Annual Changes of Stands of *Trapa natans* L. in Takahamairi Bay of Lake Kasumigaura, Japan.

Seiichi NOHARA

Abstract

A field survey was made of the annual biomass changes of *Trapa natans* L., a floating-leaved plant, from 1985 to 1986 in a natural stand in Takahamairi Bay of Lake Kasumigaura, Japan. Aerial photographic surveys were done from 1985 to 1990. In addition to the photographs, vegetation maps from 1972 to 1990 were made, based on photographs of 1972, 1976, 1980, 1984. A violent wind during a typhoon in late August 1985 caused a subsequent decrease in the stand of *Trapa natans* whose maximum biomass was 340 g dry weight m⁻² before the typhoon. The stand recovered in 1986 from buried seed and seed generated before the typhoon. Because the plant floats at the end of a long stem, the sudden rise in water level (100 cm) after the typhoon in August 1986 did not cause a subsequent decrease in the stand of *Trapa natans* wherever strong water current were absent. The violence of winds and water currents during the growing period are important factors in determining the survival of *Trapa natans* in Lake Kasumigaura. Due to buried seeds and long stem length, the stands of *Trapa natans* survive in spite of frequent disturbances.

Key words: aquatic plant, wind, *Trapa natans*, water current, water level

1. Introduction

Hydrological factors, wind and waves, alter aquatic vegetation since the plants cannot fix themselves at wavy sites (SCULTHORPE, 1967; HUTCHINSON, 1975). There are many hydrological and geographical studies on Lake Kasumigaura (UTSUNOMIYA, 1979; MURAOKA and FUKUSHIMA, 1981; MIKAMI *et al.*, 1983; FUKUSHIMA, 1984). However, only a few studies have been made on the effect of hydrological and geographical factors on floating-leaved plants (SAKURAI, 1981; NOHARA, 1991).

A floating-leaved plant, *Trapa natans*, is one of the most dominant species in Takahamairi Bay of Lake Kasumigaura (SAKURAI, 1981; TSUCHIYA, 1986). There is still little agreement on species delimitation in *Trapa* (KADONO, 1987; 1988). The present author identified the dominant species in Takahamairi Bay as *T. natans* L. which is distinguished by two spiny fruits.

Many papers have been published on the ecology of *Trapa* spp. (UCHIDA, 1973; MOMOSHIMA and NAKAMURA, 1979; TSUCHIYA and IWAKI, 1979; 1983; 1984; HAYASHI, 1984; IWAKUMA and TSUCHIYA, 1986; TSUCHIYA *et al.*, 1987; KUNII, 1988a; 1988b; ARIMA, 1990; KURIHARA and IKUSIMA, 1992). Only a few studies have been made on seasonal or year-to-year changes of their distribution within a lake (ISHIYAMA *et al.*, 1986). The biomass changes of *Trapa natans* in Takahamairi Bay have been previously reported (TSUCHIYA *et al.*, 1987). The aim of the present study is to reveal the role of water current on the distribution of *Trapa natans* in the lake and to determine the effect of environmental changes on the distribution of *T. natans* in a river mouth. The present paper also discusses the reasons why stands of *Trapa natans* can continue to survive in Lake Kasumigaura.

2. Study site

Lake Kasumigaura, located in the Kanto Plain (35°52'N-36°09'N, 140°13'E-140°38'E), is the second largest lake in Japan (surface area, 171 km²). The maximum and mean depths are 7.3 m and 4.0 m, respectively. This lake has 26 inflows and one outflow (Kitatone River). The stand of *Trapa natans* studied was located on Takahamairi Bay (Fig. 1), the most eutrophic region in the lake with two inflows, the Koise and Sanno Rivers. Annual mean transparency at the study site was 0.63 m from 1978 to 1987 (AIZAKI *et al.*, 1984; 1988).

Fig. 1. 1960 study sites A, B, C, D and contour map of Takahamairi Bay, Lake Kasumigaura. Clear arrows indicate direction of water current. Broken line indicates *Trapa* stand area (Fig. 4.). M: mud; S: sand; MS: muddy sand; MR: mud and rocks.

