the species of plant harvested, and the price at which it was sold. We asked about the equipment and boats used for the harvest, as well as how the harvested *Z. marina* was processed. We also asked when and why the *Z. marina* bed disappeared from Lake Nakaumi. Historical documents and statistics describing seagrass harvesting and previous water quality were collected at several city and prefectural libraries. In addition, we interviewed six elderly inhabitants around Lake Shinji to confirm whether the ecological changes observed in Lake Nakaumi had also occurred in the adjacent lagoon.

2.3 Chemical analysis of eelgrass

Because there is no *Z. marina* in Lake Nakaumi today, eelgrass was sampled at Akkeshi Bay (ca. lat 43°N, long 145°E) in Hokkaido, Japan, in August 2002 and analyzed for its nutrient content. The eelgrass sample was pulled up from where it grew (in water about 1.5 m deep) by people in a boat, in the same way as it had once been harvested. The sampled eelgrass was stored in a plastic bag with ice and delivered to the laboratory three days after the sampling. The *Z. marina* sample, including sediment, detritus, and epiphytic organisms, was weighed to determine total wet weight (ww). It was sorted, separating vital leaves, decaying leaves, and underground parts (roots and rhizomes). All parts were cleaned with a toothbrush and weighed again, both before and after oven drying (at 50°C), and homogenized separately.

The N content of *Z. marina* was determined with an elemental analyzer (model MT-5, Yanagimoto, Kyoto, Japan) by the method of Yamamuro and Kayanne (1995), and total P was determined colorimetrically with a Technicon Auto-Analyzer (Model AACS-II, BRAN+LUEBBE, Tokyo, Japan) after digestion, using the method described by Ohtsuki (1982).

3. Results

3.1 Aquatic macrophytes use at Lake Nakaumi and Lake Shinji

According to our informants, the collectors of aquatic macrophytes in Lake Nakaumi were usually farmers, rather than fishermen, who harvested aquatic macrophytes to use on their own fields. However, a few professionals also harvested aquatic macrophytes. Such specialists owned larger boats with engines, and they harvested aquatic macrophytes not only at Lake Nakaumi but also along the coast of the Sea of Japan.

All the aquatic macrophytes that grew in Lake Nakaumi were harvested for fertilizer, but two species were dominant: eelgrass, *Z. marina*, which grew on soft bottoms at depths of around 3 m; and the brown alga

Fig. 2. Harvesting *Zostera marina* with a rake especially designed for seagrass. Photo from Sakaiminato City (1986).

Sargassum thunbergii (Mertens) O. Kuntze, which grew on rocky bottoms. The area of Lake Nakaumi shallower than 3 m, as measured by planimeter on a map published in 1954 (Fig. 1C), was 2012 ha. About 20% of that was rocky bottom, supporting *S. thunbergii*, meaning that the *Z. marina* bed at Lake Nakaumi in the early 1950s covered about 1600 ha.

The *S. thunbergii* harvest was less than one-sixth that of *Z. marina* (Sakamoto, 1962), but this species was regarded as higher quality than *Z. marina* for use as fertilizer. Macrophytes with attached Asian mussels (e.g., *Musculista senhausia* (Benson)), were also regarded as fertilizer of higher quality.

Because the tidal range in this area is less than 30 cm, *Z. marina* was always submerged. A specially designed rake was used as a dredge to harvest the seagrass from a wooden boat (Fig. 2). Although seagrass beds act as a nursery for some commercial fish, local fishermen did not oppose *Z. marina* harvesting. There are several probable reasons: fishermen liked to collect the edible red algae, *Gracilaria verrucosa* (Hudson) Papenfuss, which grew on the sandy bottoms created by the harvesting of *Z. marina*; in addition, *Z. marina* caused problems for fishermen where it grew adjacent to their boat slips. The Japanese cockle, *Scapharca subcrenata* (Lischke), was a chief target for fishermen, but was collected in waters deeper than the *Z. marina* bed.

At Lake Nakaumi, *Z. marina* was harvested year-round, but it was easier to harvest in summer, when it flowered and could be easily pulled out from the bottom. *S. thunbergii* was harvested only in spring and early summer.

Aquatic macrophytes were sold commercially by wet weight, especially along the eastern shore of Lake

Table 1. Measured weight and nutrient content of *Zostera marina* samples, and estimated total quantity of nitrogen and phosphorous removed annually from Lake Nakaumi through eelgrass harvesting in the late 1940s.

