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Report on the factors affecting the decline in *Potamogeton dentatus*, an endangered water plant, in Kitakyushu City

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ABSTRACT — Factors affecting the decline in *Potamogeton dentatus*, which is a critically endangered submerged perennial plant, at an irrigation pond in Kitakyushu, the sole natural habitat of the species in Japan, were examined. The water flowing into the pond is very clear, and the physicochemical properties of the water of the pond are suitable for growth of the species, indicating that water quality is not the main factor in the drastic decline of the species at the pond. This special clarity of inflow to the pond may be why it has not been fully drained for several decades. Lack of drainage has made the quantity and quality of the bottom sediment unsuitable for growth of the species. In fact, bottom sediments with fine particles have accumulated and eutrophicated at the pond. Thus, the eutrophicated bottom sediments are likely to be the proximate factor causing the decline of *P. dentatus* at the pond. More broadly, socioeconomic changes in the 1960s and the special nature of the pond are the ultimate factors causing this decline.

KEY WORDS: Bottom sediments, Irrigation pond, Socioeconomic changes, Submerged plant

INTRODUCTION

Potamogeton dentatus Hagstr., which belongs to the Family Potamogetonaceae, is a submerged perennial (Fig. 1a), and is listed as a critically endangered species in the Red List of Japan (Ministry of the Environment Government of Japan, 2012) as well as that of Fukuoka Prefecture (Fukuoka Prefectural Government, 2011). The species formerly grew in several ponds and lakes such as Lake Kasumigaura in Ibaraki Prefecture, Inba-numa Pond and Tega-numa Pond in Chiba Prefecture, Tatara-numa Pond in Gunma Prefecture and Lake Biwa in Shiga Prefecture (Ootaki, 1975; Kadono, 1994). Kadono (1994) reported that the species once grew vigorously, such that it was previously used as green manure in Chiba Prefecture. In Japan, however, the species has become extinct in the wild because of water pollution of habitats, and now exists only in a single irrigation pond in Kitakyushu City (Fig. 2).

That the species has grown in Kitakyushu is interesting and important from a biogeographical point of view (Kadono, 1988). The habitat in Kitakyushu City (hereafter, habitat-pond) is located at the western edge of the distribution range of the species in Japan, but at the midpoint between habitats in China and those in Japan where the species formerly lived.

Many *P. dentatus* shoots with wound-up leaves and rotten stems (Fig. 1b) were observed in the summer of 2000, although such deformed shoots had seldom been seen at the habitat-pond previously. The distribution area and the biomass of the species drastically decreased at the habitat-pond in 2000 and 2001. We have been investigating the causes of the drastic decline and making protection plans for the species since 2002.

In this paper, we describe 1) the past utilization of the habitat-pond, 2) the physicochemical properties of the surface water and the bottom sediments of the pond, and 3) changes in the distribution of *P. dentatus*, and 4) its regeneration characteristics. Further, we discuss the causes of the drastic decline of the species at the habitat-pond in Kitakyushu City, which is now the sole natural habitat of the species in Japan.

STUDY SITE

The habitat-pond, an irrigation pond with an area of about 1 ha, is thought to have been constructed about 300 years ago. The pond is designated as one of the "500 Important Wetlands in Japan" (Ministry of the Environment Government of Japan, 2001).

The habitat-pond (a.s.l. ca. 100 m) is located at the foot of the Hiraodai limestone plateau. Groundwater flows into the pond from beneath the plateau. Domestic wastewater never flows into the pond. A single sluice gate, with holes, supplies water to nearby paddy fields. Water overflows a spillway even when

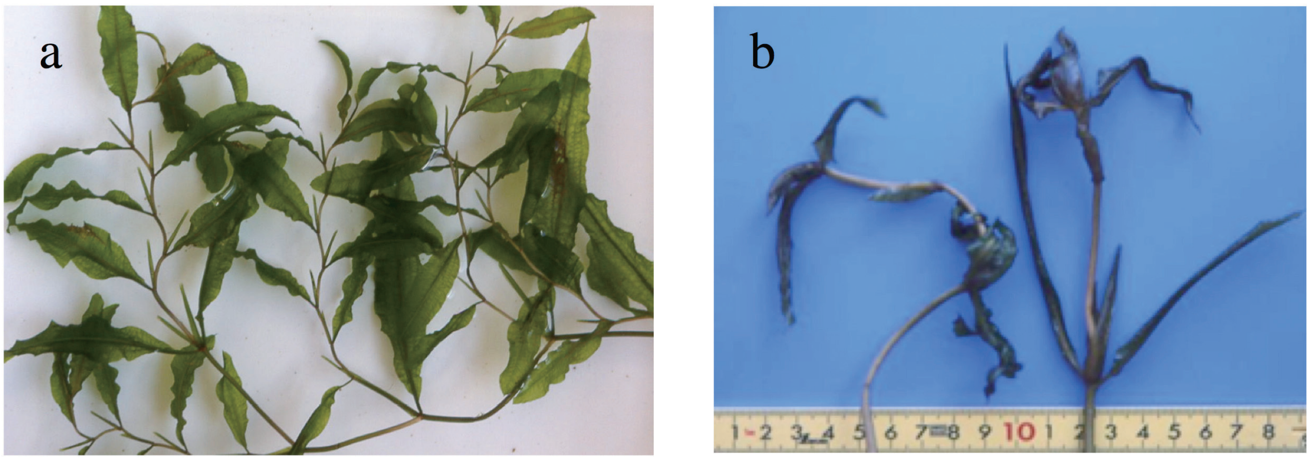

Fig. 1. The shoots of *Potamogeton dentatus* at the habitat-pond. a: normal shoot, b: deformed shoots with wound-up leaves and rotten stem.

