Zonal Distribution of Aquatic Macrophytes in the Littoral Zone of Edosaki-iri Bay in Lake Kasumigaura, Japan

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Abstract

Zonal distribution of aquatic macrophytes was investigated in the littoral zone of Edosaki-iri Bay in Lake Kasumigaura. Muddy sediment with litter was deposited on the sandy bed near the shore line. In the emergent plant zone, *Phragmites australis* (Cav.) Trin. ex Steud. tended to dominate near the shore line, but was successively replaced by *Zizania latifolia* Turcz. and *Typha angustifolia* L. toward the deeper sites. The emergent plants were distributed on the shelf to a depth of 80 cm, while a floating-leaved plant, *Nymphoides peltata* (Gmel.) O. Kuntze, occupied lakewards on the steeper slope from depths of 60 to 200 cm. Distribution of each species along the water depth gradient overlapped. The zonation of emergent plants was more associated with depth to sandy sediment surface than that with water depth and that with the thickness of muddy sediment.

Key words: *Nymphoides peltata*; *Phragmites australis*; *Typha angustifolia*; *Zizania latifolia*; zonal distribution

1. Introduction

Zonal distribution of aquatic macrophytes along a shoreline has been related to water depth, light penetration, sediment characteristics, wind and wave exposure and interspecific competition (SPENCE, 1967; HUTCHINSON, 1975; GRACE and WETZEL, 1982; SNOW and VINCE, 1984; WILSON and KEDDY, 1985; WISHEU and KEDDY, 1988; BERTNESS, 1991). However, studies of the zonal distribution in Japan are very scarce (NAKANO, 1911; HOGETSU, 1948; YAMASAKI, 1981, 1984, 1987, 1990; YAMASAKI and TANGE, 1981; SASTROUTOMO, 1982). All the latter studies were conducted in small eutrophic lakes where muddy sediment deposits, so that data is lacking for large lakes with sandy basins.

Lake Kasumigaura is one of the largest lakes in Japan with an area of 171 km² and average water depth of only 4m. This lake is highly eutrophicated with muddy sediment deposits in sheltered inlets. In the main basin, on the other hand, a sandy shelf extends where wind

and wave exposure are relatively high. SAKURAI (1981) reported that species composition of aquatic macrophytes differed between the exposed main basin and the sheltered sub-basins or inlets. At highly exposed sites only *Phragmites australis* (Cav.) Trin. ex Steud. was observed, while in sheltered sites other aquatic and wetland species were found. The precise zonal profile of macrophyte vegetation along the shore line is unknown in this lake. In the present study we attempt to determine the zonal distribution pattern at an relatively exposed site.

2. Study site

The study site is located at the inlet of Edosaki-iri Bay, south of the main basin of Lake Kasumigaura (TSUCHIYA *et al.*, 1990). Vegetation is relatively well conserved at this site. The Ono-gawa River discharges comparatively nutrient-rich water with suspended substances into the bay. However, the lake bed at the study site consists of sand or fine sand because

of relatively high wind exposure, *i.e.*, high wind speed and in conjunction with coastal water current velocity. Biomass of floating-leaved plants is less than that at other sites in the lake (TSUCHIYA *et al.*, 1990). Mud and litter accumulate along the shoreline sheltered from wave action.

Seasonal changes in solar radiation, water temperature, water chemistry and productivity of epiphytic and planktonic algae were reported by TAKAMURA *et al.*, (1990). Water level in Lake Kasumigaura fluctuated seasonally within a range of 40 cm in 1984, reaching its low in spring and fall and its maximum in July just after the rainy season (NOHARA and TSUCHIYA, 1990).

3. Methods

Ten 100 m transect lines, spaced 10 m apart, were extended westward from the shore. In this area, 200 experimental points were marked at 5 m intervals along the transect. Microtopography was conducted using a scaled stick on March 12, 1985. Water depth (surface depth of muddy or sandy sediment) at every marked point was measured by placing the stick on the sediment surface. By inserting the stick further into sediment we measured thickness of the mud layer with litter on the sandy bed. Depth

to the sandy surface is equal to the water depth plus the thickness of the mud layer. Coverage of emergent plant species in a 2 m $\times$ 2 m ground area was recorded in every 10% at the 200 marked points. Since floating-leaved plants had not reached water surface in March, we used coverage data from August 1984.

