Spatiotemporal damages on an endangered endemic aquatic plant, *Schoenoplectus gemmifer* (Cyperaceae), by a series of heavy floods

Koshi Kitamura[1], Jin Yoshimura[1, 2, 3]* , Kei-ichi Tainaka[1] and Satoshi Yokojima[1]

[1]Department of Systems Engineering, Shizuoka University, Hamamatsu 432-8561, Japan.

[2]Marine Biosystems Research Center, Chiba University, Uchiura, Kamogawa, Chiba 299-5502, Japan

[3]Department of Environmental and Forest Biology, State University of New York College of Environmental Science and Forestry, Syracuse, New York 13210 USA

*corresponding author (jin@sys.eng.shizuoka.ac.jp).

Author email list:

Koshi Kitamura: tkkitam@ipc.shizuoka.ac.jp

Kei-ichi Tainaka: tainaka@sys.eng.shizuoka.ac.jp

Satoshi Yokojima: Yokojima@sys.eng.shizuoka.ac.jp

Abstract:

River managements often conflict with the conservation of species in river ecosystems. In Japan, almost all river systems have been covered by concrete walls. Such river improvement works caused critical damages to river ecosystems. Here we report the ongoing extinction process of a rare aquatic plant by several consecutive heavy rains. The aquatic plant, *Schoenoplectus gemmifer* C. Sato, T. Maeda & Uchino, is an extremely rare endemic species that is strictly associated with spring water. The species is only found in twenty-three locations in Japan, including only two major habitats: Hamamatsu and Oita. We monitored the population fluctuations of *S. gemmifer* at three river systems in Hamamatsu. In the largest habitat, Higashikanda River, the population size of the species decreased to nearly 1/10th in 2004, due to several severe floods. Spatial and temporal records exhibit four stages of damaging process. The stepwise damages were found to be caused by a rapid flow of water accelerated by the river improvement work (made in 1985). The reproduction and growth by seeds and gemmae did not evidently cover the losses by flood washed out. In the two other rivers, one was extinct and the other is now at the risk of extinction. The modified river structures are responsible for the near-extinction of *S. gemmifer* in Hamamatsu area. We propose two policies for the conservation of this species: (1) the artificial cultivation of gemmae and seedlings and (2) the modification of river structure to decrease the number of washed-out plants. In particular, it is important to decrease the fluid velocity at floods by some methods.

Keywords aquatic plant; river ecosystem; heavy rain flood; spatial distribution; river improvement

Introduction

Conservation of biodiversity is one of the most important environmental problems (Rosenzweig 2003; Pimm 2001; Linda and Pierre 2006; Tukasa et al. 1986). Recently the conservation of fresh water ecosystems has become one of the major issues in conservation biology. Many common aquatic plants, animals and insects have disappeared in most rural ecosystems in Japan. Such species are often enlisted in the so-called Red Data Books of Japan (e.g., see NESCSP 2004). These disappearances are suspected to be due to land use development and water pollution.

Recently river management has been also questioned as an important problem. The past river management has focused on the control of floods. The concrete wall and basin has been covering almost all river systems in Japan to protect from floods. Almost all river systems are extensively modified: e.g. concrete banks, flat bottoms and straightened rivers (Kada 2006). Due to such changes, natural stream ecosystems have been destroyed completely in most places in Japan. These drastic changes and losses in aquatic and streamside habitats have resulted in the loss of many aquatic organisms used to be commonly found in rural Japan. Plants cannot grow and reproduce well on the concrete basin because of weak and shallow root systems. The damages on aquatic plants should be associated with river improvement works throughout Japan. The river ecosystems are among the most damaged ecosystems in Japan. It is important to study the close relationships between river improvement works and the extinction of aquatic plant species.

Here we report the effects of floods on a rare endemic aquatic plant, *Schoenoplectus gemmifer*, growing on the basin of three-sided concrete river systems. We have been surveying the spatiotemporal changes of the species along with rainfall dynamics. We also evaluate the effects of rocks in the streams on the plants, when the rainfall is high. Our main hypothesis here is the population dynamics (decrease) of this plant is controlled by the river stream flow associated with rainfall. We also hypothesized that the population destiny of this plant is near future extinction unless a measure of protection is introduced. We then discuss the problem of river managements for the conservation of this aquatic plant. In conclusion, we propose a measure of conservation for this rare endemic species.

Materials and Methods

Study Material

The study material is a very rare endemic species, *Schoenoplectus gemmifer* C. Sato, T. Maeda & Uchino. It is a new species of the genus *Schoenoplectus*, Sect. Actaeogeton, Cyperaceae, described in 2004 (Sato et al. 2004). It is very closely related to *S. triangulates* and has been recognized at least since 1990 (Sato and Imae 1990, Sato and Maeda 2001, Horiuchi 2003).

The genus *Schoenoplectus* consists of several hundred species with many varieties. The genus *Schoenoplectus* is further divided into 6 sections including Sect. Actaeogeton that consists of about 20 species distributed widely in the world. In Japan, about a dozen species are known in the genus *Schoenoplectus*. The Sect. Actaeogeton is mostly distributed East Asia and the surrounding regions, and about thirteen species have been found in Japan

S. gemmifer is closely related to *S. triangulates* that is common and widespread in Japan. They are an emergent plant characteristic to densely tufted triangular culms. Several morphological differences are reported between *S. gemmifer* (Plate 1) and *S.*

triangulatus. The two main features of *S. gemmifer* are (1) linear leaf blades (Plate 1C 1) and (2) gemmae (budding or vegetative form of reproduction; Plate 1B).

Linear leaf blades are the stream-form culms, while the usual still water-form stems are triangular culms. *S. triangulates* has only triangular culms which mostly stand out of water surfaces. A stock of *S. gemmifer* sometimes develops a few linear leaf blades. We also found many stocks mostly or entirely consisting of linear leaf blades after the severe floods (Plate 1C).

This plant, *S. gemmifer*, can produce its offspring by asexual (gemmae) and sexual reproductions (seeds). It grows gemmae very frequently when the culms are laid down by fast river currents (Plate 1B). In contrast, *S. triangulates* are very rarely produce a gemma. In *S. gemmifer*, gemmae are mostly made by a stream form produced at/near the tip of culm (stem) in this species. On the other hand, flowers (spikelets) and seeds are made only by a standing form (Plate 1A). The populations mainly increase by gemmae, the asexual reproduction.

S. gemmifer has another extremely unique feature: the strict association with spring water. From our survey of 17 locations, we also confirm that *S. gemmifer* is strictly associated with spring water (Table 1), which is also different from *S. triangulates*.

The currently known distribution of *S. gemmifer* is limited only about 20 locations in Japan, including some extinct localities (Fig. 1 and Table 1). The distribution of the species is highly sparse and scattered mainly in the western half of Japan (Fig. 1). The only exception is Kumamoto Prefecture, which has at least 6 identified locations. Extinction is also confirmed in several localities: (1) Okuchi, Kagoshima; (2) Shakujii Park, Tokyo; and (3) Wakayama Prefecture. We also confirmed recent extinction at Kameoka, Kyoto on September 9, 2004, which is due to the entire development of the habitat. Thus the species is one of extremely rare and extremely endangered endemic aquatic plant species only found in Japan. Currently the species are not listed in the Red Data Books in Japan (NESCSP, 2004), because its scientific name has been described after the publication of the red data books. However, from these facts, the species should be immediately categorized a critically endangered species (CR, rank IA).