Fig. 2. Photograph at the habitat-pond in 1999.

all the sluice holes are closed, indicating continual low-volume interchange of pond water.

P. dentatus and *P.* × *inbaensis* Kadono were the only water plants growing at the habitat-pond in 1987 when *P. dentatus* was discovered there (Oono, 1987a, 1987b). *P.* × *inbaensis* is a hybrid between *P. dentatus* and *P. malaianus* Miq. (Kadono, 1983).

There is a small island at the habitat-pond (hereafter called mid-island) that is connected with the bank by a small bridge. This mid-island and the artificial banks at the west side of the pond form a shallow bay (e.g. mesh #31 in Fig. 3). Secondary forest, dominated by evergreen broad-leaved trees such as *Castanopsis cuspidata* (Thunb.) Schottky, *Persea thunbergii* (Sieb. et Zucc.) Kosterm. and *Quercus glauca* Thunb., occur on the natural banks of the pond. The foliage of these trees partially limits the light incident on the pond.

STUDY SPECIES

P. dentatus maintains its population by vegetative reproduction from turions as well as by sexual reproduction from seeds (Fig. 4). In our observation, its new shoots appear from the turions from late March to early April, and grow vigorously until early June. After that, flower stalks grow and blossom until the middle of August. At most, four fruits are borne from each flower, with one seed contained in each fruit. Most shoots wither in early winter. We could not determined the period of seed and turion germination.

METHODS

Interview survey

To understand past utilization of the habitat-pond and surroundings, and the flora and fauna of the pond, interview survey was conducted in August 2002 with two representatives of the inhabitants with rights to use of the pond water. Similar surveys were also conducted with the president and the vice-president of the local neighborhood association at that time. All examinees, who were in their 60s, were born and raised near the pond.

Some of the information derived from the surveys might be secondary, with associated uncertainty.

Microtopography and the depth of the bottom sediments

A base point was established on the east bank of the habitat-pond, and five other reference points were created on the banks in the fall of 2002. The relative heights of the reference points and the surface of the water were measured using a Total Station surveying instrument using the height of the base point as zero elevation. A plane map, in and around the pond, was made using the plane-table method from the relative heights of the base and the reference points. The relative heights of the bottom of the pond and the depth of the bottom sediments were measured using a sounder.

The water level and physicochemical properties of the surface water and the bottom sediment

The water level of the habitat-pond was measured once a month from September 2002 to April 2006. The water level was further measured three times per month from May 2006 to March 2007.

The transparency of the water was measured at the center of the habitat-pond (hereafter, the center-point) using a Secchi disk (transparency disk). Surface water was collected at the inflow entrance of the underground water (hereafter, the entrance-point), at the center-point and in a shallow bay near the mid-island (hereafter, the shallow-bay). Temperature and dissolved oxygen content (DO) of the surface water were measured immediately; the pH and electrical conductivity (EC) of the samples were measured at the laboratory in the Fukuoka Institute of Health and Environmental Sciences. These measurements occurred once a month from September 2002 to March 2007.

Chemical oxygen demand (COD), total nitrogen (T-N), total phosphorus (T-P), sulphate ion (SO_4^{2-}), nitrate nitrogen (NO_3-N), chloride ion (Cl^-) and four cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) concentrations in the surface water samples were determined every odd-numbered month from September 2002 to March 2004. These were also measured in September 2004 and January 2005. The methods adopted in this study followed JIS K0102 (Japanese Standards Association, 1998) and the Standard Methods for the Examination of Water (Japan Water Works Association, 2001) for COD, T-N and T-P and others.

The ignition loss (the organic matter by loss-on-ignition), T-N and T-P of bottom sediments, which were collected at the center-point and the shallow-bay using an Ekman-Birge type of bottom sampler, were analyzed in September 2003, 2004 and 2005. T-N, T-P and the composition of the gradings in the bottom sediments were also analyzed at the center-point, shallow-bay and east shore of the mid-island (hereafter, the east-shore) in September 2006.

Distribution

The distribution of *P. dentatus* in the habitat-pond was plotted onto the plane map following visual observation on the banks and from the boat every September from 2002 to 2006. The plane maps were digitized using an image scanner, and the distribution areas of the species were calculated using Adobe PhotoShop software.

The in-pond growth area of *P. dentatus*, which could not be evaluated by visual observation on the banks and from the boat, was determined by diving in August 2004.

Regeneration characteristics

The numbers of flowers and fruits of *P. dentatus* were counted from 10 flower stalks that were sampled arbitrarily in the habitat-pond in August and September 2002. The seeds of each flower stalk were stored in a glass bottle filled with water. Those glass bottles were then stored in a test tank in the open air. The numbers of germinated seeds in each bottle were counted in the spring of 2003.

RESULTS

Interview survey

The following information was gleaned from the interview survey.

1) Plants: Abundant water plants had grown at the habitat-pond in the 1930s, although the species were unknown. Flower stalks had emerged from the water over the whole pond from mid- to late August.

2) Color of the water: The color of the water at the pond recently changed from emerald green to milky white.

3) Drainage: Drainage of the pond has been conducted only once, in the1950s and some fish and shellfish such as crabs, carp, crucian carp, eels and freshwater clams were collected when whole the pond was entirely drained.

