Aggressive Invasion of *Eragrostis curvla* in Gravelly Floodplains of Japanese Rivers: Current Status, Ecological Effects and Countermeasures

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Abstract

The floodplains on the middle reaches of rapid Japanese rivers are characterized by extensive gravelly areas with sparse vegetation cover. There are a number of plant species endemic to the gravelly floodplain habitats, including two threatened species, *Aster kantoensis* and *Ixeris tamagawaensiss*. The Kinu River is a typical rapid river in central Japan, and the river endemics have remained among the vegetation of the middle reaches until recently. These unique habitats, however, are rapidly being altered by an aggressive invasion of the alien grass (*Eragrostis curvula*), which is supposed to have become established through dispersal from upstream stands formed due to active introduction of the species for soil erosion control. The substrate condition of invaded areas tends to be changed from gravelly to sandy/silty, because tussock of *E. curvula* trap sand and silt during flooding. Thus, the original condition with sparse vegetation cover principally consisting of riparian endemics adapted to gravelly conditions is being lost. *E. curvula* exerts a strong negative influence on the performance of riparian endemics. A restoration project aimed at recovering the original condition of the floodplain by adaptive management techniques was started in 2002. As a 'first-aid' minor restoration effort, *E. curvula* was mechanically removed from a part of the floodplain (1,800 m^2), fine sands were washed out by spray the ground with a jet of water to restore the original gravelly condition, and stocked seeds of *A. kantoensis* were sown. A local population of *A. kantoensis* was successfully restored, but more extensive exclusion measures are needed in the next stage of management to prevent further negative impact of the invasive species.

Key words: *Eragrostis curvula*, gravelly floodplain, invasive alien species, restoration, river endemics

1. Statuses of Vegetation and Ecosystems in Gravelly Floodplains of Japanese Rivers

The Japanese archipelago has a unique combination of geomorphological and climatic features which produces remarkable riparian conditions with active sediment production and deposition, leading to rapid geomorphological changes of its rivers (Tsukamoto, 1973; Takayama, 1986; Oguchi *et al*., 2001). Most major rivers are much shorter and smaller than continental rivers, and have very steep profiles (*e.g*., Takahashi & Sakaguchi, 1976; Takayama, 1986). In the middle reaches of such rivers, we can find unique oligotrophic habitats characterized by a channel shelf covered by stones, gravel and sand (Umehara, 1996; Okuma, 1998).

The riparian flora characterizing such unique type of habitat include *Anaphalis margaritacea* (L.) Benth. et Hook. fil. subsp. *yedoensis* (Franch. et Savat.) Kitam., *Artemisia capillaris* Thunb., *Aster kantoensis* Kitam., *Ixeris tamagawaensis* (Makino) Kitam., *Potentilla chinensis* Ser., *Cassia mimosoides* L. subsp. *nomame* (Sieb.) Ohashi, *Lespedeza stipulacea* Maxim., *Galium verum* L. and *Dianthus superbus* L. var. *longicalycinus* (Maxim.) Williams (Miyawaki, 1986). Among these riparian species, *A. kantoensis* and *I. tamagawaensis* have declined greatly in recent years and are listed in the Japanese Plant Red Data Book (Environmental Agency of Japan, 2000) as 'Endangered' and 'Vulnerable', respectively. These riparian plants are known to have adapted morphologically and eco-physiologically to the specific environmental conditions of gravelly floodplains with sparse vegetation and poor soil conditions. The shoots are very short with rosette the leaves arranged in a leaf and they show a high physiological tolerance of intense light and accompanying heat under the unshaded conditions of gravelly floodplain, as demonstrated for *A. kantoensis* (Matsumoto *et al*., 2000a,b).

