INTEGRATED MANAGEMENT OF AQUATIC WEEDS IN JAPAN

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ABSTRACT

As a result of the increased influence of man on aquatic systems, many waterways in Japan have become eutrophic and the unwanted growth of aquatic vegetation has become a considerable problem. A new approach should be developed which reflects greater concern for the environment. Since there are various opportunities to put aquatic vegetation to economic use, the utilization of aquatic weeds as well as their control should be an important part of their management.

INTRODUCTION

The kinds and biomass of plants vary in different aquatic environments — canals, streams, rivers, lakes, ponds, marshes and wetlands. The use to which a body of water is being put determines the management objectives, and whether there is a need for the management or control of aquatic plants. A given body of water may be used for agricultural, industrial and domestic purposes. In addition, it may have a recreational role for fishing, boating, or swimming. The management of aquatic plants should be considered as part of the overall management program.

Overabundant aquatic plants (namely aquatic weeds) interfere with human activity. In many bodies of water all over the world, it has been found necessary for centuries to control aquatic weeds. There are several methods of managing aquatic weeds: mechanical harvesting, biological control, changing the aquatic environment, and chemical control. The methods selected are determined by the particular use to which the water will be put, and by the available resources.

On the other hand, aquatic plants may have a useful role for special purposes. Certain plants and seeds are useful for wild-life, providing fish and waterfowl with cover, food and a breeding site. The extent to which aquatic plants are desirable depends on the point of view of the water user. For example, reservoir managers want clear water that is free of weeds, algae and other organisms. However, conservationists try and establish suitable plant cover on watersheds and along the banks of streams, lakes and ponds to control erosion and to protect water quality. We should be well-informed about aquatic plants, so that we can choose aquatic weed management procedures to meet our objectives.

The purpose of this paper is to review the research on aquatic weed management which has been carried out in Japan, and identify key research needs for the future.

CURRENT STATUS OF AQUATIC VEGETATION IN JAPAN

Eutrophication

Many bodies of water in Japan have become eutrophic as a result of the input of excessive plant

Key words: Aquatic vegetation management, utilization of aquatic weeds, eutrophication, environmental considerations.

nutrients from urban and agricultural activities. Eutrophic waters are those which show signs of excess nutrient loading, with associated changes in flora and fauna (Jeffries and Mills 1990). The input of excessive plant nutrients may occur together with an increase in solid effluent that accelerates sedimentation. Changes in algae take place, and species composition and productivity alter. Blue-green algae tend to become increasingly dominant as eutrophication proceeds. An excessive nutrient input also alters macrophyte communities. Some tolerant species which are able to use the increased nutrients may flourish, as is characteristic of aquatic weeds, while sensitive species are lost. As a result, diversity declines (Jeffries and Mills 1990).

From the 1970s to the present time, these changes in the composition of aquatic vegetation have take place to a marked extent in most bodies of water in Japan. A severe loss of macrophyte species, particularly of submerged species, is characteristic of highly eutrophic habitats in Kasumigaura (Ibaragi prefecture), Suwa Lake (Nagano prefecture), Inbanuma (Chiba prefecture) and Kojima Lake (Okayama prefecture). (Sakurai 1983, Ueki 1984)

Major Aquatic Weeds and Water Quality

A comparative study was made of aquatic vegetation in 51 irrigation canals, ponds and rivers in Okayama prefecture, southwestern Japan, in order to document the present status of aquatic flora and water quality. This report recorded a total of 49 taxa (Une and Oki 1988). The most common plants were *Trapa japonica* in ponds, *Potamogeton malaianus* and *Hydrocharis dubia* in rivers, and *Potamogeton crispus* in irrigation canals. A number of other species, including *Paspalum distichum, Nelumbo nucifera, Trapa japonica, Potamogeton crispus, Ceratophyllum demersum, Egeria densa, Potamogeton malaianus, Cabomba caroliniana, Potamogeton oxyphyllus, Hydrocharis dubia, Spirodela polyrhiza* and *Eichhornia crassipes*, were seen to grow well in nutrient-rich water (Table 1) (Oki *et al.* 1988b). An analysis of nitrogen, phosphorus and potassium levels in these species found that the tissue concentrations of all three elements were very high (Table 2) (Oki and Une 1989a). Many of the plants which grow well in eutrophic water are serious weeds, most of them exotic species. Exotic species seem to reproduce faster and spread more vigorously than in their native range (Ikushima 1983). Some of the noxious weeds in Japan are discussed in the following section.

