J. Natl. Hist. Mus. & Inst. Chiba Special Issue No. 1: 183–188. March 1994.

Short-term Dynamics of Submerged Vegetation after Restoration Work in Funada-ike Pond, Ecology Park

Masahiko Miyata

Department of Plant Science, Natural History Museum and Institute, Chiba
955–2 Aoba-cho, Chuo-ku, Chiba 260, Japan

Abstract The Funada-ike Pond is a restored pond at the Ecology Park, Natural History Museum & Institute, Chiba. Restoration measures, which were designed to reverse the process of eutrophication, included draining and dredging of mud. The measures were implemented from June, 1987 to March, 1989. This research began in April, 1989, immediately after restoration work was completed, and lasted untill November of that year. Focus was on short-term dynamics of submerged vegetation, especially the shift in dominance from *Chara braunii* (Charophyta) to *Echinochloa crus-galli* var. *caudata* (Angiosperm) and *Fimbristylis verrucifera* (Angiosperm).

Results indicate that seeds of all three of these species remained in the bottom mud, and germinated during the disturbance caused by dredging. *C. braunii*, with a shorter germination period, was first to emerge, and dominated the submerged vegetation from April through August, when the pond began to refill with rainwater but remained shallow. During September and October, *C. braunii* was replaced by *E. crus-galli* var. *caudata* and *F. verrucifera*. Differential germination periods and fluctuations in water level were factors in this replacement, but a major role was played by selective grazing on *C. braunii* by waterfowl such as *Anas crecca, Anas clypeata, Aythya ferina* and *Aythya fuligula*. These waterfowl have continued to crop the young shoots before the oospore appears, and as of March, 1994. *C. braunii* could not be found in the Funada-ike Pond.

Key words: *Chara braunii*, Charophyta, *Echinochloa crus-galli* var. *caudata, Fimbristylis verrucifera*, Angiosperm, Waterfowl, Irrigation pond, Dredging, Restoration, Ecology Park.

Lakes, pond and marshes in the world are affected by eutrophication as caused by increased input of organic nutrients, especially in many shallow water bodies eutrophication resulted into a change from a plant-domination to a plankton-domination. Changes in nutrient loading to ponds are one of the most important reasons for fluctuations in areal coverage of submerged macrophytes as the same as light condition, water level and grazing. At interesting nutrient concentrations, submerged macrophytes decline due to shading by phytoplankton and epiphyton (Phillips *et al.*, 1978). Water level, especially too low water level, damages submerged plants due to desiccation during summer and ice during winter (Martin and Uhler, 1939). Furthermore bottom-feeding fish may damages submerged plants mechanically for feeding (ten Winkel and Meulemans, 1984), and waterfowl, macroinvertevrate may be in the same.

Funada-ike pond is a small shallow pond, as the nature reserve area, in Ecology Park of Natural History Museum and Institute, Chiba, Japan. The pond is typical irrigation pond (tame-ike) since ca. 300 years ago The eutrophication was possibly caused by the inlet of polluted water from the neighboring agricultural fields, paddy soil and live stock pasture in rainy periods, and by especially discharge from domestic waste and secondarily-treated waste water. At that time, one of the special biotic components of the pond was a rich planktonic community as *Microcystis aerginosus* and *Pandorina morum* (Matsu-