Survey Site

The major habitats of *S. gemmifer* are located at Hamamatsu (Kitamura 2005) and Oita. We have been surveying several populations newly found in three small streams near Sanaru Lake in Hamamatsu, Shizuoka Prefecture (Fig. 2): Higashikanda River (Site 1), Nakando River (Site 2) and Shin River (Site 3) (Kitamura, 2005). The habitats in Hamamatsu are unique since all the rivers locate in the highly populated residential suburb of Hamamatsu city.

The river systems of these three rivers are artificially modified to prevent floods (Table 2). In Higashikannda River, the most artificial structure has been build by 1985. Most down streams are covered by concrete walls with natural mud floor, but in mid stream, there are three-sided concrete sections. In the up streams of Higashikannda River, both concrete walls or natural mud banks are seen with natural mud floors. In the entire streams of Nakanndo River, three sides (two walls and a floor) are covered by concrete. In Shin River, most streams are covered by concrete walls with natural mud floors.

In these three rivers, the stream is modified to be linear (straight) or slightly curve-linear for smooth water flows (Table 2). The widths of these rivers are almost constant throughout a stream. The widths of Higashikannda River, Shin River and

Nakando River are 6m, 4m and 1m, respectively. The floors of the rivers are either natural or made by concretes (Table 2). The natural floors are made either by small stones or hard mud layers. All these floors are flat; all the deep corners are buried to be shallow and leveled. The cross sections of the flows (streams) are a rectangular or trapezoid shape. Therefore, the depth of a stream is relatively flat in these rivers.

Survey Methods

We have been surveying the population fluctuations of the species along with rainfall dynamics during July 2004 –March 2006 (and continuing). The survey has been continuously conducted in all three rivers: Higashikanda River, Nakando River and Shin River (Fig. 2). In their habitats, all banks are built with artificial concrete and/or block walls. In their habitats, river floors are almost flat with few small rocks. The total number of plants is counted in all the habitats of all three rivers. In Site 1 of Higashikanda River, the distributions of individual plants are mapped to study the detail spatiotemporal dynamics of the plant population in the two study sites (Fig. 2). Site 1 is located south of the Nishiyama-kita Park, and the mapping area is 6m width (river width) and 10m length. In Site 1, the survey was performed whenever the precipitation exceeds 10mm (JMA 2007 for the precipitation records). In Higashikanda River and Nakando River, the survey of the entire streams is also performed annually at February 11. In Shin River, the survey has been terminated 2 years after the extinction of the last plant.

We study the relationship between water flows and the number of washed away plants. We use the precipitation records of Hamamatsu Weather Station (N.34˚42.5', E. 137˚ 43.1'), 4 kilometers southeast of the habitats. Whenever precipitation (rainfall) exceeds 10mm, the survey of Higashikanda Rivers is carried out throughout the study durations. We also frequently check the rivers and population conditions of all three habitats throughout the study period. In 2004, three typhoons hit Japan during a short period, and they caused a series of heavy rains. This is the extraordinary event in the last decades.

To study what kinds of plants are easily washed out, we evaluate the effects of rocks on plant-washed-out by comparing the plants with/without rocks directly upstream in Sites 1 of the Higashikannda River. In Nakando river (Site 2), the survey of about 10 day intervals is also carried out to estimate the population growth by distributing gemmae (budding plants) during June, 2005 and February, 2006.

To evaluate the growth conditions of *S. gemmifer*, the measurement of water quality is also performed in Higashikannda River. The measurement items are (1) Total carbon, (2) Total nitrogen, (3) Total phosphates, (4) nitrogen in the form of nitric acids, (5) nitrogen in the form of subnitric acids, (6) nitrogen in the form of ammonia, (7) phosphoric acid ions. The water columns were collected four times (seasons) from 4 locations including the habitat in 2004: (1) upper most stream (1.5Km upper stream), (2) merging spring water (the upper most edge of the habitat), (3) Site 1, and (4) down stream (ca. 1Km down). We also measure the water quality partly including calcium and magnesium contents for nearby other rivers: (1) Nakanndo River (Site 2), (2) Amma River (not habitat; mid stream; control), (3) Kuryo River (not habitat; mid stream; control).

We also measure the growth rate of individual plants in the growth period. In Higashikanda River, the number of culms in 38 plants is counted in Site 1 at May 20, 2005 (40 plants) and at July 29, 2005 (38 plants: 2 plants washed away). The growth rate of each plant is estimated from the difference in the number of culms between the two measurements. In Nakanndo River (Site 2), the number of culms is counted for a large plant and the two gemmae reproduced by it for every ten days during June 11, 2005 and February 1, 2006. We also carried out the transplant experiments from Higashikannda River to a few nearby rivers, and in the downstream, the neighboring site (1m sides) and the same site in the river (controls).

Results

Population Dynamics

Population fluctuations (at Site 1 of Fig. 2) are shown along with rainfalls in Fig. 3 and Plate 2. In Fig. 3, the time dependence of remaining plants in the surveyed area (6m by 10m) from July 27, 2004 to May 27, 2006 is depicted along with the rainfall data (JMA 2006). At first, the plants covered the entire surveyed area and the original count is 400 stocks at Site 1 at July 27, 2004 (Plate 2a). We have no counting record on September, but the photo record (Plate 2b) reveals that no changes were seen at September 27, 2004. At October 18, 2004, many stocks have been washed away (the second red plot in Fig. 3

and Plate 2c). Three typhoons (#18, 21, 22) hit Hamamatsu with successive heavy floods in late September and early October (several tall bars just before the second red plot in Fig. 3). The almost 400 stocks (September 27, 2004) had been reduced to 177 stocks during this short period. It further dropped to 155 stocks on October 22 after heavy rainfall by Typhoon #23, and finally decreased to 70 stocks on December 1, 2004 (pink plots in Fig. 3A). Subsequent floods eventually had reduced to 55 stocks at January 3, 2005, to 34 at May 15, 2006 (Fig. 3A) and to 30 at October 28, 2007 (current survey data).

The relation between washed-away stocks and rainfall per day is shown in Fig. 3B. Pink square plots in Fig. 3B indicate that decreases of stocks had been caused by heavy rainfalls (severe floods) in 2004. However, in 2005 or later, once many plants were washed away, the remaining plants tended to stay even against heavy rainfalls (green diamond plots in Fig. 3B).

The records of spatial distribution showed four stages of damaging process (Fig. 4; Plate 2). During the short period from September 27 (Fig. 4B, Plate 2B; Stage 1) to Oct. 18 (Fig. 4C, Plate 2C: Stage 2), all stocks near river center were found to be washed away.

This should be because the fluid velocity during floods is thought to be fastest at the center of steam. Even though we have no mapping record between July 27 and October 18, 2004, the photo record (Plate 2A and 2B) indicates that the washed-away events took place after September 27, 2004. By January 3, 2005 (Fig. 4D: Stage 3), the other plants in the left side of the river are washed away. At the final stage (Fig. 4E, Plate 2D: Stage 4), all the stocks near the right bank had been also washed except a few stocks.