3. Methods

3-1. Vegetation map

Vertical aerial photographs in 1972, 1976, 1980, 1984, 1988 were supplied by the Geographical Survey Institute (GSI). Oblique aerial photographs of vegetation were taken with real color film and a 35 millimeter camera (Olympus OM4) at an altitude of 300-500 m from 1985 to 1990. Vegetation maps of Takahamairi Bay in 1972, 1976, 1980, 1984 were made using only aerial photography supplied by GSI. After various areas of vegetation in four photographs were compared for color, light intensity and fitness with photographs in 1985, the vegetation areas were divided into four types of emergent plants, *Euryale ferox* SALISB., *Nelumbo nucifera* GAERTN. and *Trapa* spp.. I entered the position of vegetation on these enlarged photographs into a microcomputer using a tablet digitizer. Vegetation maps of the littoral zone from 1972 to 1990 were traced on the positions after projective transformation to the vertical photograph supplied by GSI in December 1988 (NOHARA, 1991).

3-2. Biomass determination

The biomass of *Trapa natans* was determined at the same site used by TSUCHIYA *et al.* (1987) in 1985 (1 m depth, Site A, Fig. 1). The sediment of the site is sandy mud. Plants were harvested in 3-5 quadrats (1×1 m) near the center of the vegetation zone from May to August. After the typhoon in late August 1985, 10-20 plants were harvested at site A and brought to the laboratory to be washed with tap water. The main stem length was measured. The fresh plants were divided by each organ [leaf, stem, seed, root in mud (root) and root in water (water root)] and oven-dried at 85°C for two days to obtain dry weight. For an optional sampling, four plants were harvested at the center of Takahamairi Bay (2 m depth at mud site, site B) and 13 plants at mud site (1 m depth, site C) on 12 and 13 June 1985.

3-3. Seed density

Three seed traps (plastic basket, 74 cm long × 50 cm wide × 26 cm high) were set on the bottom of site A in the vegetation zone on 4

August 1985. Seeds in the traps were collected and counted on 12 November 1985.

Seeds from two locations (1.2 m and 1.5 m depth) near site A were taken with an Ekman Birge grab (30×30 cm) on 4 December 1985. Seed samples in 0.45 m² were collected at three places in each sampling site. The seeds were freeze-dried to obtain dry weight.

Seedlings and seeds from six locations near site A were collected with a Kamiya type dredge sampler (20×40 cm opening, Rigosha Co., Ltd., Tokyo) on 8 May 1986. The accurate towing distances were unknown. The plants were freeze-dried to obtain dry weight.

3-4. Environmental factors

The daily maximum wind velocities near the lake from 1985 to 1986 were obtained by the Lake Kasumigaura Research Station of the National Institute for Environmental Studies at Ohya, 17 km south-southeast of the study

site (Fig. 1). Wind velocity sensors were set on the laboratory roof (23 m high and 150 m distant from the lake shore) and on the lake shore (6 m above water level). The mean water levels of Lake Kasumigaura at Ushibori and of the Koise River at Ishioka were obtained from Ibaraki Prefecture. It was presumed that the water level data of the Koise River and the water current data at the river mouth were correlated. Datum level was showed by Yedogawa Pail (Y. P., 0.0 Y. P. m below mean sea level by 0.8402 m). Three typhoons struck the study site, one in July 1985, another in late August 1985 and a third in early August 1986. Dissolved oxygen (DO) concentrations of the surface and bottom were measured with a DO meter (YSI Model 58) at the same time that biomass was determined in 1985.

Fig. 2. Distribution of main aquatic plants in 1972(A), 1976(B), 1980(C) and 1984(D) in Takahamairi Bay. E: Emergent plants; EU: *Euryale ferox*; NE: *Nelumbo nucifera*; TR: *Trapa* spp. C: shore with concrete protection. Areas surrounded by fine line indicate paddy fields reclaimed in 1925.

4. Results

4-1. Vegetation area

A marked change in aquatic plant vegetation was observed at Takahamairi Bay between 1972 and 1984 (Fig. 2). The vegetation area of

emergent plants tended to decrease gradually. A large stand of *Euryale ferox* SALISB. vanished after 1972. A margin of large stand of *Nelumbo nucifera* GAERTN. spreads very rapidly radially. During expansion of the marginal area, many plants died at the center of the stand.