Parts	Portion (w/w %)	Dry/Wet (w/w %)	Nitrogen (w/w %)	Phosphorus (w/w %)	Removed N (t)	Removed P (t)
Vital leaf	57.8	8.1	1.85	0.353	48.6	9.3
Decaying leaf	7.0	6.2	1.15	0.150	2.8	0.4
Root and rhizome	19.9	13.3	0.70	0.219	10.4	3.3
Attached materials	15.2	—	—	—	—	—
Total					61.9	12.9

Nakaumi (the Yumigahama Peninsula), where the farmers specialized in growing cotton. Our informants said that cotton requires more potassium than other crops, and *Z. marina* was considered a superior fertilizer for cotton because it contains more potassium than terrestrial plants. Aquatic macrophytes were also used as fertilizer for taro, potato, sweet potato, vegetables, and mulberry (for silkworm culture). On a nutrient basis, aquatic macrophytes were sold for only about 6% of the price of dried fish, which was also used as fertilizer. Therefore, cotton could be produced at far less cost where aquatic macrophytes were available for fertilizer than in areas where they were not.

The harvesting of aquatic macrophytes at Lake Nakaumi began to decline in the mid-1950s. At that time, farmers on the Yumigahama Peninsula gradually began to change from growing cotton to tobacco, which has a low salt tolerance. Chemical fertilizers with potassium also came into common use about the same time. The decline of the *Z. marina* bed also began in the mid-1950s. Subsequently, the *S. thunbergii* and *G. verrucosa* biomass also decreased, because they no longer grew in the deeper waters but only in the shallower waters along the shore. Most aquatic macrophytes had disappeared by the end of the 1960s. The remaining shallow beds were finally destroyed by land filling and reclamation projects begun in 1968. Why aquatic macrophytes originally began to decline in the mid-1950s is still unknown. Our informants said that it coincided with the beginning of the extensive use of herbicides in the area.

The use of SAV as fertilizer was not common around Lake Shinji. Our informants who knew the SAV in Lake Shinji were therefore all fishermen. Two of the six informants said that they used to harvest SAV in Lake Shinji for their own use as fertilizer. At present, one fisherman mainly targets fish and the five others target the Asiatic clam, *Corbicula japonica* Prime. This clam is presently the dominant macrobenthic fauna in Lake Shinji, accounting for 97% of the wet weight of all macrobenthos, including those without shells (Nakamura *et al.*, 1988). However, all informants said that *C. japonica* was not as abundant before the mid-1950s, because the shallow bottom now inhabited by *C. japonica* was covered with SAV. The SAV started to decline around the beginning of the 1950s and had completely disappeared by 1960. Five of the six Lake Shinji informants believed that the use of herbicides was the cause of the SAV die-off.

3.2 Nutrient removal through Zostera marina harvesting in Lake Nakaumi

The wet weight of the *Z. marina* sampled at Akkeshi Bay, including sediment, detritus, and epiphytic organisms, was 956.2 g. After cleaning, the wet weights of vital leaves, decaying leaves, and underground parts (roots and rhizomes) were 552.6, 67.4, and 190.7 g, respectively (a loss of 145.5 g). The loss was attributed to the attached materials, and not to the *Z. marina* itself (Table 1). The wet/dry weights (dw) varied from 6.2% to 13.3%, depending on the part of the plant being weighed. N and P concentration also varied considerably (Table 1). Therefore, we estimated the N and P content in the harvested *Z. marina* by plant part.

In Tottori Prefecture, the mean annual harvest of aquatic macrophytes from Lake Nakaumi in 1948 and 1949 was estimated by the local fisheries station as at least 56,250 t ww, most of which was *Z. marina* (Sokuri, 1955). Based on our analytical results, the amount of N and P annually removed through the harvesting of *Z. marina* from the lake in Tottori Prefecture was 61.9 t and 12.9 t, respectively (Table 1).

Annual production of the aboveground portion of *Z. marina* (i.e., the leaves) at Otsuchi Bay, northeastern Honshu, was estimated to be 1100–2400 g m^{-2} dw yr^{-1} (Iizumi, 1996). If comparable productivity rates were typical of the entire 1600-ha *Z. marina* bed in Lake Nakaumi, total annual leaf production would be 17,600–38,400 t yr^{-1} (dw). Applying the 8% dw/ww ratio of the leaves (Table 1), 22–48 × 10^4 t yr^{-1} ww of *Z. marina* would have been produced during the early 1950s. Because 42% of annual production in the lake was estimated to have been harvested from Lake Nakaumi each year in early 1960's (Sakamoto, 1962), the annual *Z. marina* harvest of 56,250 t from Tottori Prefecture in the late 1940s, estimated by the local fisheries station, is consistent with these calculations.