2. Invasion by Alien Pasture Grasses in Floodplains

Riparian habitats are considered to be particularly prone to invasion by alien plants (*e.g*., Planty-Tabacchi *et al*., 1996; Hood & Naiman, 2000). Plant invaders pose serious threats to natural ecosystems and the biodiversity of riparian habitats through alterations of geo-morphological processes (Buell *et al*., 1995), hydrology (Mueller-Dombois, 1973) and soil chemistry of the habitat (Vitousek & Walker, 1989). In combination with change of the physical environments, competition may lead to replacement of native vegetation by single-species-stands of nonindigenous species (Witkowski, 1991; Holmes & Cawling, 1997; Mooney & Hobbs, 2000; Miyawaki & Washitani, 2004a).

During the age of mass construction works in Japan (1960s-1980s), alien grasses such as *Festuca arundinacea* Schreb. (Tall fescue) *F. pratensis* Huds. (Meadow fescue), *Lolium multiflorum* Lam. (Italian rye-grass), *L. perenne* L. (Perennial rye-grass), *Dactylis glomerata* L. (Orchard-grass), *Zoysia* spp. *Cynodon dactylon* (L.) Pers. (Bermuda grass) and *Eragrostis curvula* (Schrad.) Nees (Weeping-love-grass) were introduced in enormous amounts into construction sites for erosion control and/or re-vegetation (Muranaka & Washitani, 2002; Washitani, 2002a, 2004). Unfortunately, many of these alien grasses have become major invaders and are now exerting a significant negative impact on certain types of ecosystems including riparian areas (Committee for Investigating the Effects of and Countermeasures against Riparian Nonindigenous Species, 2001, 2003; Washitani 2002a).

E. curvula (Fig.1) is a representative invasive perennial grass, which was first introduced into Japan for erosion control. In recent years, vast quantities of the seeds of the species (30,689 kg/year; 1991-2000) have been imported mainly from North America (Plant Protection Station, The Ministry of Agriculture, Forestry and Fisheries of Japan, 1991-2000). The species dispersed from the anthropogenically established stands across the basin and spread over the river floodplains (Committee for Investigating the Effects of and Countermeasures against Riparian Nonindigenous Species 2001, 2003; Miyawaki *et al*., 2004b). The species established monospecific long-lasting stands in middle reaches of 105 out of 123 Japanese rivers under the jurisdiction of The Ministry of Land, Infrastructure and Transport Government of Japan (Committee for Investigating the Effects of and Countermeasures against Riparian Nonindigenous Species, 2001). Up to 1999, the total area occupied by vegetation dominated by the species was 379 ha (the total area investigated was approximately 82,000 ha) (Miyawaki & Washitani, 2004).

Fig. 1 *Eragrostis curvula*.
Photo taken in 1999 along the Kinu River in central Japan.

Nakatsubo (1997) reported that in the Ota River of Hiroshima Prefecture sand accumulation in and around tussocks of *E. curvula* alters the micro-topography of gravelly floodplains. Altered substrate conditions which are totally absent from the original gravelly floodplains facilitate the invasion and population growth of ruderal plants including itself (Umehara, 1996). Thus, the original condition and vegetation of gravelly floodplains, i.e. sparse vegetation cover consisting principally of riparian endemics growing in gravelly-sandy conditions, is lost.

3. Invasion of *Eragrostis curvula* into the Riparian Floodplains of Kinu River

3.1 Vegetation status and changes after flooding of the Kinu River

Aggressive invasion of *E. curvula* into the gravelly floodplain was revealed by a floristic and vegetational study in the middle reaches of the Kinu River (Fig. 2), which is a rapid-flow river in central Japan and where