Fig. 3. Changes in vegetation area of main aquatic plants from 1972 to 1990 (B-O) obtained by aerial photogrammetry.

The central area of dead plants, or the dead center, expanded more rapidly than the marginal expansion in 1980. The stand had disappeared entirely by 1984. *N. nucifera* occurred at shallower locations than those for *Trapa* spp.. Which had completely replaced *N. nucifera* by 1984. *Trapa* spp. were distributed at various locations less than 2 m in depth. Stand areas of *Trapa* spp. in Takahamairi Bay very radically from year to year.

Figure 3 shows the change in vegetation area near the northeast shore (sites A, and D) of Takahamairi Bay from 1972 to 1990. Shore protection works in this location (dashed line area, Fig. 1) were constructed from 1978 to 1980. After the works were completed emergent plants along the eastern shore disappeared. A thick stand of *T. natans* was distributed at the site from depth of 0.5 to 1.8 m. In July 1985, the stand area of the western shore (D, the sediment of mud) decreased. After the typhoon in late August 1985, almost every stand on the eastern shore (A, the sediment of sand) vanished. In 1986, the stand at site A recovered to the size of the area on July 1985. However, the water level rose by 1 m following the typhoon in early August 1986. The stand at site D was washed away again by the water current in early August 1986 (based on observations made on 8 August 1986), but recovered by 1988. The *T. natans* stands at sites A and D decreased in 1989 and 1990.

4-2. Biomass and stand structure

Figure 4A shows the seasonal changes in both biomass and lamina fresh weight per rosette of *T. natans* in 1985. The biomass of *T. natans* in 1985 reached only one peak because the typhoon on 31 August cleared the *T. natans* stand. The maximum biomass was 340 g dry weight m^{-2} on 20 August. The relative growth rate in biomass just after seeding establishment was $0.018 \text{ g dry weight } m^{-2} \text{ day}^{-1}$. The rosette size (lamina fresh weight per rosette, Fig. 4A) rapidly increased in August. The maximum lamina fresh weight per rosette was 38 g on 20 August.

Figure 4B shows the seasonal changes in stem length. The maximum stem length was 3.30 m

Fig. 4. Seasonal changes of biomass and fresh weight of lamina per rosette (A) and stem length (B) of *Trapa natans* stand at site A in 1985. Solid circle indicates mean of biomass at site A. Clear circle indicates mean of lamina fresh weight per rosette. Vertical bar shows SD. Clear square and triangle indicate means of stem length at site B and C, respectively.

plant $^{-1}$ on 20 August. The mean stem elongation rate was 2.6 cm day^{-1} . The maximum stem length was over 2.00 m when the yearly maximum of water depth at the site reached 1.84 m on 1 July 1985. *T. natans* were very rare in the center of Takahamairi Bay (site B). The length of stem at site B exceeded those at the other shallower sites.

4-3. Seed density

Seed number (new seed produced during 1985) in the traps at site A was $64 \pm 53 \text{ m}^{-2}$ (mean $\pm$ SD, $n=3$) on 12 November 1985.

Seed density (new seed plus buried seed) on the bottom (1.2 m depth) at site A obtained using the Ekman Birge grab was $54 \pm 7 \text{ m}^{-2}$ (mean $\pm$ SD, $n=3$) in December 1985. Seed density at a depth of 1.5 m at site A was $3 \pm 4 \text{ m}^{-2}$ (mean $\pm$ SD, $n=3$). The spatial distribution of seed density varied with water depth at each site. This variation was thought to be caused by differences in seed production or to disturbances from the typhoon. Sufficient data is lacking to clearly establish the cause.

The total numbers of buried seed and seed-

ling that were collected by the dredge sampler at six locations in 8th May 1986 were 40 and 74 plant, respectively. About 35% of the seeds did not germinate by 8 May.

5. Discussion

5-1. Effects of environments

There are three main reasons for the change in stand area of *Trapa natans* in Takahamairi Bay: water current during the typhoon; wind velocity during the typhoon; and aggravation (low DO) caused by over growth of *Trapa*.