The survey area, Site 1, is at a bend of the river (Fig. 4A). A major feature of the flow in a bend is that a zone of high streamwise velocity appears near the inner bank at the inlet and then moves to the outer-bank side through the bend, and a similar pattern is observed for the zone of maximum bed shear stress (see e.g. Robert 2003; Imamoto, Ishigaki and Fujisawa 1982). It reasonably explains why all the stocks near the left (outer) bank had been washed away (Fig. 4 B-E).

The surviving plants often locate near a large stone. Fig. 5 shows the stock distribution in relation to large stones. Many remaining plants are located near the stones. Fig. 6 shows the number of washed away plants near by (or not near by) the stones. All the plants near by the stones are less washed out (highly significant at 0.005 level χ^2-test).

Thus plants are often protected from washed away by large stones. The nearby stones may slow down the river flows at floods.

The pile of clays in the downstream inner-bank at Site 1 (Fig. 5) should be carried over by a secondary flow from the outer bank (Robert 2003; Falcon 1984; Blanckaert and de Vriend 2004). Flow in meander bends is characterized by the existence of cross-stream circulation cells (secondary flow), which caused by a combination of two forces acting in the bends: centrifugal forces and pressure gradient forces. Near the bed, the cross-stream pressure gradient exceeds the centrifugal force. This tends to drive the flow, and thereby the bed material in the case of a mobile bottom, towards the inner bank over the bed surface (Robert 2003; Imamoto, Ishigaki and Fujisawa 1982). This also agrees with the flow feature at a bend (Fig.4A).

Usually the fluid velocity is less than 0.4m/s even in sprinkle rain. No stock is washed away with this velocity. When heavy rain continues, the velocity of river flows increases extraordinarily. Unfortunately, the velocity during floods is not measurable. The flow velocity at Site 1 should be very fast due to river improvement works. From the spatiotemporal records (four stages) at Site 1, we find that the stocks suffered higher damage, as the flood velocity at their location is thought to be faster. We also monitored at the other sites. In Site 2 (Nakando River), the abundance of the plant reduced from 20 to 8 stocks during the floods. At Site 3 (Shin River), the plant (5 stocks) went extinct.

Gemmae reproduction

We also surveyed the reproduction of the plant in Site 1. This plant can reproduce by seedlings and gemmae (vegetative reproduction). Reproduction by seedlings is not observed in the entire habitats of Hamamatsu (Fig. 2). We performed the germination experiments of seedlings. Seedlings germinate and grow under day light condition (no growth in the dark) to young plants in the experimental container without water flow. However, seedlings are very small. We find no settlement of seedlings in the natural habitats in Hamamatsu.

Reproduction by gemmae is most active during summer, but observed throughout a year in Site 1 (Fig. 7). The gemmae grow to the size of adult plants in about half a year. The overall population size of the species is increasing from January 1, 2005. However, it cannot cover the extraordinary loss in the fall of 2004. Furthermore, the new gemmae tend to settle more randomly in the river than the distribution of old plants. Therefore it can be easily washed out with moderate floods. This is also shown by the lost gemmae that are once settled (Fig. 8). The remained gemmae are about 70 plants, while the lost ones that are once settled are about 40 during January 1, 2005 and October 28, 2007 (Fig. 7).

Even though the gemmae reproduction is active, the entire stocks of Higashikanda River are rather stable after the huge loss in the fall of 2004. The entire stocks counted at February 11 in 2005, 2006 and 2007 are 708, 687 and 760, respectively. This means that young gemmae replace old plants to a large extent in Higashikanda River. Thus in the entire population of Higashikanda River, the resistance against floods is significantly weakened. In contrast to Higashikanda River, the recruitment in Nakando River is active. Table 3 shows that the overall changes in the entire stocks in Nakando River. Note that the plant was at the verge of extinction. After this point reproduction by gemmae is highly active, reaching to 77 plants in October 28, 2007. Note that newly established gemmae were frequently washed away, because the three sides (both banks and floor) of Nakando River is covered by concrete wall (Table 2). The current population consists of the gemmae that are produced by gemmae that are also produced by gemmae, and so on. Several hundred gemmae were at least produced and some of them are settled once, but most of them were washed away, and remaining is currently 77 plants (Table 3). In Shin River, five stocks were found in the entire stream in June 24, 2004, but no plants had been seen since January 1, 2005. The extinction of this species is confirmed in Shin River.

Culm growth

We also checked the growth of an individual plant by counting the number of culms (stems). We counted the culms of the old plant, the winter gemma and the spring gemma every ten days for about 6 months (Fig. 9). This suggests that the growth of culms is very fast once the plant becomes a sufficient size, irrespective of gemmae or old plants. We also tested the grow by transplant to Kryou River, Anma River (spring water seen), Toyoda River, Miyakoda River, and the natal site, one meter aside, more than 1 km down stream, 100 m upstream (no spring water) of Higashikanda River. All the different rivers and the up stream and down stream of Higashikanda River are not the habitat of S. gemifer. A single large plant is divided to three to four culms for each location. In the habitat of Higashikanda River (the natal site, 1m aside, and downstream), the culm growth are seen. In Anma River, the growth is highest; the number of culms grows from 4 to 48 culms with 44 buds for new culms. The plant died at the other locations (other rivers, the upstream of Higashikanda River). Thus the conditions are met, the plant grows very fast. However, the plant withered in winter in Anma River, probably due to the heavy water pollution at that time.

Water quality

We checked the water quality of Higashikanda River at four locations: upstream, spring water, Site 1 and downstream (Table 4). The upstream and downstream are not the habitat of S. gemifer. Spring water site is just above the habitat. We checked four times in a year. The water quality of the entire Higashikanda River including the spring water site is mildly polluted with life wastewater (Kawamura and Nozaki 2005; Takeda and Urabe 2006). The water quality was worse in winter due to low flow (December and February). We also checked the water quality of nearby rivers (Table 5). These rivers are all polluted at least mildly. Nakando River, one of the habitat is highly polluted by calcium ions. Note that the culm growth was very fast in Nakando River (Fig. 9). From these data, S. gemifer seems not so sensitive to pollution by life wastewater.

Discussion

The damage of floods on this plant is strongly enhanced due to past river improvement works (Kada 2006). The rivers at all monitoring sites are artificially modified (Table 2). The banks are covered by concrete walls. The stream is modified to be linear (straight) or slightly curve-linear for smooth water flows (Robert 2003). The widths of these rivers are almost constant throughout a stream; the widths of Sites 1, 2 and 3 are 6m, 1.3m and 4m, respectively. Moreover, the floors of the rivers are flattened; deep depressions are filled up. The cross sections of the streams are a rectangular or trapezoid shape (Plate 2). Thus the fluid velocity at flood becomes faster by such river improvement works (Robert 2003; Kada 2006). The extinction at the Site 3 and the drastic reductions at both Sites 1 and 2 should be definitely associated with these river modifications.