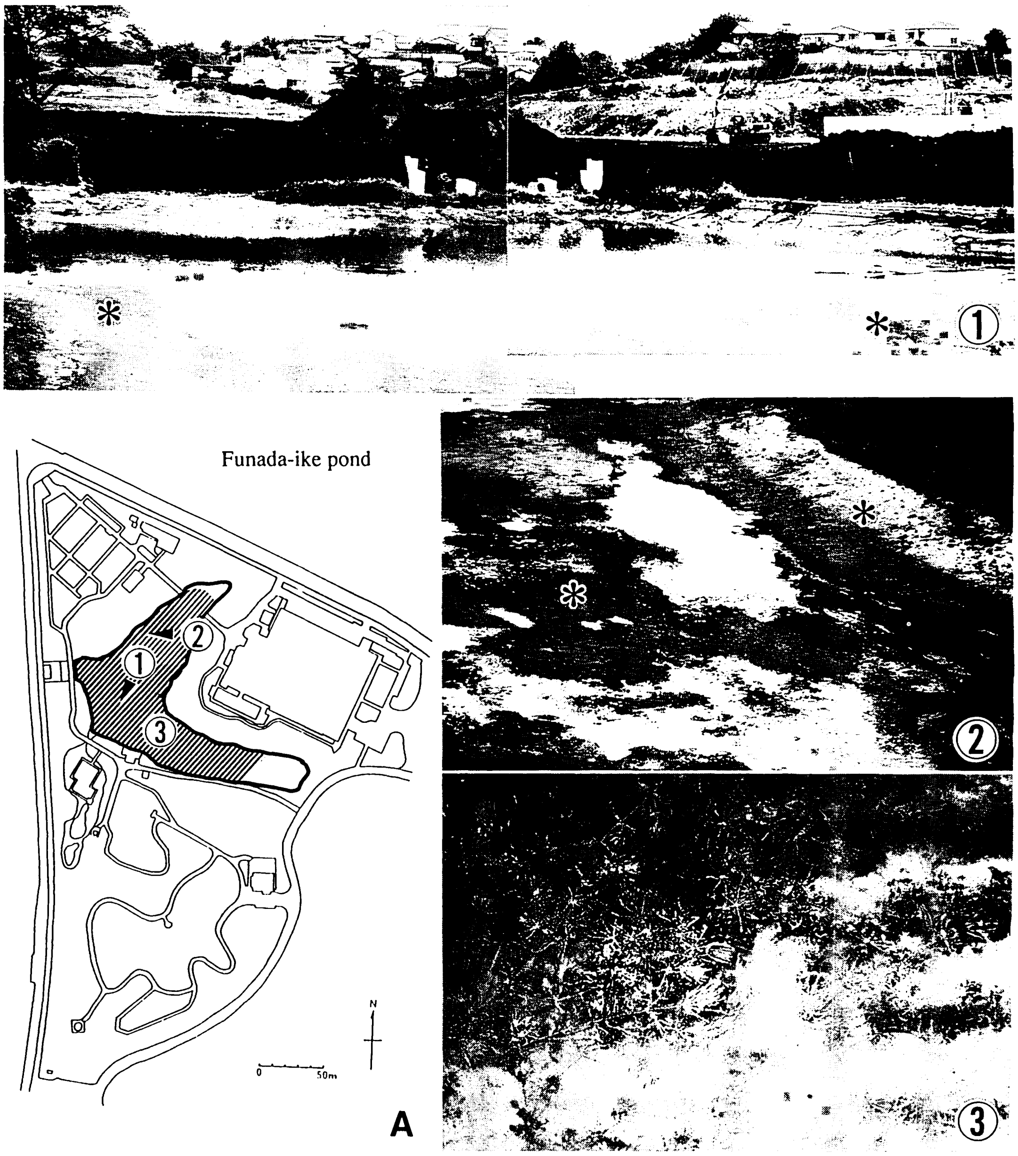

Fig. 1 Funada-ike pond and vegetation of *C. braunii*.
A: Funada-ike pond in Ecology Park (35°36′N, 140°8′E) covered with *C. braunii* on July, 1989. The oblique indicate the dominant area by population of *C. braunii*
① View from station 1 towards south coast. Coast, bank and bottom in the pond became matted by *C. braunii* (*) at low water level.
② View along the north coast from station 2. Almost bottom covered with *C. braunii* (*).
③ Population of *C. braunii* at the station 3

naga, 1983; Hara *et al.*, 1985), and the occurence of the rare macrophyte, *Spirogira* sp. The bottom was partly covered with diatom species, *Gomphonema parvulum, Melosira granulata* and *Cyclotella meneghiniana*, which is known as tolerant to eutrophication (Idei and Hara, 1986; 1987). Unfortunately documentation on submerged macrophytes was incomplete before restoration. Restoration measures to improve of hydrospheric ecosystem was done during June 1987 to March 1989 in Funada-ike pond. The pond was drained, and the mud with a high organic contents was removed by dredging ca. 1 m in thickness to improve bottom conditions, and then the bottom was covered with marine sediments before amass waters.