5-1-1. Effects of water current

Water current is the most important factor for aquatic plants. In 1897, there was one main current line in the middle of the Bay and four branch lines (MIKAMI *et al.*, 1983). In 1925, after paddy fields (surrounded by fine line) in the northwest were reclaimed (Fig. 2), the main current shifted to the north side. The artificial change in water current line changed the topog-

raphy of the river mouth, decreasing lobate delta in the Bay after 1925. Another delta developed from 1947 to 1980 (MIKAMI *et al.*, 1983). A decrease in the vegetation area of emergent plants can be explained by two factors. One is an increase in water depth due to diminished soil supply following the change in water current and a consolidation by draining of soil water (MIKAMI *et al.*, 1983). Another is the heavy movement of water during typhoons. Based on observations in early August 1986, the vegetation of emergent plants was washed out by these powerful water current.

Trapa stands are also washed out easily by strong water currents. The typhoons in July 1985 and early August 1986 caused severe flooding (Fig. 5B) accompanied by powerful water currents at the river mouth (Fig. 5C). The typhoon in late August 1985 caused no flooding or strong water currents but brought a high wind velocity. A *Trapa* stand (site D, the west

Fig. 5. Seasonal changes in daily maximum wind velocity at Ohya (A), dissolved oxygen (DO) concentration at site A (A), daily water level in Lake Kasumigaura at Ushibori (B), daily water level in Koise River at Ishioka (C) 1985-1986. Solid circle indicates daily maximum wind velocity over $10 \text{ m} \cdot \text{sec}^{-1}$. Clear circle in DO panel indicates value at surface (clear circle over vertical line) and bottom (clear circle under vertical line).

shore) near the river mouth was distributed in June 1985 and July 1986 (based on my observations). The stand was repeatedly washed away by water currents from the typhoons in July 1985 and early August 1986 (Fig. 5). The stand along the west shore recovered in 1988. The stand on the east shore (site A) was not washed out by those two typhoons because the site was away from the current and was on the shady side of the bank.

5-1-2. Effects of wind velocity

At the margin of the lake, the mechanical action of wind and waves is likely to be the most important environmental factor for aquatic vegetation (HUTCHINSON, 1975). The velocity of water currents caused by wind is higher at the surface layer than at other depths, and also higher in the littoral than in the pelagic zone (FUKUSHIMA, 1984). The daily maximums of wind velocity on 1 July 1985 and late August 1985 were 21.5 and 18.3 $\text{m}\cdot\text{sec}^{-1}$, respectively (Fig. 5). The direction of both winds were from offshore toward the stand (south-south-east). At the same time, the wind velocity maximums at the lake shore of Ohyama were 42.3 and 37.2 $\text{m}\cdot\text{sec}^{-1}$. The maximum wind velocity in early August 1986 was 17.2 $\text{m}\cdot\text{sec}^{-1}$ (28.0 $\text{m}\cdot\text{sec}^{-1}$ at the lake shore).

In *Trapa natans* the leaf weight as a percentage of total plant weight is larger than that of other parts (TSUCHIYA *et al.*, 1987). *Trapa* spp. shows a flag-type profile in the biomass structure, and more than 40% of the total plant biomass was concentrated in the topmost 30-cm portion from late May until September (KUNII, 1988a). *T. natans* produced rapidly developing large lamina and floats in the petiole after August (Fig. 4). The average petiole inclination is larger at high than at low biomass (TSUCHIYA, 1986). In the present study, heavy wind and waves in July 1985 did not affect the *Trapa* stand along the east shore (Site A) because the foliage was flat at low biomass. In late August 1985, typhoon wind and waves broke the stand along the east shore, presumably because the petioles extended above the water surface at the time when *T. natans* had high lamina weight per rosette. On the other

hand, the vegetation areas of other aquatic plants around site A, such as *Nelumbo nucifera* and emergent plants, were not altered by heavy wind and waves in late August 1985, because the plants were rooted in shore sediment. A floating strategy such as *Trapa*'s that is loosely rooted in sediment is advantageous during water level fluctuations but disadvantageous during heavy wind and wave action.