4. Results

Fig. 1 shows microtopography expressed as depth to the sandy sediment surface at the study site. A sandy shelf facing northeast with a gentle, somewhat wavy slope extends out to about 80 cm in water depth, beyond which a relatively steep slope continues lakeward. Mud and litter are deposited thickly on a hollow slope nearest to the shoreline to create a smooth sediment surface.

Distribution of dominant macrophytes with microtopography of water depth (depth to sediment surface) is shown in Fig. 2. An emergent plant zone about 50m wide along the shoreline was dominated by a mixed vegetation of *Phragmites australis* (Cav.) Trin. ex Steud., *Zizania latifolia* Turcz., and *Typha angustifolia* L. *P. australis* occurred at the landward sites and was successively replaced by *Z. latifolia* and *T. angustifolia* towards deeper sites. At the lakeward edge of the emergent plant zone, *T.*

Fig. 1. Microtopography of study site in depth to sandy sediment surface viewed from pelagic site. Vertical bars show thickness of mud deposited on sand. Water depth at each point expressed as annual mean value.

Fig. 2. Distribution of emergent plants (*Phragmites australis*, *Zizania latifolia*, *Typha angustifolia* and other species) and floating-leaved plant (*Nymphaeoides peltata*) with topography viewed from a pelagic site. Coverage of each species shown by diameter of solid circle. Vertical bars show thickness of mud deposited on sand.

angustifolia occurred almost exclusively. At landward sites we observed other emergent species including wetland plants, *Polygonum lapathifolium* L., *Polygonum thunbergii* Sieb. et Zucc., *Cicuta virosa* L., *Lycopus lucidus* Turcz., *Paspalum distichum* L. and *Iris pseudacorus* L.. Only a minor fraction of coverage was occupied by free-floating species, *Lemna* spp., and detached macrophytes, e. g. *Nymphaeoides peltata* (Gmel.) O. Kuntze and *Egeria densa* Planch., which were observed under the canopy of emergent plants.

N. peltata dominated almost exclusively on the steep lakeward slope, while we found very

low coverage of *Trapa natans* L. and several submerged species, *Potamogeton malaianus* Miq., *Potamogeton crispus* L., *Potamogeton pectinatus* L., *Potamogeton maackianus* A. Benn., and *Vallisneria asiatica* Miki. No submerged vegetation was found beyond the floating-leaved vegetation zone extending to a water depth of 200cm.

Occurrence of dominant species seemed to depend on water depth (Fig. 3). Emergent plants were distributed on the shelf at depth shallower than 80 cm, while *N. peltata* occurred on the steeper slope from 60 to 200 cm in depth. Among emergent plants *P. australis* usually

Fig. 3. Mean coverage of *Phragmites australis* (top), *Zizania latifolia*, *Typha angustifolia* and *Nymphaeodes peltata* (bottom) with water depth (left), depth to sandy surface (middle) and mud thickness (right).

occurred at the shallowest sites. As a rule, *Z. latifolia* was observed at the middle depth and *T. angustifolia* dominated the deepest sites. However, their distributions along the water depth overlapped considerably and the boundary water depth of *T. angustifolia* was uncertain.

Distribution of emergent species was more closely associated with depth to sandy sediment surface than that with water depth (Fig. 3). The distribution range of *T. angustifolia* in depth to sandy surface was much narrower than that in water depth. *T. angustifolia* was distributed from 40 to 70 cm in the depth to sandy surface, while *P. australis* and *Z. latifolia* were found frequently at sites shallower than 50 cm. The depth to sandy sediment surface could not also completely account for the difference in distribution of *P. australis*, *Z. latifolia* and *T. angustifolia*, while *N. peltata* was found exclusively in sandy sites.