Even though the particular pollution was not observed by the measurements, the pollution level in the three rivers is relatively high (Kawamura and Nozaki, 2005; Takeda and Urabe, 2006). However, the individual growth of the plant seems not be affected unless the pollution in winter is severe (Fig. 9). The test transplant to Anma

River was extremely well (the number of culms grows from 4 at June 4 to 44 at August 15 in 2004) until winter when the pollution kills the plant. Thus a special care against water pollution seems not necessary in the current state of water quality in these rivers.

The reproduction and recruitment is a key to save this plant species. This species produces offspring by both sexual and asexual ways (Sato et al. 2004; Kitamura 2005). The latter by buds (gemmae) is the main method for reproductive success. The seed reproduction is seen on many plants. However, the seedlings of this species are very small (seeds are about 1-2mm length) and easily washed away. During our observation, we find no established seedlings in the entire study areas.

In contrast, the recruitment by gemmae is very common and considerably fast (Fig. 7). Small gemmae are easier to be washed away than the old plants. Many gemmae are established and washed away sooner or later (Figs. 7 and 8). However, the total remaining gemmae is increasing steadily. The recruitment of gemmae was relatively fast and at least balancing to the gradual decrease of old plants during January 16, 2005 and October 27, 2006 (Fig. 7). However, the radical decreases of old plants on October 2004 by caused by a series of heavy floods could not be balanced by the recruitment by gemmae (Figs. 3 and 7). Furthermore, all the remaining gemmae were also washed out by these events. Unless we start some protection measures, an eventual extinction of this species in Higashikanda River is almost definite as in Shin River (extinct) and Nakando River (almost extinct).

It seems that the root growth is critical to the establishment of the plant on the river (Plate 3). The patterns of gemmae distribution are nearly random and much more widespread than the old plants. This means that many gemmae have rooted on the areas in which plants are easily washed away. This also suggests that gemmae are more likely to be affected by the stream flows than the old plants. The rate of successful rooting is extremely low, except the vicinities of mother plants or slow flows.

The conservation measure of this species could be based on the reproduction of gemmae. The culm growth of individual gemmae is fast and easily cultured in the artificial pool or stream (see Fig. 9). We cultured a stock in a water pot for nearly 4 years. An average plant in the study sites produces about 10-100 gemmae. Note that most of them are washed away. The large amounts of gemmae can be easily collected from the plants growing Higashikanda River and Nakando River. The reproduction by seeds is also possible, though it may take a longer time to grow, since seedlings are very small. The germination of seeds is easily carried out on a Petri dish. Seeds can be also easily collected from the natural plants. Therefore, we can culture the plant from gemmae (seeds) collected from the natural habitats.

These cultivated plants have to be replanted to the river habitats. Here the rooting of the cultivated plant becomes a key to the successful conservation (see Plate 3). There are almost no rooting places on the flat river floors of these rivers. We should prepare the rooting place on the river floors. River floors are mostly made of concrete or natural silt layer, either of them cannot support roots. We may drill a hole to the floor and place the root through these flat floors. We may also modify the river flows from straight to winding as in natural rivers to reduce the flow velocity during floods. These protective measures on the river structure may be also applied to the natural plants. The secure rooting is the key to the conservation of this species. With these conservation and management measures, we may save this very rare endemic aquatic plant from extinction.

In conclusions, the entire population is still at a high risk of washed away by future heavy consecutive rainfalls, as those in 2004 (Tukasa et al. 1989). Due to the global warming, the worldwide weather patterns change drastically in the last 20 years (Metz et al. 2007). Thus we may expect in near future another heavy flood or severe draught which is also very critical to the persistence of this aquatic plant. Thus we need some urgent policies to save this species (Pimm 2001). For conservation, we propose two urgent measures. One measure is the cultivation of gemmae to assist the reproduction of the species. The culm growth of gemmae is fast enough on fertile soil. Another measure is secure rooting, the protection from washed away. Modifying the flat river floors or some modification of river flows is necessary to suppress the fluid velocity at flood (Stewart and Mallik 2006). It should be important to save this residential (populated) habitat for this rare endemic plant in the sense of maintaining nature in the city area in restoration ecology (Rosenzweig 2003).

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Table 1. Survey of *S. gemmifer* habitats in Japan.

No.	River	Prefecuture	Date	Habitat	Spring water	Notes
1.	Higashikanda R.	Shizuoka	2003.6.5	Stream	yes	
2.	Nakando R.	Shizuoka	2003.9.15	Stream	yes	Danger
3.	Shin R.	Shizuoka	2003.9.20	Stream	yes	Extinct
4.	Kitachi R.	Oita	2004.8.28	Stream	yes	
5.	Eda R.	Miyazaki	2004.8.29	Stream	yes	
6.	a pond at Sogabe-cho	Kyoto.	2004.9.9	Reservoir	yes*	Extinct
7.	Hussaki R.	Ehime	2004.9.10	Stream	yes	
8.	Morinoki-izumi	Ehime	2004.9.11	Stream	yes	
9.	Sankason-izumi	Ehime	2004.9.11	Stream	yes	
10.	Kamo R.	Toyama	2004.10.2	Stream	yes	
11.	Kuma R.	Kumamoto	2004.10.30	Stream	yes	
12.	Ishitobi water	Kumamoto	2004.10.30	Stream	yes	
13.	Nagare Marsh	Kumamoto	2004.10.30	Stream	yes	
14.	Kogihara R.	Yamaguchi	2005.9.3	Stream	yes	
15.	Okanji R.	Tochigi	2006.5.12	Stream	yes	
16.	Kumakubo Sluce	Tochigi	2006.5.12	Stream	yes	
17.	Sengokuhara marsh	Kanagawa	2006.5.16	Stream	yes	few plants

*past record.

Table 2. Habitat types and structures of the study sites

River	Width	Length	Side walls	Floor
Higasikannda	6m	5.2Km	concrete, straight	Flat natural (stone, and hard mud) and concrete*
Shin	4m	3.2Km**	concrete, straight	Flat natural (stone, and hard mud)
Nakando	1.3m	1.5Km	concrete, straight	Flat concrete

*the most downstream habitat and upstream (not habitat)

**Length to Lake Sanaru (not including down stream from Lake Sanaru to Lake Hamana).

Notes: The hard mud is Sahama Mud Layer. The stone floor is the Mikatabara Stone Layer that is directly above the Sahama Mud Layer.

Table 3. Annual changes in population size of *S. gemmifer* in Nakando R. The entire stocks are counted.

Date	the number of stocks
October, 2003	ca. 20
27 Sep. 2004	3
6 Feb. 2005	10
11 Feb. 2006	7
2 Feb. 2007	57
28 Oct. 2007 (current)	77

Table 4. Water quality of Higashikanda River.