5-1-3. Effects of environmental aggravation

The third reason for the change in the vegetation area of *Trapa natans* in Takahamairi Bay is environmental aggravation such as low dissolved oxygen (DO) concentration in water. The center of stands in the present study was partly destroyed (dead center) in 1980 and 1983 (Fig. 3). In spring 1985 *T. natans* was distributed uniformly at site A. Only a small dead center was observed from July to August 1985. DO concentration in water of the culture tanks of *T. natans* is inversely correlated with plant biomass (IWAKUMA and TSUCHIYA, 1986). In the present study, DO concentration at the bottom was low from June to August (Fig. 5). DO concentration in the same site was low in August 1978 (SEKI *et al.*, 1979). If the concentration is kept at a low level for a long time, stem and root growth may weaken, leading to decay. Such a low level of DO concentration may be one of the triggers for the disappearance of *T. natans* at the center of the stand. Further studies will be necessary to clarify the relationship between the distribution of *Trapa* and changes in DO concentration.

5-2. Strategy of *Trapa natans*

IKUSHIMA and KURIHARA (1989) discussed the strategy of *Trapa natans* var. *japonica* NAKAI in a eutrophic lake. They concluded that reserves of buried seed was one of the essential adaptations for the maintenance of the *T. natans* stand. The present paper discusses two reasons that *Trapa* can continue to exist in Lake Kanumigaura despite many disturbances. One of the reasons is a high proportion (35%, data of dredge sample) of buried seed. MIKI (1927), HAYASHI (1984), KUNII (1988a) and KURIHARA and IKUSIMA (1991) also report the

occurrence of buried dormant seeds in Ogura-ike Pond (17%), Lake Kitauro (50%), Ojagaike Pond (50%) and Lake Inba-numa (40-50%), respectively. UCHIDA (1973) reported that the seed of *Trapa* spp. can remain alive 2-9 years or more. KUNII (1988b) also reported the dormancy of *Trapa* for more than 2 years. HAYASHI (1984), KURIHARA and IKUSIMA (1991) reported the importance of buried *Trapa* seed to the stability of the stand in a eutrophic lake. Also, because there are many disturbances such as the strong water current and wave action in Lake Kasumigaura, it is probable that buried viable seeds play an important role in population dynamics.

Another reason favoring the maintenance of *Trapa* in Lake Kasumigaura is that the plant has a long stem characteristic of climbing plants supported by water. The annual mean water level at Ushibori from 1985 to 1986 ranged from 0.86 to 1.99 m. Other floating leaved plants such as *Nelumbo nucifera* (NOHARA and TSUCHIYA, 1990) and *Nymphoides peltata* (GMEL.) O. KUNTZE (TSUCHIYA *et al.*, 1990) are affected by flooding because most of their petioles could not extend efficiently during a sudden rise in water level. The stem length of *Trapa bicornis* L. var. *iwasakii* (NAKANO) NAKANO in Lake Kitauro was 19 m at 1-2 m water depth (HAYASHI, 1984). During flooding in July 1985, *Trapa natans* had a long stem (2 m) and a high stem elongation rate as observed in the present study. *T. natans* biomass was not affected by flooding in July 1985 and early August 1986 (Fig. 4). Therefore, *Trapa*'s long stem is clearly advantageous in the event of frequent flooding.

5-3. Conclusion

In conclusion, artificial changes over many years in the current line at the river mouth attended the topography of Takahamairi Bay in Lake Kasumigaura. The ground level of aquatic vegetation sank gradually. From time to time the vegetation of emergent plants and *Trapa natans* were washed out by water currents and heavy winds during typhoons. Construction of shore protection works resulted in a decrease of aquatic vegetation. The emer-

gent plants could not develop in the deep region for some time yet. A high proportion and longevity of buried seed together with a long stem may have enabled *T. natans* to dominate in Takahamairi Bay in spite of water currents and vigorous winds from typhoons.

Acknowledgements

I would like to acknowledge the value of discussions with Dr. T. IWAKUMA of the National Institute for Environmental Studies (NIES). I am indebted to the Erosion & Dam Control Division of Ibaraki Prefecture for providing the water level data. Thanks are also due to Dr. M. AIZAKI and Dr. T. KAWAI of NIES for the offer of wind data and aerial photographs in 1978.