4) Sluice: For a short period in the 1950s, a company, which had used the pond for rainbow trout breeding, had broken the bottom holes of the sluice gate, called 'Doro-Hibi' in Japanese. Then, those bottom holes were closed by the company using concrete. Further, no one knows the location of the closed holes, indicating that it would now be very difficult to completely drain the pond.

5) Water use: Previously, considerable pond water was used for farming, and the water level had typically gone down in the summer to the extent that residents could not dive into the pond in late August. Nowadays, the water level of the pond goes down at most only 30 cm, even in the summer, because a decrease in the area under cultivation, over the last 10 years, has reduced the amount of water used for farming.

6) Vegetation of surrounding area: Vegetation around the pond has changed from grasslands and shrubs to forests. Consequently, the limestone plateau behind the pond was no longer visible.

Microtopography and the depth of the bottom sediments

The natural topography still remained around the habitat-pond except for the north to northwest banks (Fig. 3). The depth of the water increased rapidly as the distance from the banks increased, except for the banks on the periphery of the mid-island. The maximum water depth was about 3.5 m.

The bottom sediments tended to be thicker in deeper water (Fig. 3), although they attained a thickness of more than 15 cm at the shallow-bay where the water depth was low.

The water level and physicochemical properties of the surface water and the bottom sediments

The fluctuation in the water level at the habitat-pond was ±0.1 m over the period September 2002 to April 2006 (Fig. 5). A similar variation was observed during the period when the water level was measured three times per month. Thus, the water level of the pond was usually stable, although some exceptions were observed. For example, the water level dropped 1.5 m during the rainy season in 2005, when the precipitation was very low, and rose 0.3 m in the 2006 rainy season. A decline in water level during January and February 2007 was due to test drainage of the pond.

The mean transparency in the habitat-pond water was 2.0 m, with the range of 2.7 m to 1.4 m, during September 2002 to March 2005. The transparency was low in summer —the time in which *P. dentatus* usually grows vigorously (Fig. 6). The transparency of the water deteriorated in the period April 2005 to March 2007 (mean: 1.6 m, range: 1.0-2.3 m). In this period, the transparency of the water was low even in the winter, suggesting that the annual transparency fluctuation pattern had changed from the earlier period (September 2002 to March 2005). This fact might indicate that the drastic change of aquatic ecosystem at the habitat-pond, known as regime shift, had occurred due to the severe drought in the rainy season in 2006.

The water temperature was almost stable, with the mean of 14.4℃ (range: 14.3-14.5℃) at the entrance-point. The mean and the range of water temperature at the center-point were 14.4℃ and 6.7-26.2℃ , respectively, and were similar to those at the shallow-bay (mean: 14.4℃ , range: 6.2-27.1℃).

The mean pH was 7.7 at the entrance-point was slightly lower at both the shallow bay and the center-point (Table 1). The means of DO and EC were also similar among the three survey points (DO: 9.9-10.3 mg/l, EC: 275-287 μS/cm). The COD at the entrance-point was lower than the minimum limit of determination, except for two measurements (January and March 2005), and also lower than at the center-point (minimum limit-2.2 mg/l) and at the shallow-bay (0.5-3.2 mg/l). The differences in the mean T-N and T-P concentrations were also small. The concentrations of the ions in the water analyzed were also similar among the three points.

The ignition loss of the bottom sediments differed among the years analyzed (Table 2). T-N of the bottom sediments at the shallow-bay was higher than at the center-point, although T-P was similar at the shallow-bay and the center-point. Further, in 2006, T-N and T-P were much higher in the center-point and the shallow-bay sediments than at the east-shore.

The bottom sediments were mainly composed of very fine particles such as silt fractions (>81%) and clay fractions (11%) at the center-point and the shallow-bay (Table 3). By contrast, rough particles such as granules (71%) and coarse sands (23%) were the main components of the bottom sediments at the east-shore.