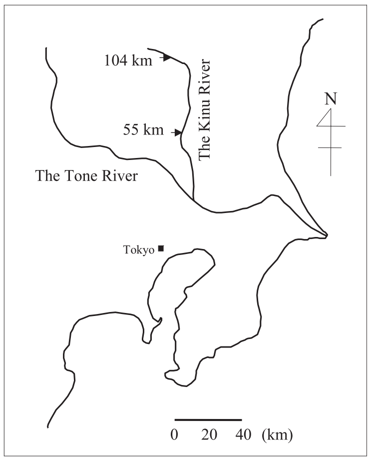
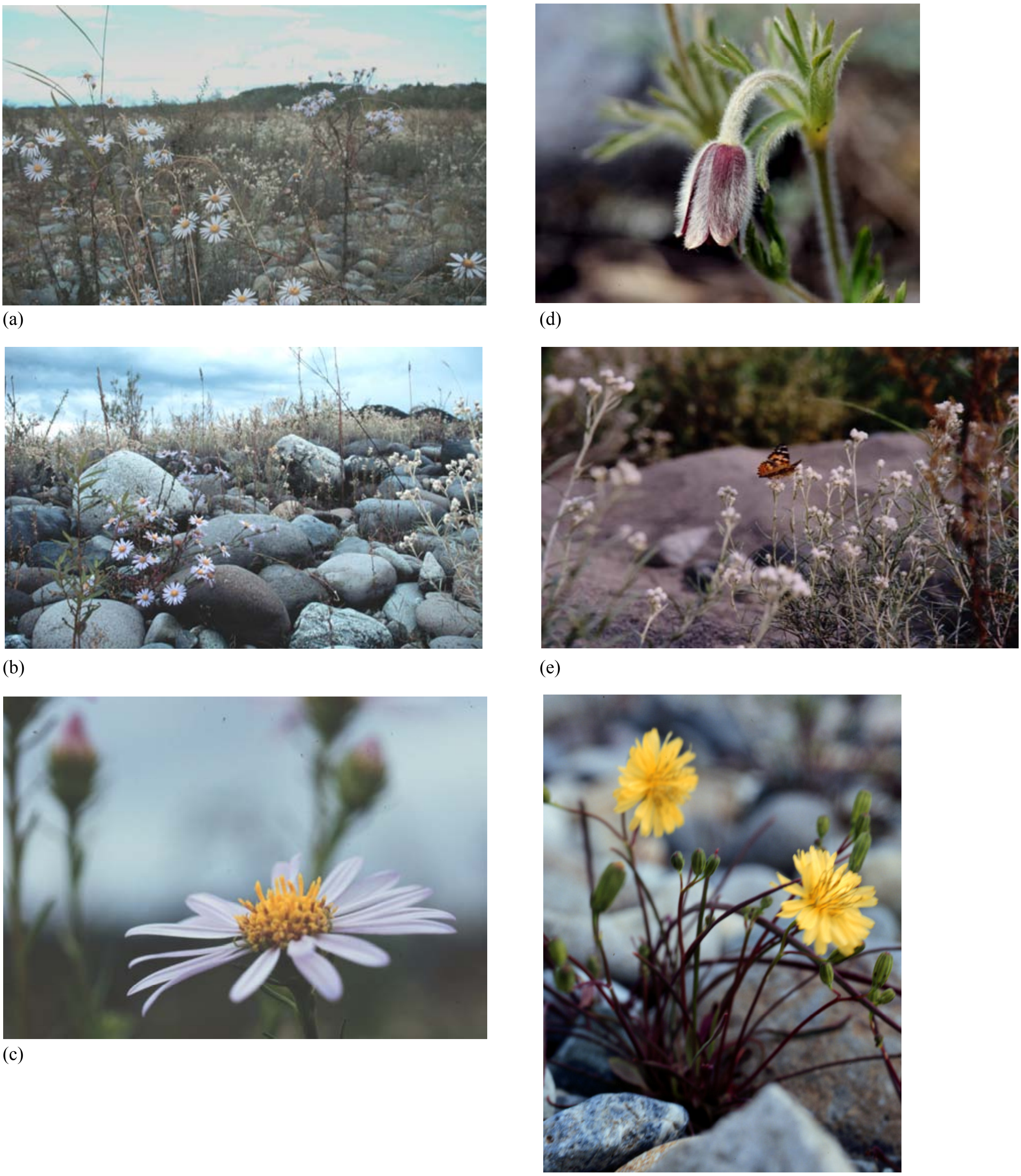


Fig. 2 Location of the Kinu River in central Japan.
Distances from the confluence point with Tone River are shown.

typical gravelly floodplain vegetation has been preserved until recently (Muranaka & Washitani, 2001a,b). In the 1990s, river endemics such as *Aster kantoensis* and *Ixeris tamagawaensis* still dominated the vegetation, but *E. curvula* began to invade certain parts of the floodplain (Fig. 3).