Monitoring of submerged vegetation after restoration in pond, lake and marshes may offer a good opportunity to explore the likely causes for both long- and short-term fluctuations of submerged macrophytes vegetations and more generally understand macrophyte ecology. The purpose of this study is to describe the short-term dynamics of submerged vegetation immediately after restoration measures in Funada-ike pond.

Materials and Methods

C. braunii is distributed through Europe and Asia from the Scandinavian countries to India and Japan (Wood and Imahori, 1965) and is common in Boso Peninsula (Kasaki, 1975). The habitat is in ponds, paddy fields, swamps, lakes, ditches and river and they are growing solitary in pH 6.8–8.0 (Imahori, 1954; Kasaki, 1964).

Funada-ike pond is a small shallow pond (0.98 ha), in the maximum depth 2.3 m, in Ecology Park (35°36′ N, 140°8′ E) of Natural History Museum and Institute, Chiba, Japan (Fig. 1A). After restoration measures, the submerged vegetation was observed during April to November 1989. Submerged macrophytes were collected by dredging and partly snorkeling from a rowing boat. Specimens collected were identified and for *Chara braunii* Gemelin (Characeae, Charophyta) preserved in 10% formaldehyde solution buffered pH 7.2–7.5 to prevent from decalcification, and stored in Herbarium of Algology in Natural History Museum and Institute, Chiba (CBM-BA).

Results

In April 1989, immediately after restoration measures, *C. braunii* was sparsely distributed as small aggregated clumps in protected areas. Individual plants were small and weakly attached to the substrate. The abundance and size of the clusters increased markedly throughout the May to June, with the plants massing into large clumps up to ca. 0.3 m in height and reaching nearly 100% coverage in almost areas. In July to August, *C. braunii* became matted to the sandy bottom as dominant vegetation (Figs. 1-A, ①, ②), and abruptly replaced by vegetations of *Echinochloa crus-galli* var. *caudata* and *Fimbristylis verrucifera* during September to October (Okubo, 1994; Ohba, 1994 pers. comm.). When population of *C. braunii* decreased rapidly on September to October, waterfowls, such as *Anas crecca* (no. = 35), *Anas clypeata* (no. = 15), *Aythya ferina* (no. = 93) and *Aythya fuligula* (no. = 18), were reported in Funada-ike pond. Especially, *Aythya ferina* and *Aythya fuligula* were first record (Kuwabara, 1994 pers.comm.) in this pond, which mainly feed plant as *Chara, Potamogeton* (Cramp, 1986). Population of *C. braunii* disappeared on November 1989, and there is no evidents of *C. braunii* untill March 31, 1994.

Discussion

Where did *C. braunii* come from for rapid colnization immediately after restoration work ?

C. braunii rapidly colonized in almost areas on pond bottom on April to June, 1989. This suggests that oospores of *C. braunii* in large quantities presented in muddy bottom before restoration measures, and germinated synchronously in submerged disturvance caused by dredging and amassment of water. Furthermore, the fact indicates that oospores of *C. braunii* tolerate both drying and freezing in shallow pond (Proctor, 1967), though the oospores may be also easily imported and dispersed by waterfowl, as they can pass through the alimentary tracts of these birds without being damaged (Kamat, 1967). Recently, Blindow (1992) shows that the sediment contained high densities of oospores (two samples: 8300 and 24900 oospores m^{-2}, respectively, upper 10 cm of the sediment) in eutrophic shallow Lake, Krankesjön (Sweden) and readily germinated (8.3% germination, $n = 2400$) in the laboratory.

Moreover charophyta may have been superior competitor for space over angiosperms because of their high biomass per unit area probably due to fast growth during April to August in Funada-ike pond and may also been inhibited phytoplankton and microalgae more efficiently than angiosperms by substantial nutrient accumulation and release of toxic compounds (Blindow,1992) and these may increase light availability.