摘 要

霞ヶ浦高浜入におけるヒシ植分の年変動

霞ヶ浦高浜入に生育する浮葉植物ヒシの野外調査を1985年から1986年に行った。また、航空写真を用いて1972年から1990年の植生の変化を調べた。1985年8月に最大現存量 $340 \text{ g 乾重} \cdot \text{m}^{-2}$ になったが、8月下旬の台風による激しい風によってよく発達したヒシ植分は崩壊した。1986年には攪乱前に形成された種子と埋土種子によって植分は回復した。1986年8月上旬の1mの増水にも拘わらず長い茎によって浮くため、流れの少ない所にあるヒシ植分は減少しなかった。生活史の中で起こる台風による激しい流れと風の攪乱は重要な環境因子である。攪乱にもかかわらず埋土種子と長い茎によってヒシが霞ヶ浦で生育することができると考えられた。

References

- AIZAKI, M., T. FUKUSHIMA, S. EBISE, M. HOSOMI, T. IWAKUMA, N. TAKAMURA, S. HANAZATO, S. KASUGA, M. YASUMO, A. OTSUKI, T. KAWAI and M. NISHIKAWA (1984): Limnological data for Lake Kasumigaura. Res. Data Natl. Inst. Environ. Stud., B-25: 319-376.
- AIZAKI, M., S. NOHARA, T. KAWAI, T. IWAKUMA, N. TAKAMURA, T. HANAZATO and A. OTSUKI (1988): Limnological data in littoral zone of Edosakiiri Bay, Lake Kasumigaura. Res. Data. Natl. Inst. Environ. Stud. Jpn., 33: 67-105 (In Japanese).