5. Discussion

At Edosaki-iri Bay *P. australis* occurred at

shallower sites than *Z. latifolia*, though their precise zonal distribution boundary is not clear. This zonal pattern is consistent with other reports in relatively small Japanese eutrophic ponds (NAKANO, 1911; HOGETSU, 1948; YAMASAKI and TANGE, 1981; SASTROUTOMO, 1982). *Z. latifolia*, though it had a lower growth rate at shallow sites than *P. australis*, can be distributed at deeper sites (YAMASAKI and TANGE, 1981) because it can supply oxygen to its roots and rhizomes more abundantly (YAMASAKI, 1984, 1987). *Z. latifolia* has been reported to grow even at depths of 1.5-1.7 m in a small pond, Tega-Numa (NAKANO, 1911; HOGETSU, 1948), while its lower boundary was only 70 cm at Edosaki-iri Bay. This may be due to differences in wind and wave exposure.

In contrast to *P. australis* and *T. angustifolia* which uses stout vertical aerial stems and rhizomes to anchor itself in sandy sediment, *Z. latifolia* can be easily damaged by wind and wave action due to its compressed internodes and linear elongated rosette leaves. Moreover *Z. latifolia* has roots and rhizome are most

prevalent in the surface layer of sediment (HOGETSU, 1948) so that along lakeward boundary it often forms a floating mat with the litter. This mat can be easily washed away by wave action. Thus, the habitat of *Z. latifolia* may be restricted to relatively sheltered sites.

There have been a few observations associating *T. angustifolia* with *Z. latifolia* (OKUDA, 1978). SASTROUTOMO (1982) reported that *Z. latifolia* flourished in silt and clay soil, while SHIMODA (1985) related *T. angustifolia* with sandy and/or gravelly sediment. In Lake Kasumigaura *Z. latifolia* was often found on the muddy northwest shore, the most eutrophicated area in the lake. *T. angustifolia*, however, favored the less eutrophicated southern sandy shore exposed to wave action. (SAKURAI, 1981). MIKI (1927) reported that *T. angustifolia* grew in nutrient-poor sandy sediment better than *P. australis* and *Z. latifolia* while doing less well in nutrient-rich muddy sediment. The negative association between *T. angustifolia* and *Z. latifolia* seemed to be related to the sediment conditions, considering the relatively large scale of distribution. However, in a small local area such as Edosaki-iri Bay, vegetation was not firmly associated with the sediment characteristic.

MIKI (1927) supposed that *T. angustifolia* invades first on bare sandy sediment just after a disturbance, with *P. australis* and *Z. latifolia* following and finally replacing it. Co-occurrence of *Z. latifolia* and *T. angustifolia* at Edosaki-iri Bay may be merely a transitional phase. The depth of sandy surface is thought to be related to previous water depth during to a period of high wind and wave exposure or just after a heavy disturbance. The accumulation of muddy sediment with litter along the shore line may not be a result rather than a cause of inhabiting of emergent plants. It is likely that the distribution of *T. angustifolia* in muddy sediment is a temporary phenomenon (TSUCHIYA *et al.*, in preparation).

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摘 要

霞ヶ浦・江戸崎入りにおける 水生大型植物の帯状分布

霞ヶ浦・江戸崎入りの湖岸帯で水生大型植物の帯状分布と微地形を調査した。江戸崎入り底質は砂であるが、抽水植物群落の発達した湖岸では砂質の基底の上に泥やリターの堆積がみられた。陸側の水深 80 cm 以浅には抽水植物（陸側からヨシ、マコモ、ヒメガマの順）が、水深 60 から 200 cm の沖側には浮葉植物（アサザ）が分布していた。しかし、これらの帯状分布は、水深や泥質層の厚さよりも（泥質層をのぞいた）砂層までの深さと相関が高かった。