Egeria densa and Elodea nuttallii

Around 1960, *Elodea nuttallii* was noticed growing wild in Lake Biwa in Japan (Ikushima and Kabaya 1965), and around 1970, *Egeria densa* was also first observed in the same place (Tanimizu and Miura 1976). Since then, the rapid colonization by these two species of diverse aquatic habitats has made them two of the most troublesome aquatic weeds. *Egeria* prefers a habitat where the water is stagnant and highly enriched (Fig. 1) (Oki *et al.* 1988a). Both *Elodea* and *Egeria* can overwinter in Japan, forming a dense mat of vegetation just above the lake bottom.

Eichhornia crassipes (Waterhyacinth)

Since the introduction of this weed as an ornamental plant in the 1890s, it has spread rapidly into many waterways and lakes in Japan, creating great problems in water management, especially in the south. The annual productivity of this weed in natural waterways during the growing season (May through October) is about 20 mt dry matter/ha/year (Oki 1990).

Trapa japonica

Trapa, an annual floating-leaved weed, has enlarged its distribution area greatly in recent years in Japan, in spite of being a native aquatic plant. The foliage of the weed covers the water surface in a dense floating film, becoming the dominant species in stagnant water with a high organic content where there is a nutrient-rich mud bottom (Oki and Une 1989b, Kunii 1991, Kadono 1982). There is a tendency for significant negative correlations between pairs of species to be found only with *Trapa japonica* (Fig. 2) (Une and Oki 1988).

Other Noxious Weeds

These include *Paspalum distichum, Cabomba caroliniana, Hydrocharis dubia, Spirodela polyrhiza, Lemna* sp.*, Nelumbo nucifera, Phragmites communis, Typha* sp.*,* and *Myriophyllum aquaticum.*

MANAGEMENT OPTIONS

Mechanical Control

Mechanical control of aquatic weeds is the oldest method, and still has many practical advantages. Physical removal is most effective for

Table 1. Chemical ranges of the occurrence of 24 aquatic plant species in relation to COD, inorganic nitrogen and inorganic phosphorus

Species	COD (mg/1)		Inorg. - N (mg/1)		Inorg. - P (mg/1)	
	Max. – Min.	Average	Max. – Min.	Average	Max – -Min.	Average
Zizania latifolia	10.01-4.49	6.86	1.43-0.05	0.78	0.23-0.01	0.12
Phragmites communis	7.07-2.94	4.78	2.18-0.02	0.59	0.31-0.00	0.11
Typha latifolia	8.08-2.86	5.54	0.21-0.02	0.12	0.04-0.00	0.02
Leersia japonica	6.58-3.68	5.71	1.42-0.11	0.39	0.23-0.03	0.11
Paspalum distichum	7.69-4.80	6.34	1.43-0.30	1.14	0.23-0.11	0.18
Nelumbo nucifera	10.32-4.10	8.41	0.59-0.05	0.26	0.06-0.01	0.03
Trapa japonica	35.74-2.86	7.65	2.83-0.02	0.43	0.31-0.00	0.07
Potamogeton octandrus	11.79-2.86	4.97	1.41-0.09	0.36	0.34-0.01	0.11
Potamogeton distinctus	7.04-2.94	4.53	0.48-0.08	0.18	0.31-0.00	0.08
Brasenia schreberi	7.61-2.94	5.48	0.15-0.08	0.11	0.31-0.00	0.10
Hydrilla verticillata	11.79-1.37	5.00	1.76-0.02	0.66	0.34-0.00	0.10
Potamogeton crispus	35.74-1.30	7.30	2.83-0.11	0.90	0.25-0.00	0.10
Ceratophyllum demersum	35.74-1.37	8.69	1.76-0.15	0.88	0.25-0.01	0.15
Egeria densa	35.74-1.37	10.27	2.83-0.05	0.82	0.21-0.01	0.11
Potamogeton malaianus	11.79-1.37	4.59	2.18-0.37	1.10	0.34-0.00	0.15
Myriophyllum verticillatum	7.61-1.37	4.04	1.73-0.11	0.74	0.25-0.01	0.11
Potamogeton pusillus	7.61-3.05	4.46	1.76-0.08	0.91	0.25-0.00	0.13
Vallisneria natans	4.26-1.37	3.21	1.76-0.37	0.82	0.25-0.01	0.08
Cabomba caroliniana	8.23-3.20	4.60	1.76-0.68	1.31	0.25-0.06	0.19
Elodea nuttallii	13.43-1.37	6.92	1.35-0.23	0.59	0.18-0.01	0.09
Potamogeton oxyphyllus	7.69-3.27	4.77	1.76-0.30	1.06	0.25-0.11	0.19
Hydrocharis dubia	35.74-3.20	9.25	1.76-0.13	0.94	0.25-0.03	0.17
Spirodela polyrhiza	35.74-3.81	11.91	1.42-0.18	0.76	0.23-0.02	0.14
Eichhornia crassipes	10.01-3.81	6.30	1.43-0.17	0.96	0.21-0.08	0.17