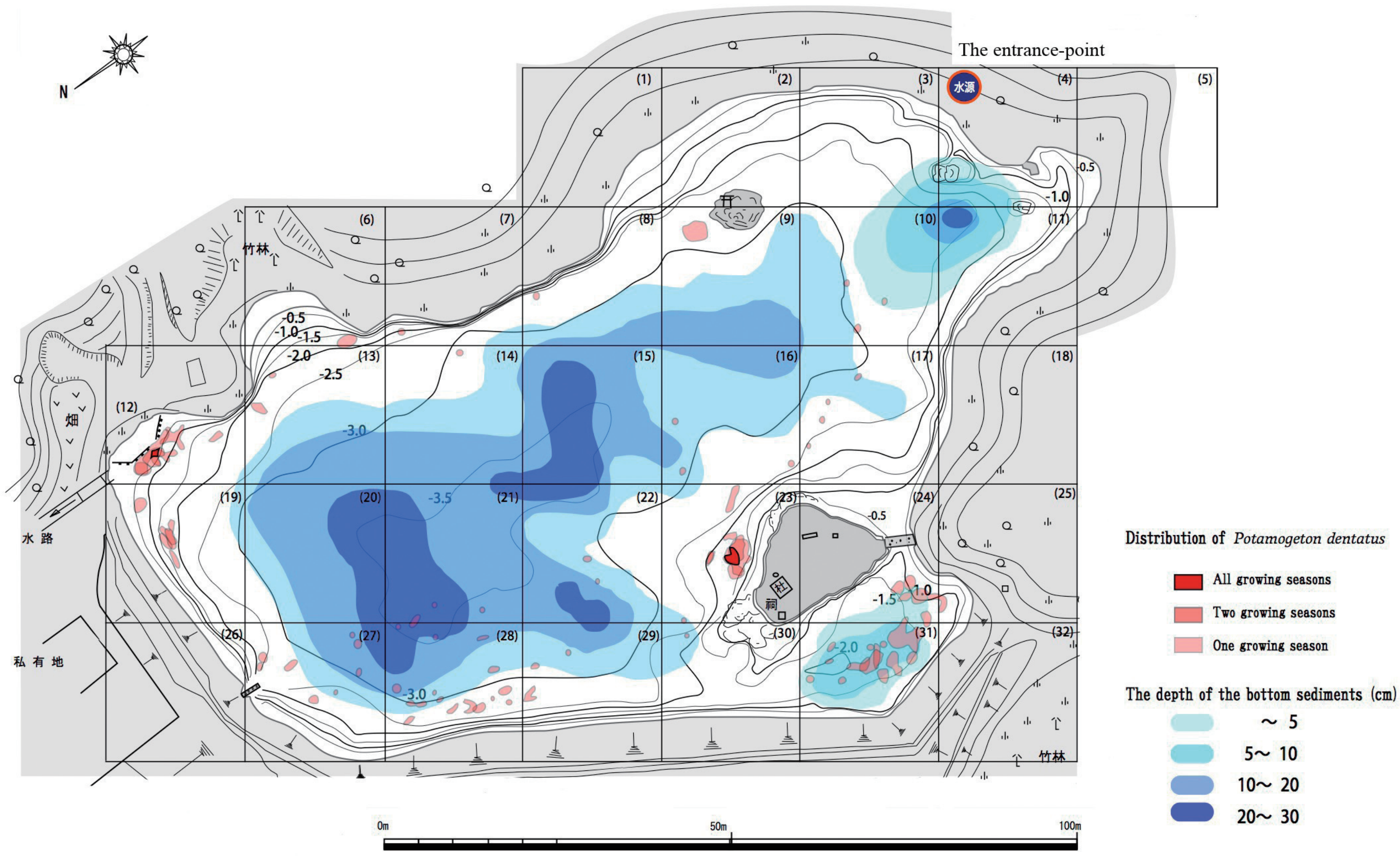

Fig. 3. The water level, the depth of the bottom sediments and the change in distribution of *Potamogeton dentatus* from 2002 to 2004 at the habitat-pond. The narrow lines and the numbers added to the lines show the isopleths and the values of the water level in October 2002, respectively. The number in parentheses is the mesh number for reference.

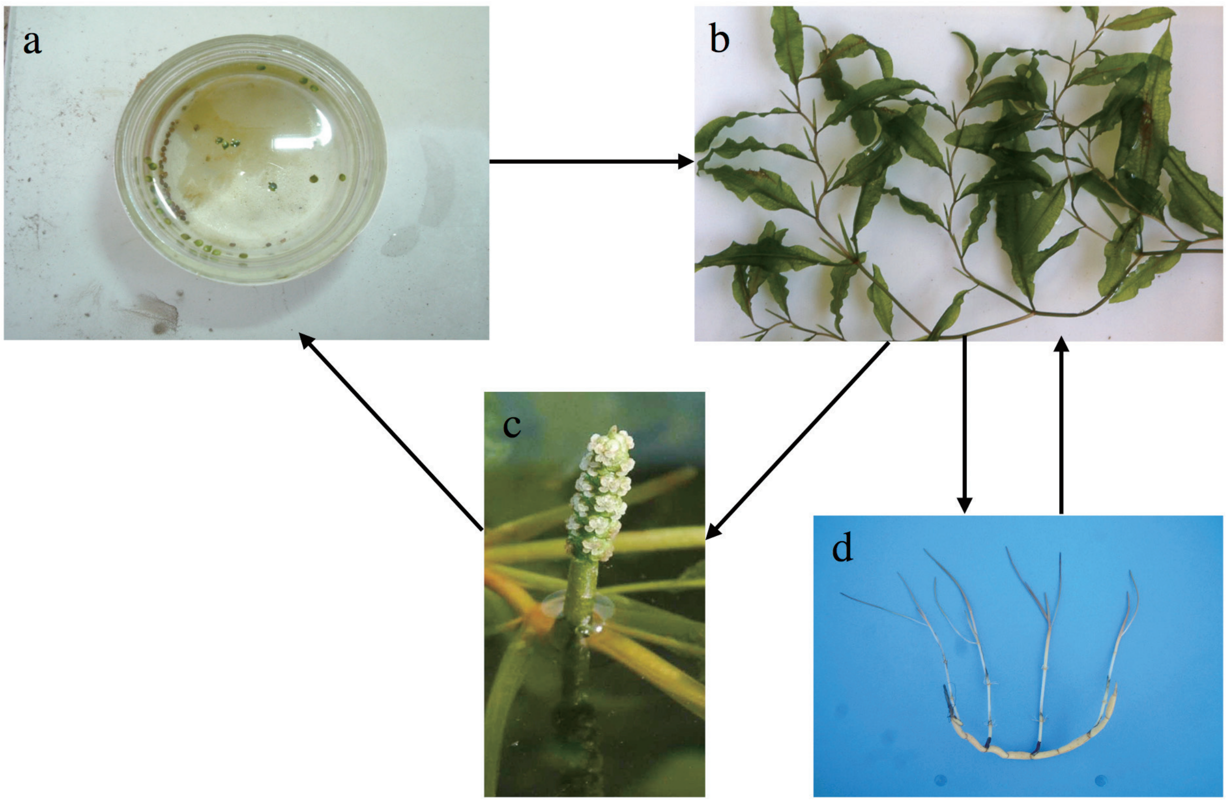

Fig. 4. Life history of *Potamogeton dentatus*. a: seeds, b: shoots of mature individuals, c: flower stalk, d: turion.