What was the reason for rapidly replacement of submerged vegetations from Charophyta to anigiosperm ?

Life cycle and morphology (Hutchinson, 1975), as well as depth distrbution and light response (Chambers and Kalff, 1985), differ considerably between plant groups. So there may have been three factors to cause for replacement of the vegetations which are time-lag of growth periods in life cycle, water level (or desiccation) and grazing, in Funada-ike pond.

Delay of expansion of angiosperms is probably not caused by lack of seeds and may has depended on time-lag of germination periods between *C. braunii* and both *E. crus-galli* var. *caudata* and *F. verrucifera*. Seeds of two angiosperms germinated on May to July as compared with April to June in *C. braunii*, which is embeded in large quantities in muddy bottom as the same of *C. braunii*. When two angiosperm species reached peak of growth periods on last August to September, the replacement of vegetation occured.

C. braunii expanded on May low water level and decreased the population in high water level on September to October. Both charophyta and angiosperms favoured in low water level during the growing season. Then angiosperms extend deeper than charophytes with gradually rising water level, which is explained by specific adaptations such as shoot elongation, canopy formation and storage of large energy amounts in hibernales (Blindow, 1992). Submerged macrophytes may react to water level as the same of light availavility in germination and growing periods. Water level is one of the most important factor causing fluctuations in areal coverage of submerged macrophytes as found in other lake (Classen, 1982). Figures ①-② indicate the dominant population of *C. braunii* in low water level on July 1989. Subsequently, there may be several times in fluctuation of water level during July to September, 1989, and untill March 1994.

A total disappearance of submerged macrophytes can be caused by a catastrophic event such as desiccation (fluctuation of water level) and mechanical damage like a feeding by animal, birds and macroinvertebrate.

Macroinvertebrate densities was reported higher in charophytes vegetation than in angiosperms vegetation (Blindow *et al.*, 1991). In Funada-ike pond the macroinvertebrates may reduce epiphyton densities and thus to increase light availability to the plants in growing season. Charophyta may be the only type of submerged vegetation able to form a stable clear-water state shallow, wind-exposed and temperate pond, while dominance of angiosperm vegetation occurs only as a transitional phase.

Waterfowls, as genus *Aythya*, graze primarily seeds and vegetative parts of aquatic plants such as rhizomes, buds, shoots, leaves and tubers, by diving in depths of 1 m–2.5 m (Cramp, 1986). On *Aythya ferina* Pochard, the food habitat and feeding habitat may relate to invariably aquatic plant. Most frequently records in stomach indicate stoneworts *Chara*, pondweeds *Potamogeton*, milfoil *Myriophyllum*, hornworts *Ceratophyllum*, sedges *Carex* and *Scirpus*, persicarias *Polygonum*, and grasses (Cramp, 1986). From England and northern Ireland during September to January, 43 stomachs of *Aythya ferina* contained mainly water plants (86.1% total volume), and chiefly stoneworts Charophyta (*Chara* and *Nitella*) and seeds (Cramp, 1986). *C. braunii* may have been most important food with seeds for *Aythya ferina* in Funada-ike pond during September to October, 1989. Similar results from USSR indicate that the stomach contained chiefly *Chara* (60%), mainly *Chara edule* Ruppia seeds (8.5%) and molluscs (28%) (Cramp, 1986).

The rapid replacement of submerged vegetations from charophyta to angiosperms may have been owning in catastorophic event as the continuous cropping the entire young shoot before bearing oospore of *C. braunii* during September to October, 1989. At the same time of the replacement. *Aythya ferina* and *Anthya fuligula* were reported firstly in Funada-ike pond. While generally charophyta come into sight in late spring, reaching its greatest luxuriance from summer to autumn, then gradually diminishes towards winter in Japan (Imahori, 1954) and in Boso peninsula. On these circumstances, population of *C. braunii* may have been selected by mainly the grazing of waterfowl, especially *Aythya ferina* and *Aythya fuligula*, during September to October, 1989, after restoration measures, and as the results replacement of submerged vegetation may have occured for two months in Funada-ike pond.