Decayed *Z. marina* in Lake Nakaumi sometimes caused objectionable smells in the summer, and local fisheries officers consequently tried to use *Z. marina* as raw material for sandpaper. They harvested 54 t ha^{-1} of *Z. marina* in five days in June and nine days in August 1933 (Shimane Prefectural Fisheries Experimental Station, 1935). If the same rate is applicable to the entire 1600 ha of the former *Z. marina* bed in Lake Nakaumi, 86,400 t could have been harvested in one year. This is circumstantial evidence that *Z. marina* was once abundant enough in Lake Nakaumi for an annual harvest of 56,250 t.

The nutrient content of 56,250 t of *Z. marina* would be 61.9 t of N and 12.9 t of P, while the present annual nutrient load to Lake Nakaumi is 1164 t N and 116 t P (Shimane Prefecture, Report for FY 1998). Therefore, the former *Z. marina* harvest removed an equivalent of 5.3% and 11% of the present N and P loads to Lake Nakaumi. Because we have excluded from consideration nutrients removed by the *Z. marina* harvested from Shimane Prefecture, and because the lake is probably more eutrophic now than it was in the late 1940s, these percentages should be considered minimum estimates.

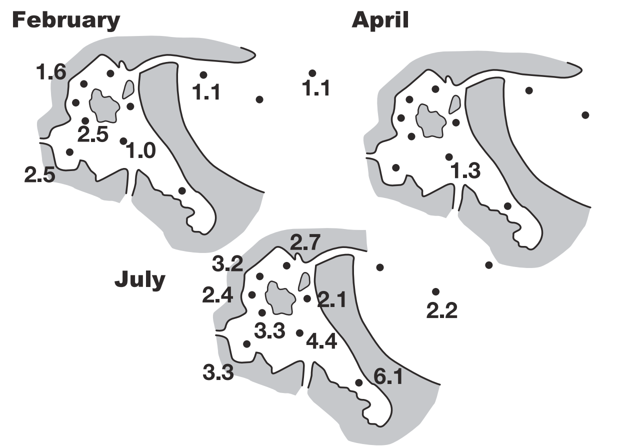

Fig. 3. Chlorophyll *a* concentration (mg L^{-1}) in the surface water of Lake Nakaumi in 1961. Data compiled from Ondoh (1962).

4. Discussion

4.1 Water quality change after eelgrass bed disappearance

Loss of SAV is often attributed to increases in turbidity due to eutrophication (Moore and Wetzel, 2000; Scheffer *et al.*, 2001). The chlorophyll *a* threshold, beyond which SAV is not present, is statistically derived as 15 μg L^{-1} in estuarine environments (Kemp *et al.*, 2004). In Lake Nakaumi, maximum chlorophyll *a* concentration in 1961 (by which time most SAV had disappeared) was 6 μg L^{-1} (Fig. 3), or well below the threshold. Therefore, the decline of the eelgrass bed at Lake Nakaumi was not likely to have been caused by eutrophication. Rather, it is the loss of the eelgrass bed that contributed to the eutrophication (Mitchell, 1989). The annual *Z. marina* harvest in the late 1940s from Tottori Prefecture contained N and P amounts equivalent to 5% and 11% of the present N and P loads, respectively, in all of Lake Nakaumi. The nutrients previously used by *Z. marina* to sustain growth would have been used by phytoplankton instead, thus causing further decline of the *Z. marina* bed by reducing the amount of light reaching the bed.

Aioi (2003) suggested that one of the causes of the nationwide decline of *Z. marina* beds is the widespread use of herbicides in Japan. At present, 14.3 kg ha^{-1}yr^{-1} of herbicides and pesticides are used in Japan, which is 3.2 times the European and 7.2 times the United States' usage (Aioi, 2003). Sixty-seven percent of herbicides and pesticides used in Japan are used on rice paddies, and 35% of that amount is herbicides (Aioi, 2003).

In Japan, herbicides are registered at the Ministry of Agriculture, Forestry and Fisheries; once registered, the herbicides are used widely. Herbicides are used intensively in rice paddies for 30 to 50 days after transplantation of seedlings. Thus, it is during the rainy season, between June and July, that the annual dose of herbicides is sprayed in the rice paddies. During this period, the herbicides drain to rivers and downstream to eelgrass beds.