Source: Oki *et al.* 1988b

Table 2. Chemical composition of 19 selected macrophyte species, showing the maximum, minimum and average values of N, P and K (% on a dry-weight basis)

Species	N (%)		P (%)		K (%)	
	Max. – Min.	Average	Max. – Min.	Average	Max. – Min.	Average
Leersia japonica	1.85-1.52	1.69	0.22-0.12	0.16	2.23-1.37	1.77
Paspalum distichum	2.02-1.80	1.93	0.31-0.19	0.25	3.85-3.05	3.53
Trapa japonica	4.02-1.19	2.40	0.63-0.13	0.28	2.74-0.10	1.42
Potamogeton distinctus	1.63-1.23	1.43	0.21-0.12	0.18	2.18-1.12	1.62
Brasenia schreberi	2.08-1.61	1.77	0.18-0.14	0.16	1.30-0.88	1.04
Nymphaea tetragona	2.24-1.06	1.65	0.20-0.14	0.18	2.47-1.70	2.09
Hydrilla verticillata	4.30-1.71	3.14	0.81-0.08	0.43	4.93-2.13	3.45
Potamogeton crispus	3.84-2.02	2.87	0.78-0.31	0.52	5.92-0.52	3.30
Ceratophyllum demersum	4.49-2.67	3.52	1.07-0.24	0.67	6.30-3.52	4.97
Egeria densa	4.13-2.02	3.28	0.78-0.32	0.60	6.53-1.82	3.84
Potamogeton malaianus	3.51-2.11	2.79	0.57-0.29	0.41	2.91-2.02	2.40
Myriophyllum verticillatum	3.90-2.07	2.87	0.62-0.19	0.42	2.50-1.03	1.45
Vallisneria natans	3.09-2.74	2.99	0.59-0.38	0.48	6.05-1.99	3.87
Cabomba caroliniana	3.22-2.43	2.72	0.48-0.37	0.42	5.54-1.14	2.48
Elodea nuttallii	4.78-3.07	3.90	0.76-0.20	0.49	5.12-1.74	3.75
Potamogeton oxyphyllus	3.77-2.80	3.34	0.74-0.58	0.64	3.95-2.29	2.95
Hydrocharis dubia	5.17-2.08	3.41	0.62-0.15	0.49	6.22-2.42	4.55
Spirodela polyrhiza	4.57-2.78	3.70	0.51-0.29	0.44	4.99-1.43	2.95
Eichhornia crassipes	3.70-2.14	3.15	0.61-0.46	0.53	6.03-4.79	5.39