Distribution

Based on photographs (e.g., Fig. 2) and memories of a field survey undertaken by the authors (Suda and Manabe) in 1999, *P. dentatus* foliage covered at least one-third of the pond at that time. Thus, the species covered more than 330 m^2 of the pond in 1999. However, the area had decreased substantially (135 m^2) in 2002 and further decreased (ca. 25 m^2) in 2003 (Fig. 7).

On the other hand, small individuals of *P. dentatus* were observed at the bottom, by diving, near the southwestern bank of the habitat-pond (mesh #14 in Fig. 3). The depth of the water was about 2 m, and those individuals could not be observed from the banks or the boat. These points were beneath the crowns of evergreen broad-leaved trees growing on the natural banks of the pond.

The changes in the distribution of *P. dentatus* at the habitat-pond from 2002 to 2004 are shown in Fig. 3. The small part at the east-shore was the sole areas where the species were found in all studied growing seasons (2002-2004).

Regeneration characteristics

The flower stalks of *P. dentatus* that were arbitrarily sampled in the habitat-pond had six to 12 flowers per unit length (1 cm) of the spike (Table 4). The fruiting ratio (the number of flowers that set seeds / the number of flowers) differed widely among the flower stalks (41.5-95.7%). The germination rate of seeds from each flower stalk was low (3-30%). No seeds borne by four of the flower stalks germinated.

Since 2004, most flower stalks bloomed under the water, and bore few seeds.

DISCUSSION

Proximate factors causing the decline of the species

Many large carp grow in the habitat-pond and some waterfowls were kept for over ten years at the habitat-pond. These suggest that *P. dentatus* might have been preyed by the carp and the waterfowls. However, those predation might not be the main factor causing the drastic decline of *P. dentatus*, as it would not expect that the amount of prey by those predators increased suddenly around 2000 in which *P. dentatus* has decreased drastically in the pond.

The T-N means in surface water at Inba-numa Pond and Tega-numa Pond in Chiba Prefecture, where *P. dentatus* had once grown, were 2.3 mg/l and 4.3 mg/l, and those of T-P were 0.10 mg/l and 0.44 mg/l respectively (Yamada *et al*., 1993). The T-N and T-P means in surface water at 119 irrigation ponds in Aichi Prefecture were reported as 0.93 mg/l (range: 0.13-5.72 mg/l) and 0.06 mg/l (range: 0.01-0.83 mg/l) over the period 1992 to 1996 (Kasuya, 2001). T-N and T-P in surface water were