Locality	Date	TOC	TN	TP	Nitric Acid-related nitrogen	Nitrous acid-related nitrogen	Ammonia related nitrogen	Phosphoric acid ion
Upstream								
	24 Jun. 2004	10.0	5.7	1.0	2.5	>0.1	0.21	1.8
	10 Aug. 2004	4.7	4.5	0.38	2.9	>0.1	>0.05	1.2
	1 Dec. 2004	11.5	10.0	1.3	6.3	>0.1	1.5	3.9
	14 Feb. 2005	/	/	/	/	/	/	/
Spring water								
	24 Jun. 2004	>0.5	3.9	0.33	3.5	>0.1	>0.05	>0.05
	10 Aug. 2004	>0.5	4.4	>0.02	3.5	>0.1	>0.05	>0.05
	1 Dec. 2004	>0.5	4.5	>0.02	4.5	>0.1	>0.05	>0.05
	14 Feb. 2005	3.7	3.9	>0.02	3.6	>0.1	>0.05	>0.05
Site 1								
	24 Jun. 2004	1.4	5.4	0.16	4.4	>0.1	>0.05	0.37
	10 Aug. 2004	2.3	6.5	0.23	4.7	>0.1	>0.05	0.44
	1 Dec. 2004	1.3	8.5	0.15	8.2	>0.1	>0.05	0.44
	14 Feb. 2005	8.5	8.9	0.40	7.0	>0.1	>0.05	0.68
Downstream								
	24 Jun. 2004	2.1	5.7	0.14	4.6	>0.1	>0.05	0.28
	10 Aug. 2004	5.4	6.0	0.05	4.0	>0.1	>0.05	0.05
	1 Dec. 2004	2.9	9.1	>0.02	8.6	>0.1	>0.05	0.26
	14 Feb. 2005	4.2	8.3	0.19	7.1	>0.1	>0.05	0.35

* unit mg/L

Table 5. water quality of nearby rivers

Locality	Date 1 Feb. 2005	Calcium ion	Magnesium ion
Spring water		5.2	3.2
Site 1(Higashikanda R.)		12.0	5.7
Nakando R.		21.0	6.3
Miyakoda R.		12.0	8.0
Anma R.		27.0	6.8
Kuryo R.		21.0	6.4

* unit mg/L

Figure Captions

Fig. 1. The distribution of the endemic *S. gemmifer* in Japan (Black with numbers indicates the prefectures with the number of sites).

Fig. 2. Locations of three study sites on Hamamatsu city in Shizuoka Prefecture: Higashikanda River (Site 1), Nakando River (Site2) and Shin River (Site 3).

Fig. 3. Relation between abundance of *S. gemmifer* and rainfall during the period from July 27, 2004 to Oct. 12, 2006 in the surveyed area (6m x 10m) in Site 1 of Higashikanda River. (A) Time dependences of stock number (pink and green circles) are plotted against rainfall (black bars). Pink circle are the stock number on July 27, 2004, Oct. 18, 2004, Jan. 3, 2005 and May 15, 2006. (B) Relation between rainfall and washed away plant. The number of washed away stocks are depicted against rainfall per day. Pink plots represent the cases of early period (2004/7/27－2004/12/31), while green plot mean late period (2005/1/3－2006/10/12).

Fig. 4. Temporal change of spatial distribution of stocks in the surveyed area (6m x 10m) in Site 1 of Higashikanda River. A: the map of the site; B: July 27, 2004; C; Oct. 18,

2004, D: Jan. 3, 2005, E: May 15, 2006.

Fig. 5. Same as Fig.6, but stones recorded on Aug. 1, 2005 are also displayed. A: July 27, 2004 (before washed out). B: Aug. 1, 2005 (after washed out). By Aug. 1, 2005, a pile of clay with weeds had been deposited (red shadow) near right bank.

Fig. 6. The effect of stones against flood. The number of washed-away stocks near by and not near by stones are displayed.

Fig. 7. The population dynamics of S. gemifer during January 16, 2005 and October 28, 2007 in the Site 1 of Higashikanda River. The area surveyed is 6m x 10m. The total (yellow triagles) is the sum of the old plant (dark blue diamond) and the gemmae (pink square). The lost gemmae (light blue cross) indicate the number of washed away gemmae that were once settled on the floor of the stream.

Fig. 8. Spatial distributions of old plants (open circle), rooted gemmae (filled circle) and washed gemmae, once rooted (red circle) during January 16, 2005 and October 28, 2007.

Fig. 9. Growth of individual plants in *S. gemifer* during June 11, 2005 and January 21, 2006. The number of culms (stems) is plotted for a parent plant (dark blue), a winter gemma settled on January (pink) and a spring gemma settled on June (yellow). The parent plant and the winter gemma were cut on the top of plants leaving about 5 cm from the root at June 11, 2007 during the cleaning activity of the banks of a river.

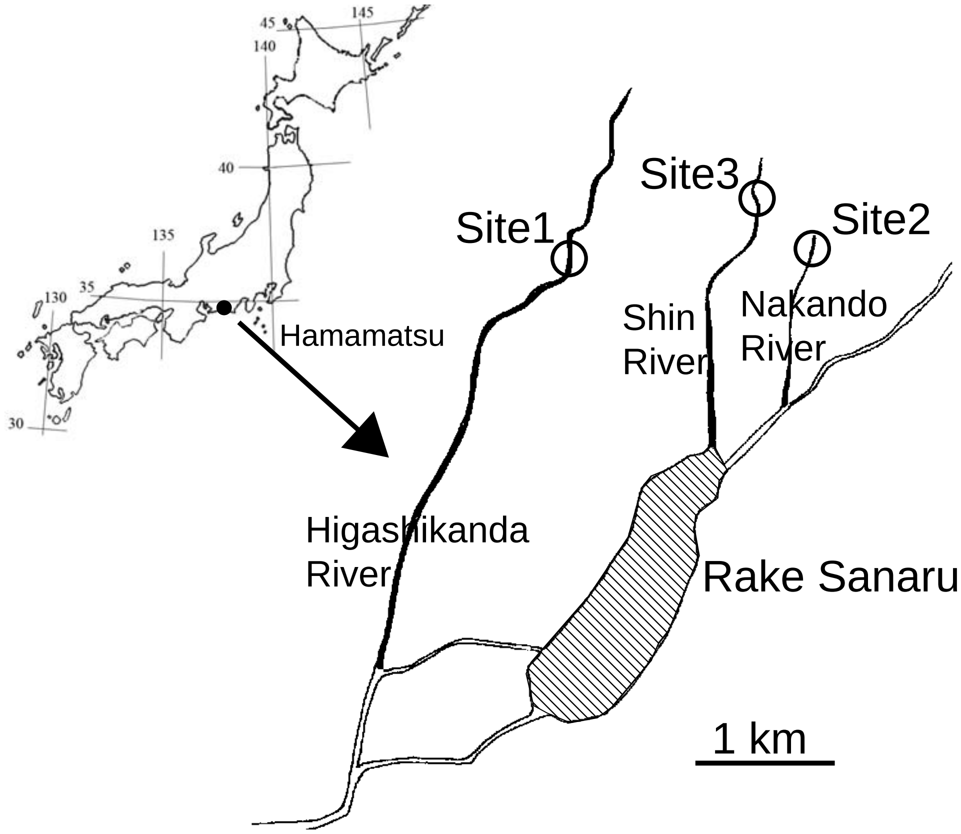
Plate 1. The life forms of *S. gemmifer*: A: standing form with flowers (spikelets) (August 11, 2005, near Site 1 at Higashikanda River). B: a steam form with gemmae (August 27, 2005, ca 30m downstream of Site 1 at Higashikanda River). C: a stream form with linear blade leafs (May 21, 2005, near Site 1 at Higashikanda River).