After a heavy flood caused by a typhoon in August 1998, the river channel pattern had changed greatly with sand and silt deposited over a large tract of the channel shelf (Fig. 4). *E. curvula* began to spread rapidly and became one of most dominant alien grasses in the riparian habitat by 1998 (Muranaka & Washitani, 2001b). A similar rapid increases in *E. curvula* and sand accumulation have also been observed after floods in 2001 and 2002. In contrast, a declining trend in endangered river endemics has accelerated since



(a) (d) (b) (e) (c) (f)

Fig. 3 Physiognomy and representative species of a gravelly floodplains dominated by river endemics.
(a-b) Floodplain vegetation in 1996. Photo taken 104 km from the confluent point to the River Tone.
(c-f) River endemics and endangered plants. (c) *Aster kantoensis*, (d) *Pulsatilla cernua*, (e) *Anaphalis margaritacea* subsp. *yedoensis*, (f) *Ixeris tamagawaensis*.

1998. The number of *A. kantoensis* plants decreased rapidly from 100,000 in 1996 to 110 in 2001 (Muranaka & Washitani, 2001b), when an area of 50 ha was already dominated by *E. curvula* (Fig. 5).

Fig. 4 Sand accumulation in and around tussocks of *E. curvula* altering the microtopography of the floodplain by the formation of sandy mounds after flooding. Photo taken along the Kinu River in 2001.

Fig. 5 Gravelly floodplain area invaded by *E. curvula*. Photo taken 91 - 92 km from the confluent point to the River Tone in 2004.

3.2 Influence of the *Eragrostis curvula* invasion on performances of river endemics

Vegetation survey data suggest that river endemics can hardly coexist with *E. curvula* in the same microsite (0.25 m^2) (Muranaka & Washitani, 2001a). Ecophysiological investigation demonstrated that shading by the grass has a significant negative impact on seedling growth of *Aster kantoensis* (Matsumoto *et al*., 2000a,b). No seedlings survived to the stage of established rosettes, even under light availability of 20% - 60% relative PPFD in mid-summer (Matsumoto *et al*., 2000a). In a field experiment, it was also demonstrated that seedling survival and growth were generally low at low light availability with relative PPFD of less than 30% (Matsumoto *et al*., 2000b).

Another study (Takenaka *et al*., 1996) suggested competitive exclusion of *A. kantoensis* by alien grasses. Being less than 10 cm in height in the vegetative stage, *A. kantoensis* cannot compete for light in fertile habitats with intense competition among plants. Thus, invasion by *E. curvula* tussocks exerts a strong negative influence on the colonization, establishment and growth of the river endemics, whose substrate preference of which is partially shared by *E. curvula*.

In an *in situ* experiment, seedling survival, growth, flowering, and seed production of *A. kantoensis* were compared under four types of semi-natural conditions, i.e., combinations of existence or absence of *E. curvula* combined with gravelly or sandy substrates (Muranaka & Washitani, submitted). Under conditions without *E. curvula* with gravelly substrate, the highest percent survival, growth, and fitness (= number of productive seeds / number of sown seeds) were observed (39.7), but under the three other conditions, the fitness percentage was less than 2.4.