This study don't offer any informations of relationships between waterquality and fluctuation of submerged vegetation in the pond. So particular analysis are needed on the relationships. Then the nature reserve Funada-ike pond has not yet reached a stable situation and so it is important to continue the pond's monitoring to determine whether the reported fluctuation of submerged vegetation will sustain.

Acknowledgements

The author is indebted to staffs of the Department of Ecological Science, Natural History Museum and Institute, Chiba, especially for very useful comments on the manuscript and for financial support. This study is a part of Research Project on the Ecosystem in the Ecology Park, Natural History Museum and Institute, Chiba.

References

Blindow, I. 1986. Decline of charophytes during eutrophication: a comparison to angiosperms. Freshwater Biology 28: 9–14.

Blindow I., G. Anderson and A. Hargeby. 1991. Are shallow, eutrophic lakes systems with alternative stable states ? *Interaction between submerged macrophytes andmicroalgae in shallow lakes*. Ph. D. Thesis of I. Blindow, University of Lund, Sweden.

Blindow, I. 1992. Long- and short-term dynamics of submerged macrophytes in two shallow eutrophic lakes. Freshwater Biology 28: 15–27.

Chambers, P. A. and J. Kalff. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Canadian Journal of Fisheries and aquatic Sciences 42: 701–709.

Claasen T. H. L. 1982. Limnological data of an isolated Duchbroad. Hydrobiologia 55: 209–218.

Cramp, S. 1986. Handbook of the Birds of Europe, the Middle East and North Africa, The Birds of the Western Palearctic Volume I. 722 pp. Oxford Univ. Press, New York.

Crawford, S. A. 1977. Chemical, physical and biological changes assoiciated with *Chara* succession. Hydrobiologia 55: 209–218.

Hara, K., I. Inoue, S. Kato and M. Narata. 1985. Microalgae flora in Funada-ike pond. *In* Chibaken Shizenshishiryou Chousakai (eds.), Report of basic surbey and sampling for construction of "Chibakenritsuchuouhakubutsukan", 1985, pp. 25–29. Chibaken Shizenshishiryou Chousakai, Chiba. (in Japanese)

Hutchinson, G. E. 1975. A Treatise on Limnology. Vol. III: Limnological Botany. 660 pp. J. Wiley and Sons, New York.

Idei, M. and Y. Hara. 1986. Microalgae flora in Funada-ike pond II. Bacillariophyta. *In* Chibaken Shizenshishiryou Chousakai (eds.), Report of basic surbey and sampling for construction of "Chibakenritsuchuouhakubutsukan", 1986, pp. 6–11. Chibaken Shizenshishiryou Chousakai, Chiba. (in Japanese)

Idei, M. and Y. Hara. 1986. Microalgae flora in Funada-ike pond III. Bacillariophyta. *In* Chibaken Shizenshishiryou Chousakai (eds.), Report of basic surbey and sampling for construction of "Chibakenritsuchuouhakubutsukan", 1987, pp. 8–11. Chibaken Shizenshishiryou Chousakai, Chiba. (in Japanese)

Imahori, K. 1962. A dispersal factor of Charophytes (Fresh-water algae). Acta Phytotax. Geobot. 20: 282–284. (in Japanese)

Imahori, K. 1954. Ecology Phytogeography and Taxonomy of the Japanese Charophyta. 234 pp. Kanazawa Univ., Kanazawa.

Kamat, N. D. 1967. Dispersal of charophytes by the pintail. Current Science 36: 134.

Kasaki, H. 1964. The Charophyta from the lakes of Japan. J. Hattori Bot. Lab. 27: 217–314.

Kasaki, H. 1975. Charophyta in Chiba Prefec. *In* Biological Society of Chiba Prefecture (eds.), Flora and vegetation of Chiba Prefecture, pp. 250–265. Inoue Book Co., Tokyo. (in Japanese)

Martin, A. C. and F. M. Uhler, 1939. Food of game Ducks in the united States and Canada. U.S. Department Agriculture Technica Bulletin 634.