- ARIMA, S. (1990): Growth of vegetative organs in water chestnut, (*Trapa bispinosa* ROXB.). Bull. Fac. Agr. Saga Univ., 68: 49-64.
- CRAWFORD, R. M. M. (1982): Physiological responses to flooding, p. 453-477. In: LANG, O. L., NOBEL, P. S., OSMOND, C. B. and ZIEGLER, H. (ed.), *Physiological Plant Ecology II*, Springer, Berlin.
- FUKUSHIMA, T. (1984): *Studies on the characteristics of water in a shallow lake and management methods of water*. Ph. D. Thesis, Tokyo University (In Japanese).
- HUTCHINSON, G. E. (1975): *A Treatise on Limnology. vol. III, Limnological Botany*. John Wiley & Sons, New York.
- HAYASHI, K. (1984): Life of annual floating-leaved plants. Iden (Heredity), 38: 6-11 (In Japanese).
- IKUSIMA, I. and M. KURIHARA (1989): The strategy of *Trapa natans* var. *japonica* NAKAI in a eutrophic lake. Bull. Water Plant Soc. Jpn., 37: 8-10 (In Japanese).
- ISHIYAMA, T., T. YOSHIMURA, K. TSUCHIYA, R. TATEISHI, Y. KURONUMA and T. ISHIKAWA (1986): Environmental estimation of Lake Imba-numa and Lake Tega-numa by Landsat imagery. Rep. Environ. Res. Org. Chiba Univ., 12: 31-36.
- IWAKUMA, T. and T. TSUCHIYA (1986): An experimental study of nutrient removal from lake water by a floating-leaved plant, *Trapa natans*. Res. Rep. Natl. Environ. Stud., Jpn., 96: 101-125 (In Japanese with English summary).
- KADONO, Y. (1987): A preliminary study on the variation of *Trapa* in Japan. Acta Phytotax. Geobot., 38: 199-210.
- KADONO, Y. (1988): Species problem in *Trapa*. The Natural History of Japan, 2 (8): 21-25 (In Japanese).
- KUNII, H. (1988a): Seasonal growth and biomass of *Trapa japonica* FLEROV. in Ojaga-ike Pond, Chiba, Japan. Ecol. Res., 3: 305-318.
- KUNII, H. (1988b): Longevity and germinability of buried seeds in *Trapa* sp. Mem. Fac. Sci. Shimane Univ., 22: 83-91.
- KURIHARA, M. and I. IKUSIMA (1991): The ecology of seed in *Trapa natans* var. *japonica* in eutrophic lake. Vegetatio, 97: 117-124.
- MIKAMI, Y., Y. NAGAMINE, M. IGUCHI and S. SHINDOU (1983): Physical geography of the lowland of Lake Kasumigaura region (II)-Studies on the developmental process of the delta of Koise River. Environ. Studies of Tsukuba, 7: 141-157.
- MIKI, S. (1927): Oekologische Studien über die Sumpf-und Wasser-gewächse sowie ihre Formationen im Ogura-Teiche. Report on the historical remains and scenic places in Kyoto, 8: 81-145. (In Japanese).
- MOMOSHIMA, T. and D. NAKAMURA (1979): Studies on water chestnut (*Trapa natans* L.). Bull. Saga Agr. Exp. Station, 19: 83-111 (In Japanese with English summary).
- MURAOKA, K. and T. FUKUSHIMA (1981): Lake current of Kasumigaura (Nishiura). Res. Rep. Nat. Inst. Environ. Stud. 19: 1-150 (In Japanese with English abstract).
- NOHARA, S. and T. TSUCHIYA (1990): Effects of water level fluctuation on the growth of *Nelumbo nucifera* GAERTN. in Lake Kasumigaura, Japan. Ecol. Res., 5: 237-252.
- NOHARA, S. (1991): A study on annual changes in surface cover of floating-leaved plants in a lake using aerial photography. Vegetatio, 97: 125-136.
- SAKURAI, Y. (1981): Changes of flora, vegetation area and biomass of aquatic plants in the recent progress of eutrophication in Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud. 22: 229-279 (In Japanese with English summary).
- SCULTHORPE, C. D. (1967): *The Biology of Aquatic Vascular Plants*. Edward Arnold, London.
- SEKI, H., M. TAKAHASHI and S. ICHIMURA (1979): Impact of nutrient enrichment in a waterchestnut ecosystem at Takahamairi Bay of Lake Kasumigaura, Japan. Water, Air and Soil Poll., 12: 383-391.
- TSUCHIYA, T. and H. IWAKI (1979): Impact of nutrient enrichment in a waterchestnut ecosystem at Takahama-iri Bay of Lake Kasumigaura, Japan. II. Role of waterchestnut in primary productivity and nutrient uptake. Water Air Soil Pollut., 12: 503-510.
- TSUCHIYA, T. and H. IWAKI (1983): Biomass and net primary production of a floating-leaved plant, *Trapa natans*, community in Lake Kasumigaura, Japan. Jap. J. Ecol., 33: 47-54.
- TSUCHIYA, T. and H. IWAKI (1984): Seasonal changes in photosynthesis and primary production of a floating-leaved plant, *Trapa natans* L., community in Lake Kasumigaura, Japan. Jap. J. Ecol., 34: 367-374.
- TSUCHIYA, T. (1986): *Growth characteristics of floating-leaved plants*. Ph. D. Thesis, Tokyo Metropolitan University.
- TSUCHIYA, T., S. NOHARA and H. IWAKI (1987): Annual and seasonal variations in biomass of a

floating-leaved plant, *Trapa natans* L., in Lake Kasumigaura, Japan. Jpn. J. Limnol., 48: S39-S44.

- TSUCHIYA, T., S. NOHARA and T. IWAKUMA (1990): Net primary production of *Nymphoides peltata* (GMEL.) O. KUNTZE growing on sandy sediment at Edosakiiri Bay in Lake Kasumigaura, Japan. Jpn. J. Limnol., 51: 307-312.
- UCHIDA, M. (1973): *Trapa*. Mem. Saga Women's Junior Coll., No. 8: 13-23 (In Japanese).
- UTSUNOMIYA, Y. (1979): Geomorphological study of the subaquatic topographies in Lake

Kasumigaura and accumulation rate. Res. Rep. Natl. Inst. Environ. Stud., 6: 7-21 (In Japanese with English abstract).

(著者: 野原精一, 国立環境研究所生物圏環境部,
〒305 茨城県つくば市小野川16-2; Seiichi NOHARA,
National Institute for Environmental Studies,
Onogawa, Tsukuba, Ibaraki 305.)

Received : 18 October 1991

Accepted : 15 October 1992