References

- BERTNESS, M. D. (1991): Zonation of *Spartina patens* and *Spartina alterniflora* in a New England salt marsh. *Ecol.*, 72: 138-148.
- GRACE, J. B. and R. G. WETZEL (1982): Niche differentiation between two rhizomatous plant species: *Typha latifolia* and *Typha angustifolia*. *Can. J. Bot.*, 60: 46-57.
- HOGETSU, K. (1948): Conspectus of ecological study about the water plants of Teganuma. *Bot. Mag. Tokyo*, 61: 17-24 (In Japanese with English abstract).
- HUTCHINSON, G. E. (1975): *A Treatise on Limnology*. Vol. III Limnological Botany. John Wiley & Sons, New York.
- MIKI, S. (1927): Ecological studies on water plants in Ogura Pond. *Kyoto Histri. Beutif. Sites Res. Rep.*, 8: 81-145 (In Japanese).
- NAKANO, H. (1911): The vegetation of lakes and swamps in Japan. I. Teganuma (Tega-Swamp). *Bot. Mag. Tokyo*, 25: 35-51.
- NOHARA, S. and T. TSUCHIYA (1990): Effect of water level fluctuation on growth of *Nelumbo nucifera* Gaertn. in Lake Kasumigaura, Japan. *Ecol. Res.*, 5: 237-252.
- OKUDA, S. (1978): Plant sociological studies on the vegetation of the alluvial plains in the Kanto district, central Japan. *Bull. Inst. Environ. Sci. Tech., Yokohama Natl. Univ.*, 4: 43-112 (In Japanese with English and German abstract).
- 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 abstract).
- SASTROUTOMO, S. S. (1982): Summer biomass of aquatic macrophytes in relation to sediment characteristics in Lake Aino-numa, Miyagi. Jpn. J. Ecol., 32: 45-56.
- SHIMODA, M. (1985): Phytosociological studies on the vegetation of irrigation ponds in the Saijo Basin, Hiroshima Prefecture, Japan. J. Sci. Hiroshima Univ., Ser. B, Div. 2, 19: 237-297.
- SNOW, A. A. and S. W. VINCE (1984): Plant zonation in an Alaskan salt marsh. II. an experimental study of the role of edaphic conditions. J. Ecol., 72: 669-684.
- SPENCE, D. H. N. (1967): Factors controlling the distribution of freshwater macrophytes with particular reference to the lochs of Scotland. J. Ecol., 56: 147-170.
- TAKAMURA, N., T. IWAKUMA, M. AIZAKI, and M. YASUNO (1990): Primary production of epiphytic algae and phytoplankton in the littoral zone of Lake Kasumigaura. Mar. Microb. Food Webs, 4: 239-255.
- TSUCHIYA, T., S. NOHARA, and T. IWAKUMA (1990): Net primary production of *Nymphoides peltata* (Gmel.) O. Kuntze growing on sandy sediment at Edosaki-iri Bay in Lake Kasumigaura, Japan. Jpn. J. Limnol., 51: 307-312.
- WILSON, S. D. and P. A. KEDDY (1985): Plant zonation on a shoreline gradient: physiological response curves of component species. J. Ecol., 73: 851-860.
- WISHEU, I. C. and P. A. KEDDY (1988): Species richness-standing crop relationship along four lakeshore gradients: constraints on the general model. Can. J. Bot., 67: 1609-1617.
- YAMASAKI, S. (1981): Effects of water level on the development of rhizomes of three hygrophytes. Jpn. J. Ecol., 31: 353-359.
- YAMASAKI, S. (1984): Role of plant aeration in zonation of *Zizania latifolia* and *Phragmites australis*. Aquat. Bot., 18: 287-297.
- YAMASAKI, S. (1987): Oxygen demand and supply in *Zizania latifolia* and *Phragmites australis*. Aquat. Bot., 29: 205-215.
- YAMASAKI, S. (1990): Population dynamics in overlapping zones of *Phragmites australis* and *Miscanthus sacchariflorus*. Aquat. Bot., 36: 367-377.
- YAMASAKI, S. and I. TANGE (1981): Growth responses of *Zizania latifolia*, *Phragmites australis* and *Miscanthus sacchariflorus* to varying inundation. Aquat. Bot., 10: 229-239.

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