Matsunaga, S. 1983. Water quality and plankton community in Funada-ike pond. *In* Chibaken Shizenshishiryou Chousakai (eds.), Report of basic surbey and sampling for construction of "Chibakenritsuchuouhakubutsukan", 1983, pp. 37–41. Chibaken Shizenshishiryou Chousakai, Chiba. (in Japanese)

Okubo, K, 1994. Changes in vegetation due to restoration work; Funada-ike Pond, thd Ecology

Park, Natural History Museum and Institute, Chiba. Joumal of Natural History Museum and Institute, Chiba, Special Issue 1: 175–181 (in Japanese with English abstract)
Phillips, G. L., D. Eminson and B. Moss. 1978. A mechanism to account for macrophyte decline in progressively eutrophicated freshwater. Aquatic Botany 4: 103–126.
Proctor, V. W. 1962. Viability of *Chara* oospores taken from migratory water birds. Ecology 43(3): 528–529.
ten Winkel, E. H. and J. T. Meulemans. 1984. Effects from fish upon submerged vegetation. Hydrobiological Bulletin 18: 157–158.
Wood, R. D. and K. Imahori, 1964. A revision of the Characeae. Second part. Monograph of the Characeae. 904 pp. Cramer, Weinheim.

改修工事をおこなった生態園・舟田池の沈水植物群落の動態

宮田昌彦

千葉県立中央博物館・植物学研究科
〒260 千葉市中央区青葉町 955-2

富栄養化の進んだ溜池，生態園・舟田池の水界生態系の改善を目的とした池の改修工事（排水，水干，池底土壌部の浚渫，水干，山砂投入，灌水，生活排水流入口の改修）を 1987 年 6 月から 1989 年 3 月に行った．その直後，1989 年 4 月から 6 月に水位が約 0.5 m から 1 m になった舟田池 (0.98 ha) にシャジクモ *Chara braunii*（車軸藻植物）の優占群落を認めた．そして，9 月から 10 月にシャジクモからケイヌビエ *Echinochloa crus-galii var. caudata*（被子植物）とアオテンツキ *Fimbristylis verrucifera*（被子植物）が優占する群落へ植生の交代を認めた．その後，1989 年 11 月から 1994 年 3 月に至る現在，シャジクモの群落を認めない．1989 年 4 月から 11 月に舟田池に現れ，そして消失した沈水植物群落の動態を調べた．

その結果は次のことを示唆した．浚渫されずに残った粘質砂土に埋土した多量の，シャジクモ卵胞子とケイヌビエ，アオテンツキの種子が，一時的な池底の乾燥化，灌水及び池の水位の変動と風に伴う池底部の撹乱という環境条件の変化のもとで活性化し，発芽して群落を形成した．共に一年生の生活史を示し，シャジクモは 1989 年 4 月から 7 月に生長して 6 月から 9 月に卵胞子を形成し，ケイヌビエ，アオテンツキは 6 月から 8 月に生長して 7 月から 10 月に開花し種子を形成した．この生育期間の位相がシャジクモ優占群落の形成を誘導した．シャジクモが卵胞子を形成する 6 月から 9 月に，主としてカモ類がシャジクモを選択的に摂餌した結果，シャジクモ優占群落からケイヌビエ，アオテンツキの優占する群落へ植生の交代が起こった．その際，池の水位変化も影響した．9 月から 10 月，舟田池に沈水植物を主な餌とする，マガモ属のコガモ *Anas crecca*（35 羽），ハシビロガモ *Anas clypeata*（15 羽），ハジロカモ属のホシハジロ *Aythya ferina*（93 羽），キンクロハジロ *Aythya fuligula*（18 羽）を認めた．1989 年・9 月以降，池底で越年し発芽，成長を繰り返す小量のシャジクモが生育するが卵胞子を形成する前にカモ類が藻体を摂餌するためにシャジクモ群落を認めない．舟田池のシャジクモは，主に鳥類の摂餌圧によって淘汰された．