Source: Oki and Une 1989a

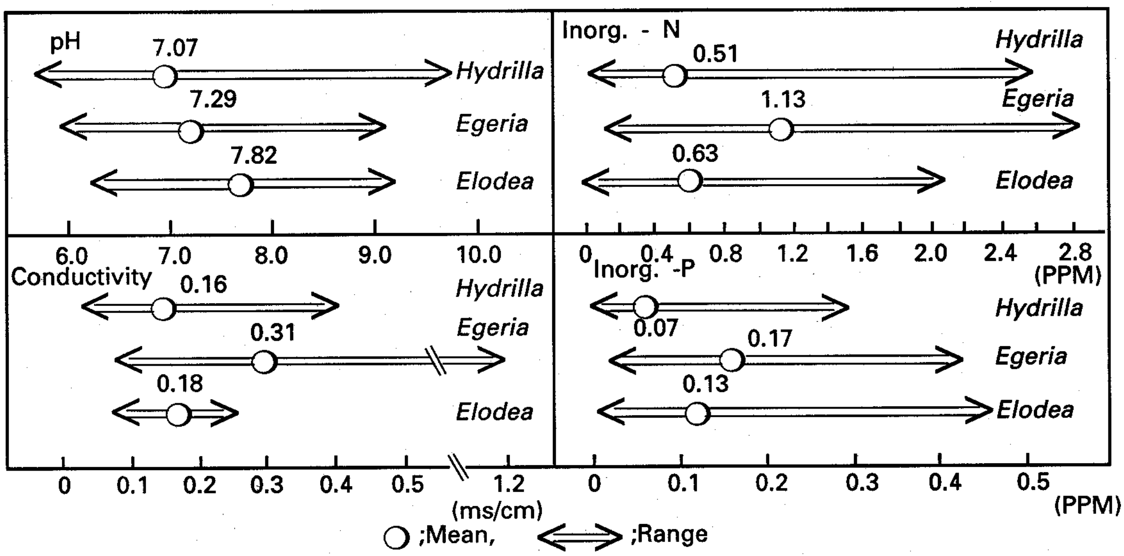

Fig. 1. Water quality in habitats of *Hydrilla*, *Egeria* and *Elodea*

Source: Oki et al. 1988a

Source: Oki *et al.* 1988a

small quantities of weed near the shoreline. The technique consists of cutting, mowing, raking, digging or pulling the vegetation and removing it from the water. In large expanses of water, a boat equipped with a cutting machine or an aquatic harvester such as the H-1500 are used to remove weeds. However, all mechanical control systems are expensive. The high reproductive rate of many aquatic weeds means that the harvesting must be carried out repeatedly to remove new growth.

Biological Control

The biological control of aquatic weeds has received considerable interest all over the world. However in the case of Japan, the efficacy of biological control agents is restricted by ecological factors. Only waterfowl and herbivorous fish have been investigated as possible agents. One species of herbivorous fish, the Chinese grass carp (*Ctenopharyngodon idella*), has been tested for the control of various species of floating, submerged and emerged weeds in various parts of Japan (Okuma *et al.* 1984). Grass carp grow rapidly, so that their food demand steadily increases (Barrett *et al.* 1990). Hence, periodic culling or re-stocking is necessary to maintain a satisfactory stocking level. We now need to carry out many practical experiments to see whether the effect of these carp in Japanese waters is beneficial.

Chemical Control

Prospects for chemical control of aquatic weeds in Japan are limited, since many herbicides seem to be toxic to fish and other animals, including human beings. However, a few trials based on chemical control are now under way, using 2,4-D Amine, Glyphosate, Fluazifop-buthyl, Diquat, Bentazone and Asulam to control emerged weeds, on the margins and along banks of lakes and rivers (Okuma 1985, Chikura 1986).

Environmental Control

Deepening shallow ponds and lakes is the most effective long-term method of preventing the growth of aquatic weeds. However, the cost of doing this may be high. This technique is therefore usually only carried out in small bodies of water.

Seasonal control of some weeds such as *Trapa* sp. has been achieved by partially draining ponds in late fall or early winter. Whole plants and seeds are usually killed when they are exposed to the cold, dry conditions of the Japanese winter for at least four months (Table 3) (Oki and Une 1989b).

UTILIZATION OF AQUATIC WEEDS

Contribution of Aquatic Plants

Aquatic plants are an essential feature of the aquatic ecosystem. The benefits they provide to the

	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	*Cabomba caroliniana*														
2	*Eichhornia crassipes*														
3	*Potamogeton octandrus*														
4	*Vallisneria natans*	** 0.29													
5	*Spirodela polyrhiza*														
6	*Potamogeton pusillus*	*** 0.37													
7	*Potamogeton malaianus*	* 0.21			*** 0.41										
8	*Myriophyllum verticillatum*	* 0.21			*** 0.53		*** 0.46	*** 0.50							
9	*Egeria densa*					** 0.34									
10	*Ceratophyllum demersum*	** 0.24	** 0.23		* 0.21	*** 0.35	*** 0.32								
11	*Hydrocharis dubia*	*** 0.32	*** 0.30			*** 0.36									
12	*Potamogeton crispus*				* 0.19	* 0.17	*** 0.61				*** 0.36				
13	*Hydrilla verticillata*	* 0.14				** 0.21	** 0.28		** 0.29				** 0.28		
14	*Trapa japonica*	* -0.29			*** -0.73			*** -1.00	*** -1.00						

Fig. 2. The Cole's coefficient of interspecific association.