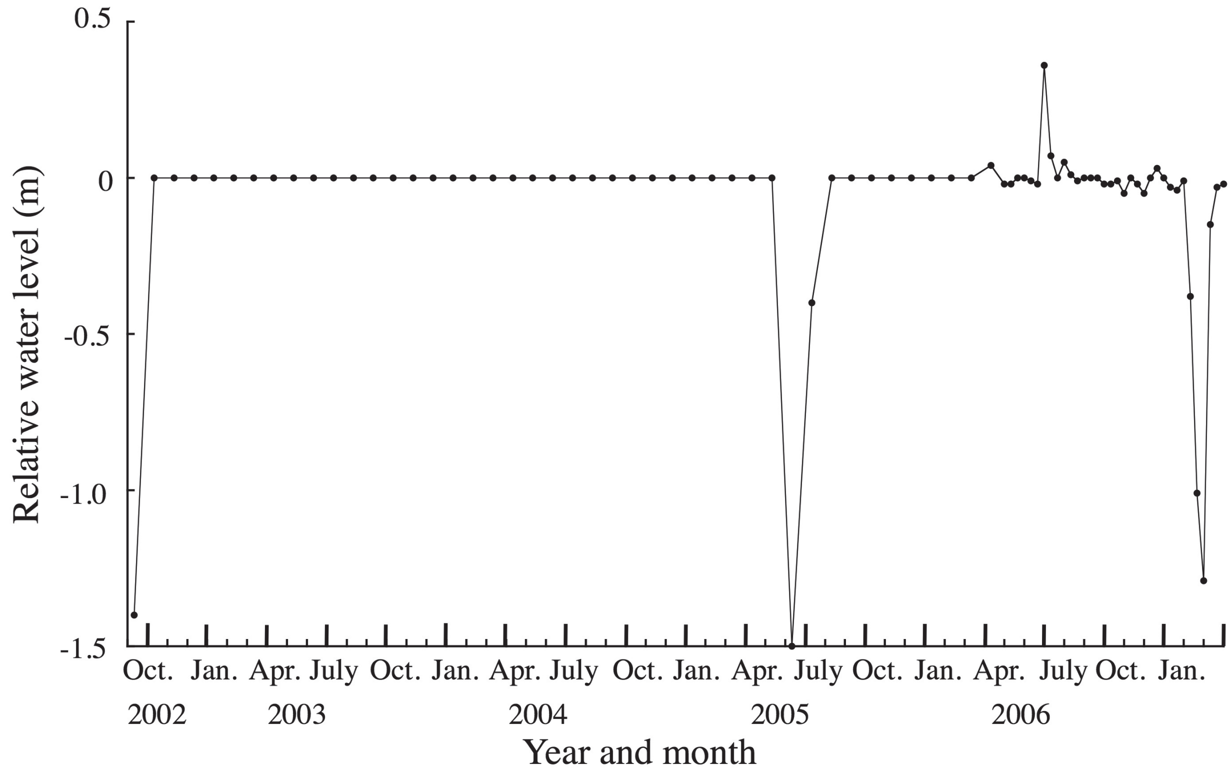

Fig. 5. The relative water level of the habitat-pond from September 2002 to March 2007. The water level was measured once a month and three times a month from September 2002 to April 2006, and from May 2006 to March 2007.

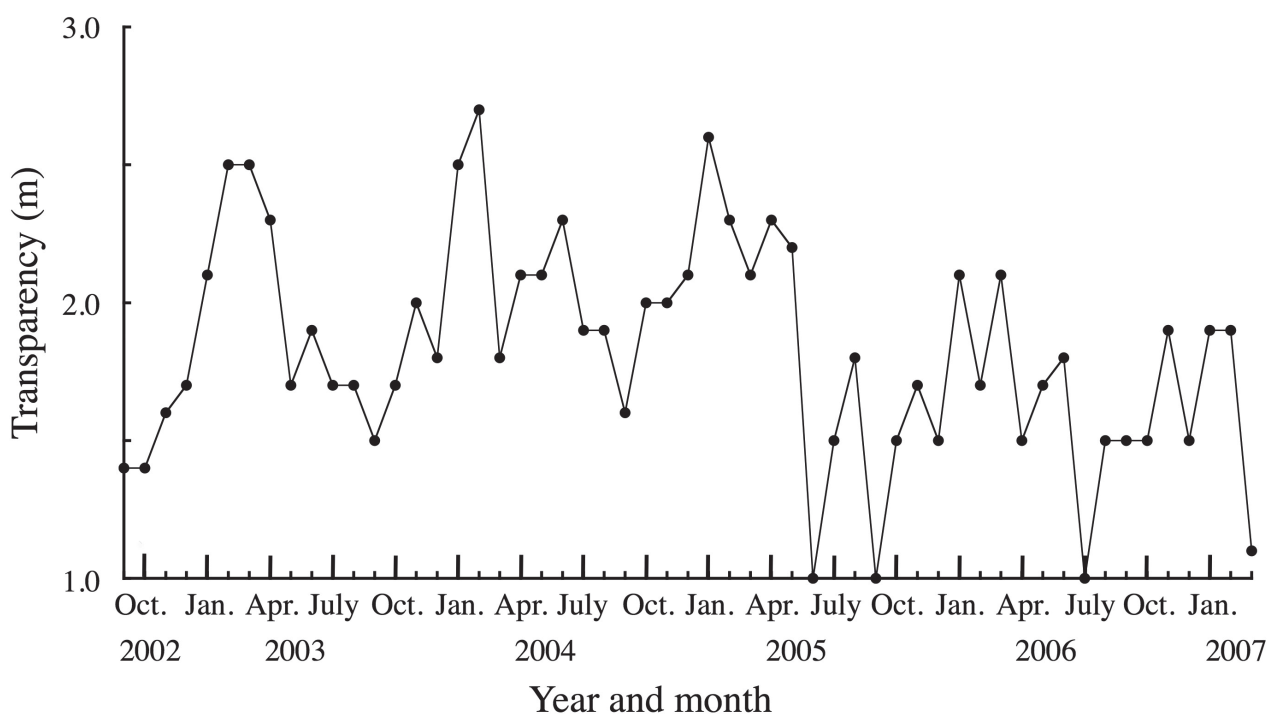

Fig. 6. The change in the transparency (m) of the water at the habitat-pond from August 2002 to March 2007.