Plate 2. The surveyed area of *S. gemmifer* at Site 1. A: July 27, 2004 (the initial record). B: September 27, 2004 (before the flood). C: October 18, 2004 (after the flood). D: August 9, 2006.

Plate 3. The stocks that are almost washed away. Roots are loosened from the bed of a river. A and B: April 4, 2005, ca. 10m upstream Site 1 at Higashikanda River.

Fig. 1

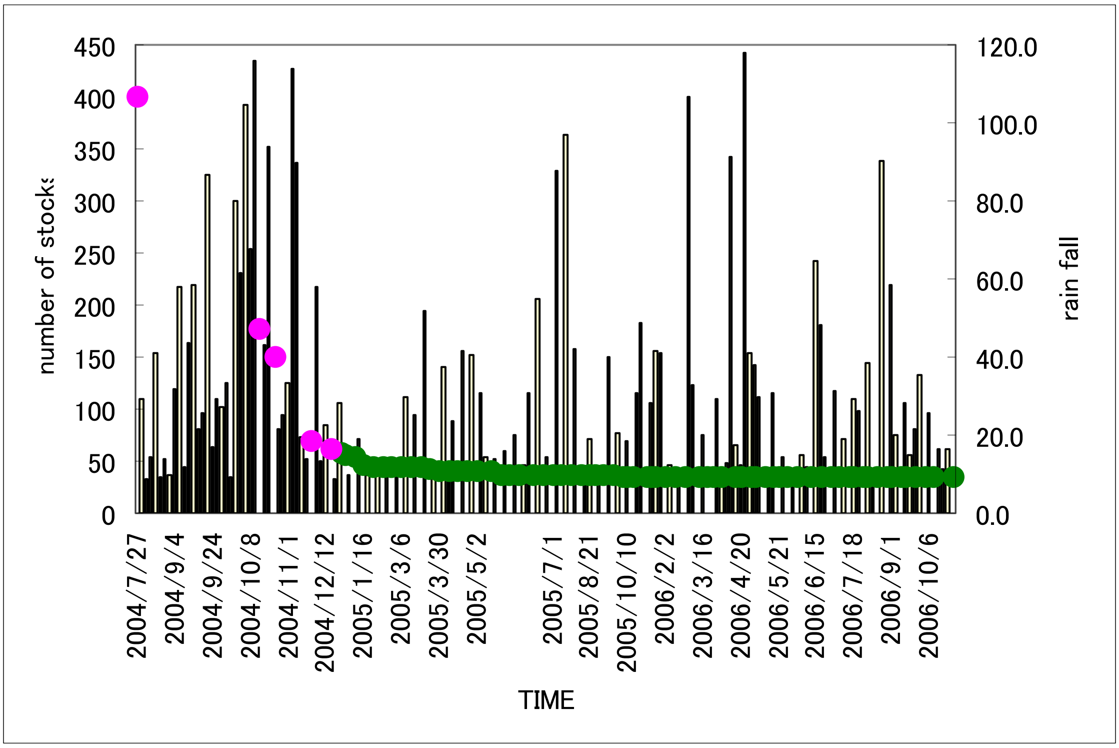
Fig. 2



45
145
140
40
135
130
35
30
Hamamatsu
Site1
Site3
Site2
Shin
River
Nakando
River
Higashikanda
River
Rake Sanaru
1 km

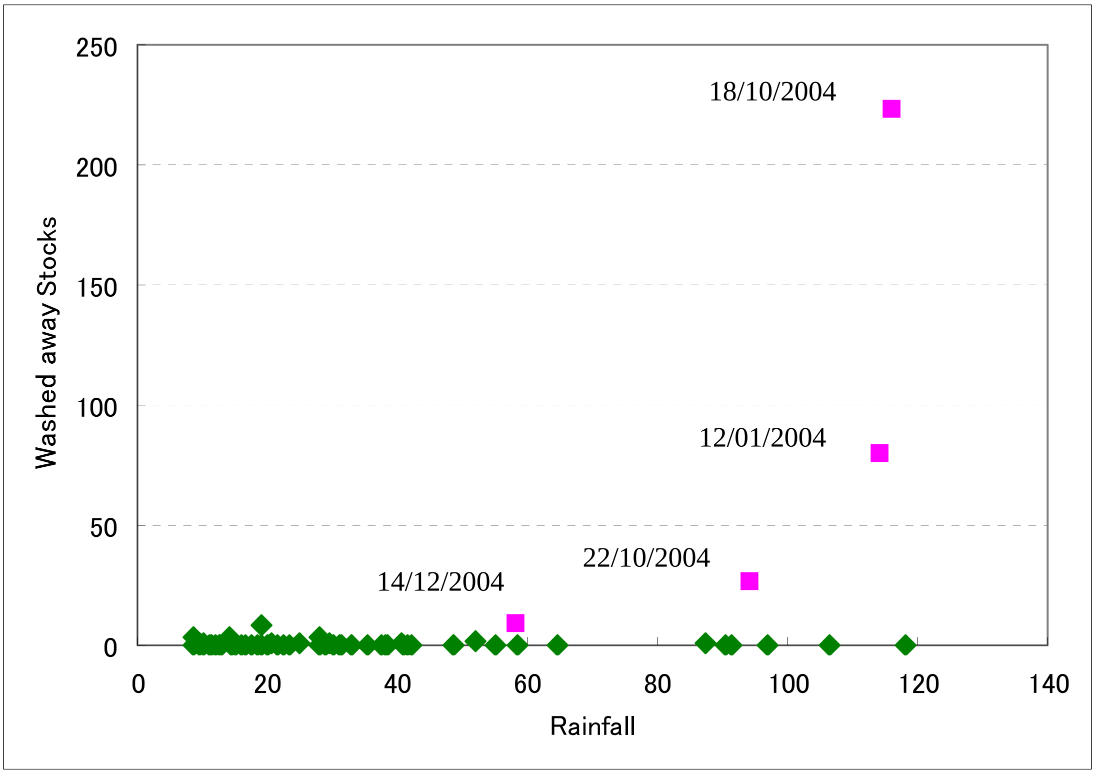
Fig. 3

A



450
400
350
300
250
200
150
100
50
0
number of stocks
120.0
100.0
80.0
60.0
40.0
20.0
0.0
rain fall
2004/7/27
2004/9/4
2004/9/24
2004/10/8
2004/11/1
2004/12/12
2005/1/16
2005/3/6
2005/3/30
2005/5/2
2005/7/1
2005/8/21
2005/10/10
2006/2/2
2006/3/16
2006/4/20
2006/5/21
2006/6/15
2006/7/18
2006/9/1
2006/10/6
TIME