The Cole's index assumes the values in the conventional range -1 to +1, where these two values represent a perfect negative and a perfect positive association, respectively. *, ** and *** indicate significance at the 0.5, 0.01 and 0.001 level of probability, respectively

Source: Une and Oki 1988

ecosystem include:

- The production of oxygen through photosynthesis,
- Cover for young fish so they can escape predation,
- Sites for attachment by a number of organisms,
- Protection against wave erosion and soil erosion of banks,
- Food supply for wildlife, including waterfowl,
- Removal of nutrients from the water (Gangstad 1978).

Aquatic plant species may also have other functions, for example as livestock feed, mulch, green manure, compost, or for handicrafts. They may also serve as ornamental plants, and add to the beauty and serenity of an aquatic landscape (Soerjani 1986). Most aquatic weeds share these functions, so that the utilization of aquatic weeds can be considered an important aspect of their management.

Application

An effort has been made in Japan to utilize aquatic weeds such as *Eichhornia crassipes*, *Lemna* sp., *Pharagmites* sp. and *Azolla* sp., as a means of reducing the nutrient levels of polluted waters, since the remarkably rapid nutrient uptake of these aquatic weeds has often been demonstrated. The use of other species such as *Typha* sp., *Scirpus* sp., *Iris* sp. and *Phragmites* sp. on both natural and artificial land for wastewater treatment is now receiving increasing attention.

A pilot plant is using aquatic weeds in the treatment of domestic sewage (Oki 1992). These facilities were established jointly by the Prefectural Public Health Center and the Town Hall of Okayama, and Okayama University. The system consists of a stabilization trench in which is growing *Eichhornia crassipes*, and two lined trenches containing soil which are designed to contain aquatic weeds of 13

Table 3. Effect of storage conditions over a 140-day period on seed germination of *Trapa japonica*

	Storage conditions		
	Flooded	Wet	Dry
Germination (%)	78.5	74.8	0.0
Viability (%)*	100.0	99.3	0.0
Soil moisture content (% dry weight)	—	43.6	2.1
Seed water content (% dry weight)	82.2	80.7	11.4

* : Represents the total of germinated seeds plus viable ungerminated seeds from TTC tests

Source: Oki and Une 1989b

species. In addition, there are three catalytic oxidation trenches. Effective removal of COD, SS, N and P has been achieved in the system over a one-year period. An 83% reduction in total N has been recorded, and a 92% reduction in total P (Table 4). It was observed that *Iris*, *Juncus* and *Elodea* appear to show promise as having a particularly marked ability to accumulate N and P. Accumulation by *Oenanthe* was higher during cooler seasons (Fig. 3).

PROPOSAL FOR FUTURE INTEGRATED MANAGEMENT

In many bodies of water all over Japan, it is being found necessary to control aquatic weeds. At present, mechanical removal is the most popular control method, but this provides only temporary relief and is expensive. Other control methods, such as chemical control and biological control, have generally been neglected because of public opinion. We should select an effective management system which makes minimal environmental impact by reducing the unwanted effects.

Barrett (1990) has pointed out that there are a number of points to be considered when deciding on the best management strategy. For example, there is a choice between total control or some form of selective control. This depends on the particular management objective. The management techniques chosen must be appropriate both to the type of weed problem, and to the uses and functions of the body of water. The risk of adverse side-effects for users of the water must always be given priority. In general, **the more effective the weed clearance, the greater will be the risk of an adverse environmental impact**.

Accordingly, aquatic weed management systems must be developed which are socially and environmentally acceptable. In addition, freshwater systems are now being viewed as a public amenity and recreational area which should be in harmony with the environment. It should be noted that no single method will guarantee the success of aquatic weed management. The combined use of several appropriate methods, including utilization of weeds as a resource, is often the best way of protecting the quality of the environment.

In my opinion, more basic research, to give us a better understanding of the biological, ecological, physiological and economical aspects of aquatic weeds, is needed for developing more effective ways of managing aquatic weeds.