2,4-Dichlorophenoxyacetic acid (2,4-D), which inhibits the growth of the temperate seagrass, *Posidonia oceanica* (Balestri *et al.*, 1998), and the Eurasian watermilfoil, *Myriophyllum spicatum* (Sprecher *et al.*, 1998), was registered in Japan in 1950 and subsequently used widely. The decline of the *Z. marina* beds in Lake Nakaumi began in the mid-1950s, apparently coinciding with the beginning of the widespread use of herbicides in the area. The Shimane Agricultural Experimental Station (SAES) records showed that 2,4-D may have been used as early as 1950; the first record of the amount of 2,4-D used was 12.99 t in 1957. Because 2,4-D scarcely degrades in soil and water (Chang *et al.*, 1998; Toräng *et al.*, 2003), a significant portion of the 2,4-D spread around Lake Nakaumi may have entered the lake.

4.2 Changes in secondary production after the disappearance of eelgrass beds

In 1961, when the eelgrass bed in Lake Nakaumi was estimated to be only 89 ha (Sakamoto, 1962), total annual production of *Z. marina* and phytoplankton in Lake Nakaumi were estimated to be 640 and 65,700 t yr^{-1} dw, respectively (Sakamoto, 1962). In the early 1950s, the *Z. marina* in Lake Nakaumi may have covered 1600 ha, with an annual production of 17,600–38,400 t yr^{-1} dw. Because phytoplankton production in the early 1950s may have been less than in 1961 (due to competition for nutrients between *Z. marina* and the phytoplankton), primary production by *Z. marina* may have been as significant as phytoplankton in the early 1950s.

The epiphytic zoobenthos abundance in the 89-ha *Z. marina* bed of 1961 was estimated to be 1.5–4.8 t dw, based on counts in sampled quadrats (Kikuchi, 1962), or 3.3 t dw, determined by towing a plankton net over the bed (Sakamoto *et al.*, 1962). At the same time, the abundance of zooplankton in all of Lake Nakaumi was estimated to be 53.4 t (Yamaji, 1962). If the same relative abundance is applied to the former 1600-ha bed, the abundance of zooplankton and epiphytic zoobenthos would have been 53.4 and 27–86 t dw, respectively. These estimates suggest that epiphytic secondary producers were as important as planktonic secondary producers when the *Z. marina* bed covered 1600 ha.

Epiphytic primary production often exceeds seagrass production (Moncreiff *et al.*, 1992; Pollard and Kogure, 1993), and the epiphytic zoobenthos generally does not consume seagrasses but feeds on epiphytes (Jernakoff *et al.*, 1996). The production rate of epiphytes in the former *Z. marina* bed of Lake Nakaumi is not available, but the equivalent abundance of zooplankton and epiphytic zoobenthos indicates a high level of epiphyte production in the *Z. marina* bed. The epiphytic and macrobenthic primary producers would have been important organic producers in Lake Nakaumi before the decline of the *Z. marina* bed.

The zooplankton fauna and the epiphytic zoobenthos of the *Z. marina* bed were distinctively different. The dominant zooplankton taxa were Copepoda, Cladocera, and Ciliata (Yamaji, 1962), whereas the epiphytic zoobenthos was dominated by Isopoda, Amphipoda, and *Neomysis* (Kikuchi, 1962; Sakamoto *et al.*, 1962). Owing to these differences, it is possible to identify the fishes that were dependent on the *Z. marina* bed for their food sources.

The contents of the digestive tracts of fishes from Lake Nakaumi examined during the late 1950s and early 1960s suggest that many of the bottom-dwelling fish depended directly on the epiphytic zoobenthos of the *Z. marina* bed for their food. For example, one rockfish, *Sebastes inermis* Cuvier, ate chiefly Amphipoda and other epiphytic zoobenthos (Harada, 1962). Another rockfish, *Sebastes schlegeli* Hilgendorf, lived in the *Z. marina* bed and ate small epiphytic crustaceans (Harada, 1962). Japanese whiting, *Sillago japonica* Temminck et Schlegel, ate Amphipoda and *Neomysis* (Kawanabe and Asano, 1962).

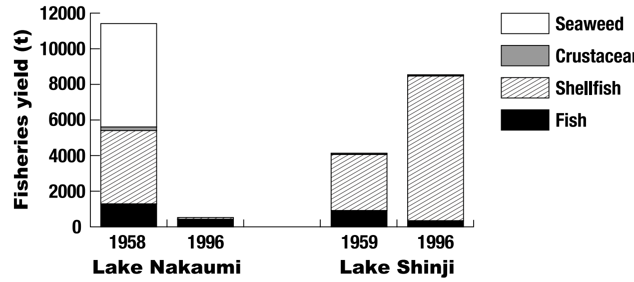

Fig. 4. Changes in the fisheries yield in Lake Nakaumi and Lake Shinji. Fisheries yield in 1959 is from Kawanabe (1962); yield in 1996 is from the website of Shimane Fisheries Station of Inland Water (http://www2.pref.shimane.jp/naisuisi/).