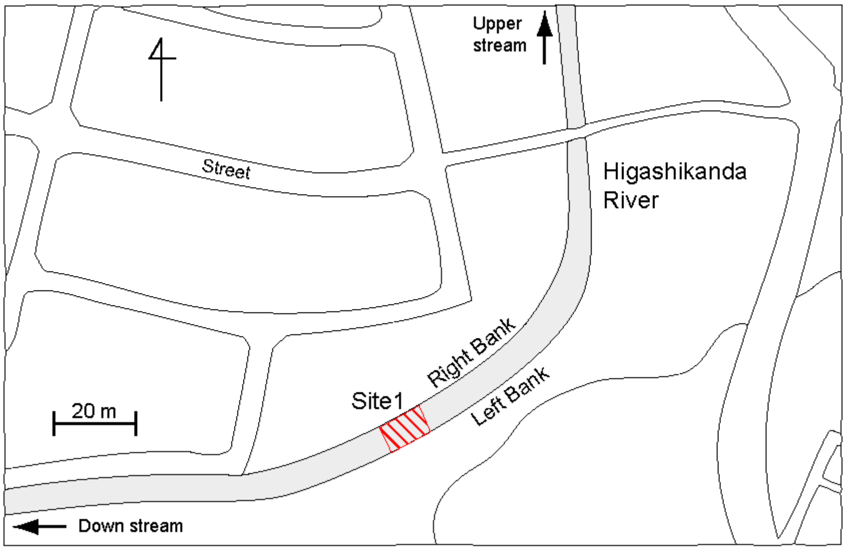
B



250
200
150
100
50
0
Washed away Stocks
0
20
40
60
80
100
120
140
Rainfall
18/10/2004
12/01/2004
22/10/2004
14/12/2004

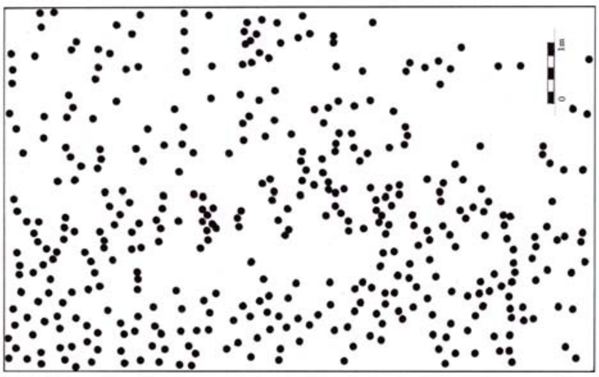
Fig. 4

A



Left Bank

B



C

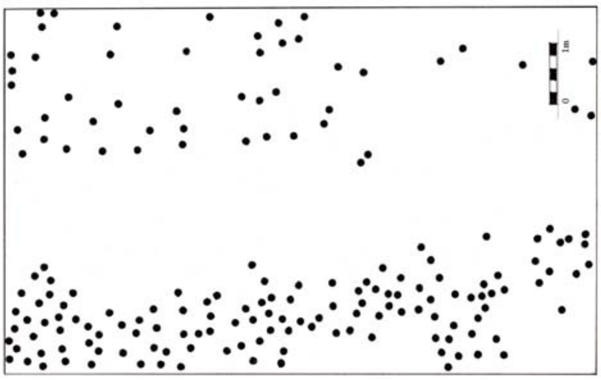
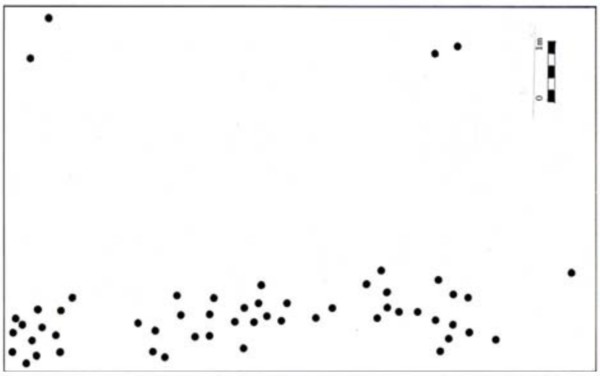
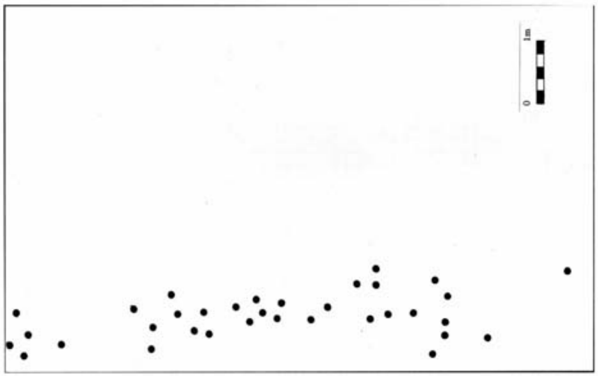