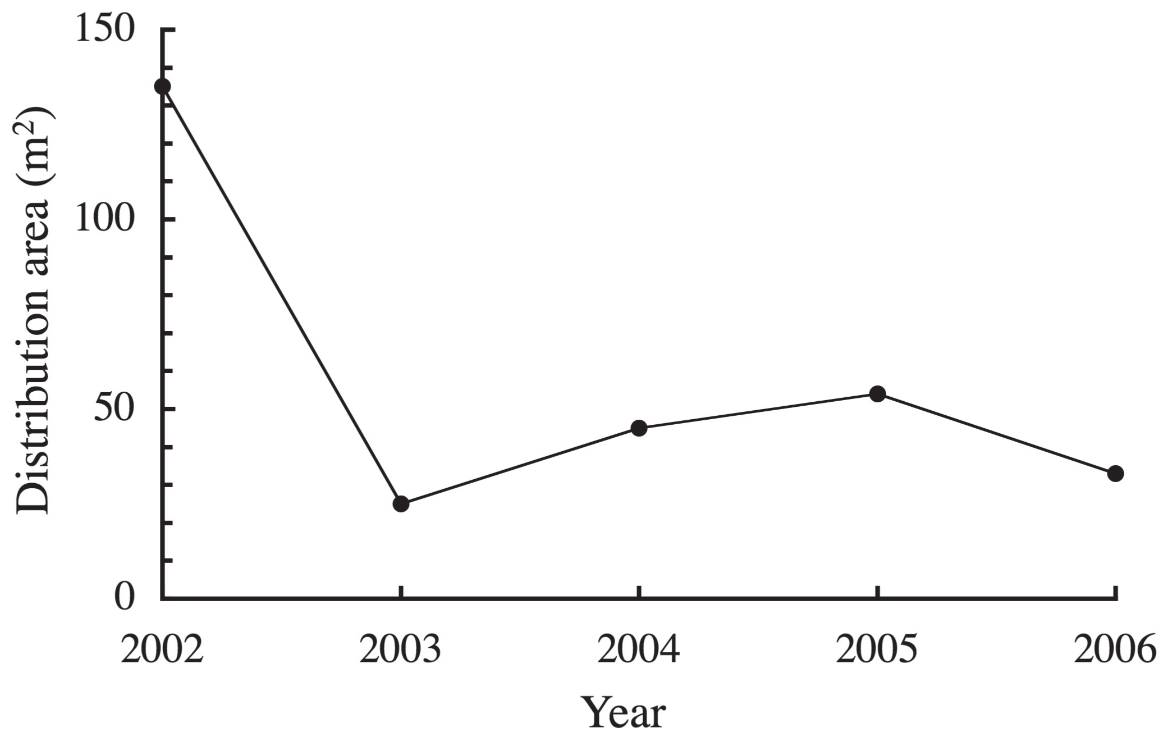

Fig. 7. The change in the distribution area (m^2) of *Potamogeton dentatus* at the habitat-pond from 2002 to 2006.

much lower at the habitat-pond than in the reported ponds in Chiba and Aich Prefectures. In addition, Shimoda & Hashimoto (1993) point out that water with mean T-N and T-P equivalent to the habitat-pond is suitable for growth of various water plants. Further, the chemical analysis by the Institute of Environmental Science at the City of Kitakyushu showed that water of the habitat-pond contained no ingredients of agricultural chemicals (Higashida, personal communication).

Therefore, the quality of the surface water is not the main factor in the drastic decline of *P. dentatus* at the habitat-pond, although the deterioration of water quality is one of the important reasons for the decline of many water plants (e.g., Yamada *et al*., 1993).

On the other hand, the center-point and the shallow-bay, where *P. dentatus* had once grown vigorously, were characterized by deep water levels and/or a large amount of the bottom sediment composed of very fine particles such as silt and clay fractions. At the center-point, the water level was deep, and substantial bottom sediments had accumulated. At the shallow-bay, the amount of the bottom sediments was similar to the center-point, although the water depth was low. Further, the ignition loss, T-N and T-P of the bottom sediments were all higher at the center-point and the shallow-bay that at the east-shore. These values indicate that the bottom sediments at the sites have been in the state of eutrophication and unsuitable for the growth of many water plants (Kobayashi, 1982). In addition, Fig. 3., which shows the changes in the distribution of the species at the pond from 2002 to 2004, indicates that the areas at the east-shore where the species were found in all studied growing seasons (2002-2004) were characterized by a shallow water level and shallow bottom sediments with a low rate of fine particles. In contrast, the shallow-bay where the species had once grown vigorously had a large amount of bottom sediments with fine particles. These findings suggest that both the amount and the physicochemical properties of the bottom sediments have influenced the decline of *P. dentatus* at the pond.

The following causal relationships between the quality and the quantity of the bottom sediments and the decline of *P. dentatus* at the habitat-pond can be inferred. A large amount of bottom sediments with fine particles brings about respiratory inhibition of the roots of the species. Deformed shoots observed in 2000 (Fig. 1b) may be attributed to respiratory inhibition of the roots. Respiratory inhibition of the roots may also induce inhibition of shoot elongation. Further, fine particles in the bottom sediments, which are stirred by strong winds or by the activities of many large carp growing in the pond, need a long time to settle and so rapidly attenuate the incident light in the water. This attenuation of the incident light can be expected to reduce the photosynthetic products of the species, which inhibits shoot elongation and turion production. Due to inhibition of

Table 1. Chemical properties of the surface water at the habitat-pond.

The places analysed		pH	DO (mg/l)	EC (μS/cm)	COD* (mg/l)	T-N (mg/l)	T-P* (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	SO_4^{2-} (mg/l)	NO^3-N (mg/l)	Cl^- (mg/l)
The center-point														
	Mean	8.0	10.4	276	1.1	0.29	0.009	41.3	1.9	4.8	0.49	8.3	0.24	5.3
	S.E.	0.0	0.1	1	0.1	0.02	0.001	2.3	0.1	0.2	0.04	0.1	0.02	0.1
	Max.	8.4	12.9	292	2.2	0.38	0.017	56.0	2.9	5.7	0.78	9.1	0.42	6.3
	Min.	7.7	8.0	252	0.5^{L}	0.16	0.005	33.2	1.4	3.4	0.22	7.2	0.12	4.7
The shallow-bay														
	Mean	8.0	10.2	277	1.2	0.31	0.009	41.4	1.9	4.7	0.49	8.2	0.22	5.2
	S.E.	0.0	0.1	1	0.2	0.02	0.002	2.2	0.1	0.3	0.04	0.1	0.02	0.1
	Max.	8.4	12.5	296	3.2	0.46	0.033	56.0	2.8	5.9	0.76	9.1	0.35	5.9
	Min.	7.7	8.2	241	0.5	0.17	0.003^{L}	33.2	1.4	3.1	0.19	7.4	0.10	4.6
The entrance-point														
	Mean	7.7	9.9	286	0.5	0.29	0.006	42.3	1.8	4.8	0.50	8.3	0.33	5.2
	S.E.	0.0	0.1	1	0.0	0.02	0.001	2.3	0.1	0.2	0.04	0.1	0.01	0.2
	Max.	8.0	11.8	307	0.5	0.39	0.014	58.0	2.8	5.8	0.76	8.8	0.42	5.9
	Min.	7.6	8.4	271	0.5^{L}	0.12	0.003^{L}	33.1	1.4	3.3	0.17	7.6	0.27	4.0

*; L indicates the minimum limit.