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Table 4. Influent and effluent loading levels for wastewater treatment system in Okayama, Japan

Date		COD (mg/1)	BOD (mg/1)	SS (mg/1)	T-N (mg/1)	T-P (mg/1)
Sept. 12 1990	Influent	18.0	19.0	23.0	10.0	1.57
	Effluent	10.0	3.0	3.0	5.6	1.25
	Removal rate (%)	44.4	84.2	87.0	44.0	20.40
Nov. 26 1990	Influent	18.0	26.0	62.0	9.4	1.30
	Effluent	6.8	2.6	<1.0	8.1	0.89
	Removal rate (%)	62.2	90.0	98.4	13.8	31.50
Dec. 21 1990	Influent	32.0	45.0	97.0	17.0	1.70
	Effluent	6.5	2.7	4.8	7.3	0.84
	Removal rate (%)	79.7	94.0	95.1	57.1	50.60
March 6 1991	Influent	77.0	107.0	162.0	23.5	7.22
	Effluent	10.0	5.2	<1.0	9.9	1.42
	Removal rate (%)	87.0	95.1	99.4	58.1	80.30
July 23 1991	Influent	160.0	680.0	740.0	25.0	31.00
	Effluent	10.0	3.0	<1.0	4.3	2.40
	Removal rate (%)	93.8	99.6	99.9	82.8	92.30
Nov. 15 1991	Influent	56.0	30.0	600.0	9.5	3.6
	Effluent	7.2	2.4	<1.0	6.3	1.1
	Removal rate (%)	87.1	92.0	99.9	33.7	69.4

Source: Oki 1992

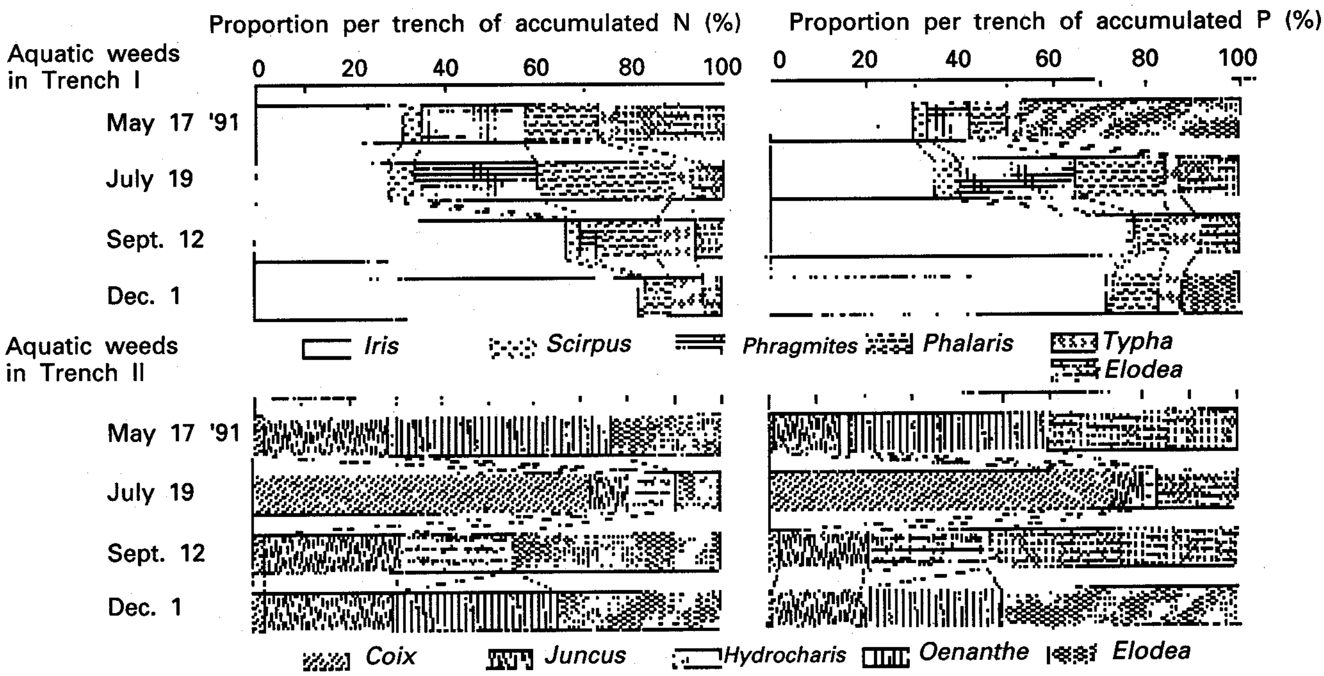

Fig. 3. Seasonal changes in relative abundance per trench of nitrogen and phosphorus accumulated in the foliage of each population of aquatic weeds

Source: Oki 1992

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DISCUSSION

During the Discussion, it was suggested that more attention should be paid to the uses and functions of macrophytes. It was emphasized that biological control agents in Japan are limited to herbivores, fish and aquatic birds, but Dr. Mochida informed participants that it is now planned to introduce water weevils into Japan to control waterhyacinth.