Fig. 4 continue

D



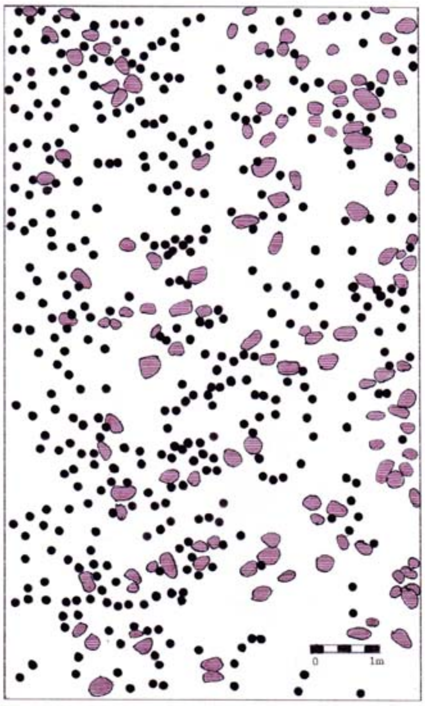
E



Right Bank

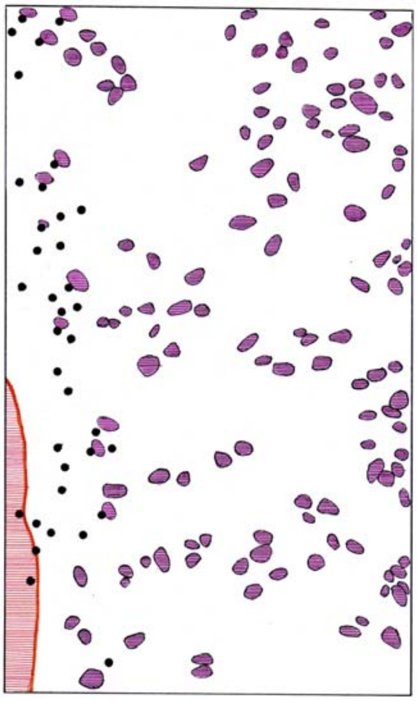
Fig. 5

A



July 27, 2004

B



Aug. 1, 2005

Fig. 6

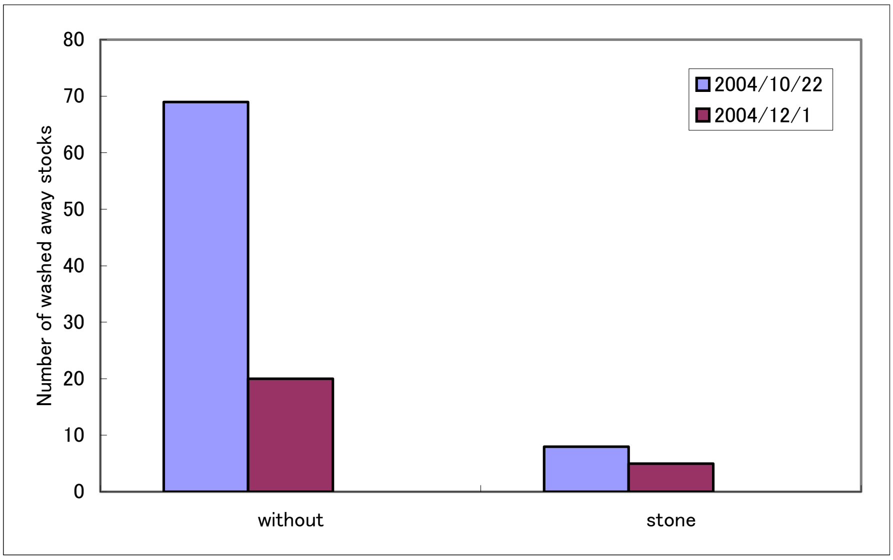

80
70
60
50
40
30
20
10
0
Number of washed away stocks
2004/10/22
2004/12/1
without
stone

Fig. 7

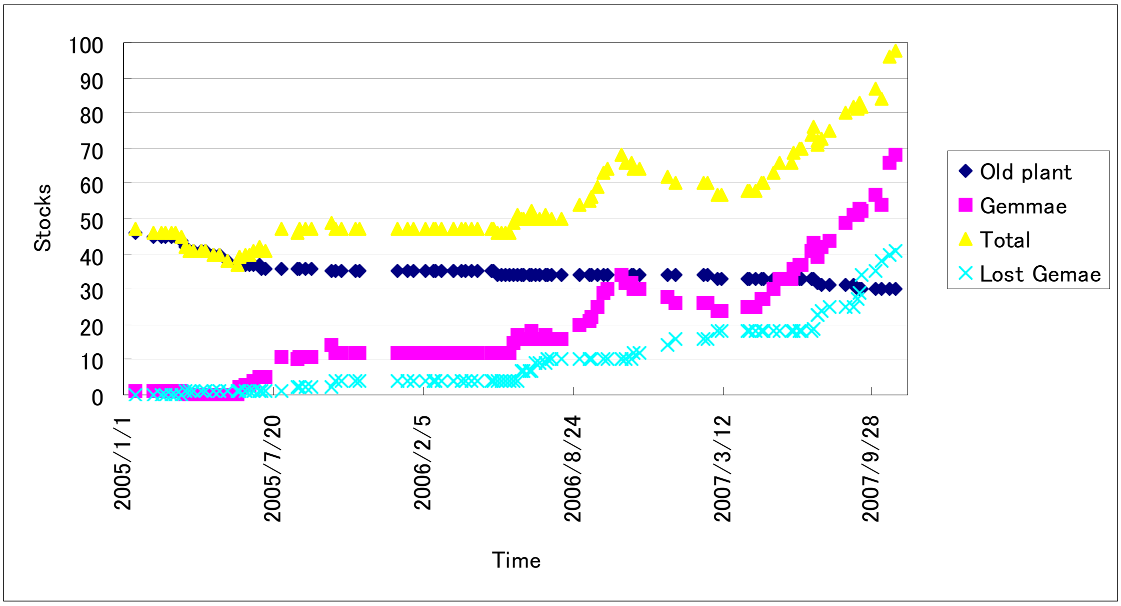

100
90
80
70
60
50
40
30
20
10
0
Stocks
2005/1/1
2005/7/20
2006/2/5
2006/8/24
2007/3/12
2007/9/28
Time
Old plant
Gemmae
Total
Lost Gemae

Fig. 8

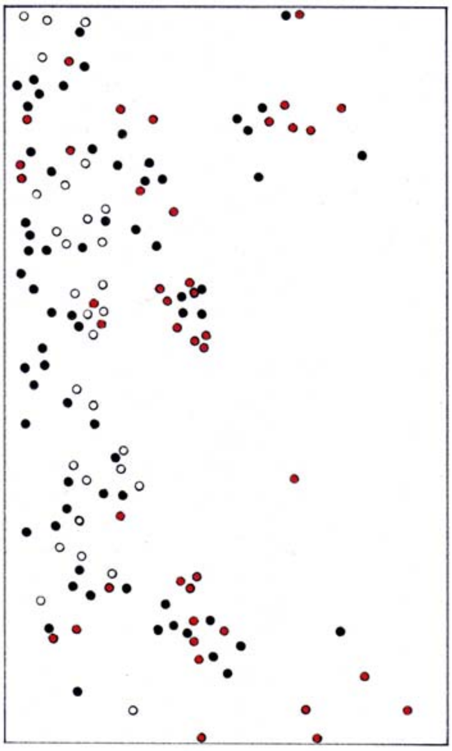
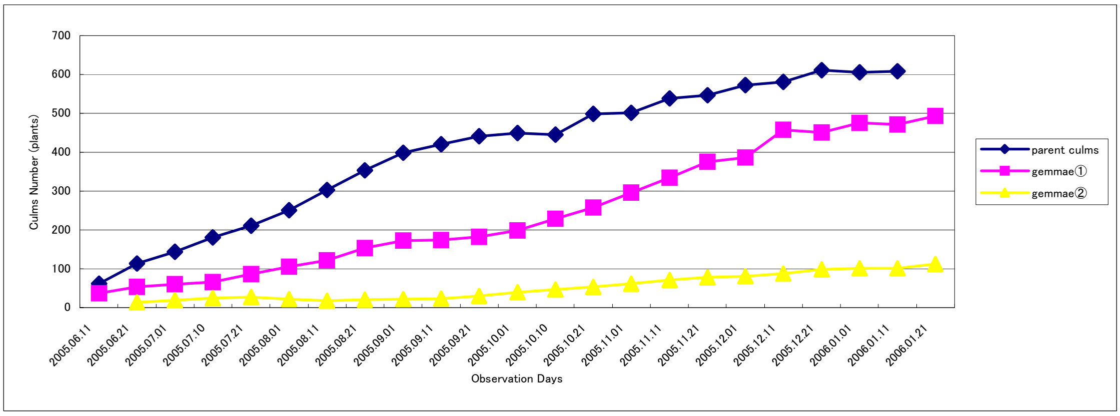


Fig. 9



700
600
500
400
300
200
100
0
Culms Number (plants)
2005.06.11
2005.06.21
2005.07.01
2005.07.10
2005.07.21
2005.08.01
2005.08.11
2005.08.21
2005.09.01
2005.09.11
2005.09.21
2005.10.01
2005.10.10
2005.10.21
2005.11.01
2005.11.11
2005.11.21
2005.12.01
2005.12.11
2005.12.21
2006.01.01
2006.01.11
2006.01.21
Observation Days
parent culms
gemmae①
gemmae②

Plate 1

A: still water form with spikelets

B: A stream form with gemmae

Plate 1 continue

C: A stream form with mostly linear leaf blades

Plate 2

A

B

C

D

Plate 3

A

B

end of manuscript