Table 2. Ignition loss (%), T-P (mg/kg) and T-N (mg/kg) of the bottom sediments at the habitat-pond.

The places analysed	Items	Year			
		2003	2004	2005	2006
The center-point					
	Ignition loss	10.4	9.4	18.0	
	T-P	510	480	510	490
	T-N	2,800	2,400	2,400	2,100
The shallow-bay					
	Ignition loss	13.2	12.6	20.8	
	T-P	530	490	550	540
	T-N	3,800	3,200	4,200	3,600
The east-shore					
	T-P				200
	T-N				500

Table 3. The composition (%) of the gradings in the bottom sediments at the habitat-pond.

Composition	The places analysed		
	The center-point	The shallow-bay	The east-shore
Granules	0.0	0.0	71.3
Coarse sands	0.1	0.3	23.2
Fine sands	7.3	3.9	5.4
Silts	81.6	84.8	0.1
Clays	11.0	11.0	0.0

Table 4. The number of flowers per unit length (cm^{-1}) the fruiting ratio (%), the number of seeds per fruit and the germination rate (%) for 10 flower stalks of *Potamogeton dentatus* at the habitat-pond.

Flower stalks	The number of flowers per unit length	The fruiting rate	The number of seed per fruit	The germination rate
1	9.7	76.5	2.6	5.9
2	7.8	55.6	2.3	0.0
3	8.0	77.1	2.6	2.8
4	11.8	45.5	3.0	0.0
5	12.4	80.6	2.3	0.0
6	10.0	95.7	2.4	16.0
7	6.6	63.0	2.4	0.0
8	8.1	69.2	1.9	30.0
9	9.8	61.4	2.3	17.7
10	9.3	41.5	1.9	6.1

shoot elongation, most flower stalks have been unable to emerge from the water since 2004. These flower stalks bloom in the water and produce few seeds. Thus, pollination has not been effective. You-Hao & Cook (1989) found that for *P. pectinatus*, in Switzerland, the fruit-set was higher for flowers that bloom above the water than for those that bloom in the water. This indicates that the inhibition of shoot elongation also diminishes seed production. Further, accumulated bottom sediments with fine particles are likely to inhibit germination of the seeds and the turions of the species, even if sufficient seeds and turions were produced.

The fruiting ratio differed greatly among the flower stalks of *P. dentatus* at the habitat-pond. This could be attributable to depression of the species through inbreeding, for the genetic diversity of the population was lower at this pond than in the Kanto region, which has regenerated from buried viable seeds (Uehara *et al*., 2006). However, the cause of the large variation of germination rate observed at the pond remains unknown.

As mentioned above, direct and indirect impacts of the depth and physicochemical properties of the bottom sediments, especially fine particles, affect various stages of the life history of *P. dentatus* at the habitat-pond. Thus, abundant accumulation of eutrophicated bottom sediments with fine particles is likely to be the proximate factor causing the decline of the species at the pond.

Ultimate factors causing the decline of the species

The recent decrease in water utilization, which is due to an increase in abandoned paddy fields, causes the stable state of the water level at the habitat-pond. As a result, surface waves usually hit the same areas of the banks, increasing erosion in those areas. Most water flowing into the pond is underground water that underflows the limestone plateau. This contains no fine particles such as silt and clay fractions. Thus, most of the fine particles in the bottom sediments must be derived from the banks of the pond.

Most flower stalks of *P. dentatus* have not bloomed above water since 2004. This may be partly attributable to the stable high water level due to the increase in abandoned paddy fields. Previously, much water was used for irrigation, and the water level of the pond would go down in the summer at the time the flowers bloomed.

In Japan, most secondary vegetation such as grasslands and shrubs was maintained by traditional methods and persisted under human impacts as 'Satoyama' (e.g., Kamada *et al*., 1991). However, a rapid transformation of the main energy source from biomass to fossil fuels in the mid-1960s, which was known as the 'fuel revolution', diminished the socioeconomic value of secondary vegetation. Consequently, much secondary vegetation has become forests through ecological succession, as seen in various areas in Japan (e.g., Kamada & Nakagoshi, 1990). The similar change in vegetation around the habitat-pond, from grasslands and shrubs to forests, has brought about not only a decrease in incident light into the water, but also an increase in leaf litter entering the water. In addition to this litter, the droppings of some waterfowls might raise the organic content, T-N and T-P of the bottom sediment.

On the other hand, the water flow into the habitat-pond is very clear. This special feature may be why the pond has not been drained for several decades. This has gradually made the quantity and quality of the bottom sediment unsuitable for the growth of *P. dentatus*. It is possible that the quantity and quality became unsuitable for survival of the species around 2000.

The local socioeconomic changes and the special nature of the habitat-pond itself are, therefore, the ultimate factors causing the decline of *P. dentatus* at the pond.

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