After the eelgrass decline in Lake Nakaumi, the nutrients absorbed by eelgrass were instead consumed by phytoplankton, which thus increased, causing an increase in plankton feeders. The physical absence of eelgrass beds may also cause a decrease in bottom dwellers. Before the loss of the eelgrass beds, shrimp (i.e., *Metapenaeus ensis*), bottom fish (mentioned above), edible seaweed (*Gracilaria verrucosa*), and cockles (*Scapharca subcrenata*) were chief targets of commercial fisheries in Lake Nakaumi. Comparing the fisheries yield in Lake Nakaumi in 1958 and 1996, the seaweed and cockle fisheries were completely destroyed, while the total catch decreased by 50% (Fig. 4).

In contrast, the neighboring oligohaline lake, Lake Shinji, shows an increase in shell fisheries. Due to the difficulty of osmotic regulation in oligohaline water, *Corbicula japonica* (one of the most popular commercial bivalves) is the only bivalve that can stably inhabit the lake. As in Lake Nakaumi, SAV disappeared from Lake Shinji during the mid 1950s. Thereafter, the abundance of *C. japonica* increased, and the number of shellfish fishermen increased accordingly. Because *C. japonica* feeds on phytoplankton, the loss of SAV and increase in phytoplankton may result in an increase in habitat and food for *C. japonica*. It now inhabits the shallow sandy bottom (up to 3 m deep) that is barely reached by anoxic water, with a population of 1000 ind m^{-2} (Nakamura *et al.*, 1988).

A similar event occurred in Lake Nakaumi. Although the number of cockles decreased, *Musculus senhausia*, a fast-growing, opportunistic bivalve, increased and became the most dominant benthos in Lake Nakaumi, with a density of more than 5000 ind m^{-2} (Yamamuro *et al.*, 2000). Because *M. senhausia* is not viewed as a commercial species, fisheries statistics showed a decline in shellfish harvested (Fig. 4). The increase in filter-feeding bivalves is likely linked to the increase in phytoplankton. Since they breed almost year-round (Yamamuro *et al.*, 2000), *M.*

senhausia populations recover quickly at the end of anoxia. We assume that the cockles could not adapt to periodic anoxia, induced by eutrophication after the decline of the seagrass bed.

5. Conclusion

Our results showed that bottom-dwelling fish and crustaceans decreased and opportunistic filter-feeding bivalves increased in Lake Nakaumi during the years between the mid-1950s and present. One of the causes of this faunal change in Lake Nakaumi was probably the change in the primary producers, from benthic macrophytes and epiphytes to planktonic microalgae, in those areas formerly occupied by *Z. marina*. In the early 1950s, the epiphytic zoobenthos of the bed was an important source of food for some bottom-dwelling fishes. Since bottom-dwelling fishes and shrimp usually have high commercial value, the decline of the seagrass beds may have reduced the economic value of this water area, not only in terms of water quality, but also in terms of fisheries productivity.

Specifying the cause of the seagrass decline is indispensable for the restoration of the beds. This study modestly suggests the possibility that not only eutrophication and construction but also herbicides may be the cause of the loss of SAV. Some forms of 2,4-D are still used in Japan. Pentachlorophenol (PCP), which is also used for rice paddies, was registered in 1956. The EC_{50} value for the seagrass *Thalassia testudinum*, after 40 h exposure to PCP, is 0.74 ppm (Walsh *et al*., 1982). Sediments of Lake Shinji accumulated during 1945–1948 contained PCP, and PCP is still detected in the surface sediments (Masunaga *et al*., 2001). Diuron, which affected the growth of *Z. marina* at concentrations greater than 0.5 μg L^{-1} (Chesworth *et al*., 2004), was registered in 1960 in Japan. Okamura *et al*. (2003) measured 142 water samples collected from fishery harbours, marinas, and small ports along the coast of western Japan, and 19 waters showed Diuron concentrations greater than 0.5 μg L^{-1}. If any of these chemicals inhibit the growth of *Z. marina*, their continued use may interfere with the re-establishment of seagrass beds, even if light availability increases due to reduction in nutrient inflow.

Acknowledgements

We thank Dr. Hiroshi Mukai for sampling *Z. marina* at Akkeshi Bay. We also thank Mrs. Shin Chou and Mrs. Sayuri Umeda for their assistance with chemical analysis. This study was financially supported by the National Institute of Advanced Industrial Science and Technology (AIST).

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