Recent environmental changes due to catchment area development, intensive flood control management and recreational uses of the floodplains as golf courses and athletic grounds have reduced both occurrence and persistence of potential safe sites for the colonization of *A. kantoensis* (Washitani *et al*., 1997). Reduction of safe sites and seed sources leads to a further decline of *A. kantoensis*, which seems to be trapped in an extinction spiral, in which the reduction in size and number of subpopulations diminishes the potential for new colonies (Washitani *et al*., 1997). In the Kinu River, aggressive invasion of *E. curvula* was the principal cause of the loss of safe sites for colonization of the species.

3.3 Prediction of the expansion of *Eragrostis curvula* in the floodplain using a simulation model

The range expansion of *E. curvula* was predicted using model simulation based on its life history and demographic traits, including seed dispersal patterns. We applied a lattice model to this simulation. Population processes in each cell (0.5 m × 0.5 m) were expressed by a stage-structured vector and a projection matrix according to the plant's demographic traits, dormancy/germination, growth, flowering, seed production, and seed dispersal (Muranaka & Washitani, 2003). The seed dispersal pattern was estimated from the distribution of adult plants and seedlings in a survey grid (5,000 m^2). The simulation predicted that after 10 years 50% of the floodplain area will be occupied, and after 12 years the whole area will be covered (Muranaka & Washitani, 2003; Fig. 6).

The simulation revealed the effectiveness of mechanical removal of *E. curvula*. It was suggested that the suitable safe sites for regeneration of *A. kantoensis* could be maintained if mechanical removal of the invasive species is performed every five to seven years in the season immediately before seed production of *E. curvula* (Fig. 7).

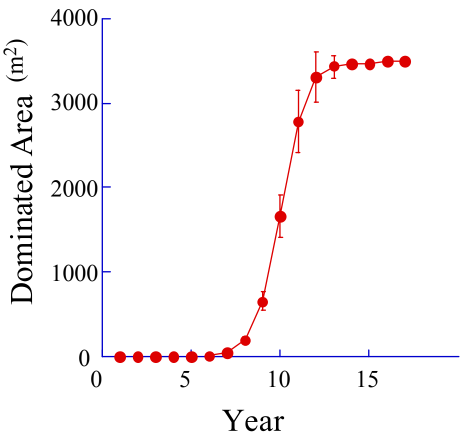


Fig. 6 The results of a model simulation predicting a trend of increasing area dominated by *E. curvula*. Modified from Muranaka & Washitani (2003).

4. Countermeasures in the Floodplains of the Kinu River

At present, there are large seed sources of *E. curvula* distributed across the basin. Moreover, recent geomorphologic alteration of the river such as the formation of compound cross-sections (*e.g.*, Shimatani, 2000) and sand accumulation (*e.g.*, Nakatsubo, 1997) are likely to result in further decline in populations of river endemics through the loss of suitable habitat due to invasion of alien grasses. Therefore, long-term countermeasures should be considered at the catchment level. However, to prevent the extinction of river endemics such as *A. kantoensis*, immediate short-term restoration is urgently needed.

Such a pilot restoration was started on the floodplains of the Kinu River in 2002. As a 'first-aid' management effort, invasive grasses were mechanically removed from a part of the floodplain (1,800 m^2), fine sand and silt were washed out using a high-pressure water jet to restore the original gravelly substrate conditions (Fig.8). Subsequently 10,000 seeds (56 seeds/m^2) of *A. kantoensis* collected from plants remaining were sown (Fig.9). As a result of this successful restoration of a local population, most of the surviving individuals flowered during 2002 - 2003. Almost 710,000 seeds were produced, and fitness of 71 was achieved (Fig.10). An experiment to restore indigenous riparian vegetation in a more extensive area (almost 1.0 ha; 54,000 seeds of *A. kantoensis* sown) was started in April 2003, and more extensive exclusion measures against *E. curvula* will be implemented within the course of fiscal year 2004. Data gathering from newly established populations from seeds sown in the pilot restoration project will contribute to the planning of long-term conservation management strategies for floodplain vegetation against the invasion of alien grasses.

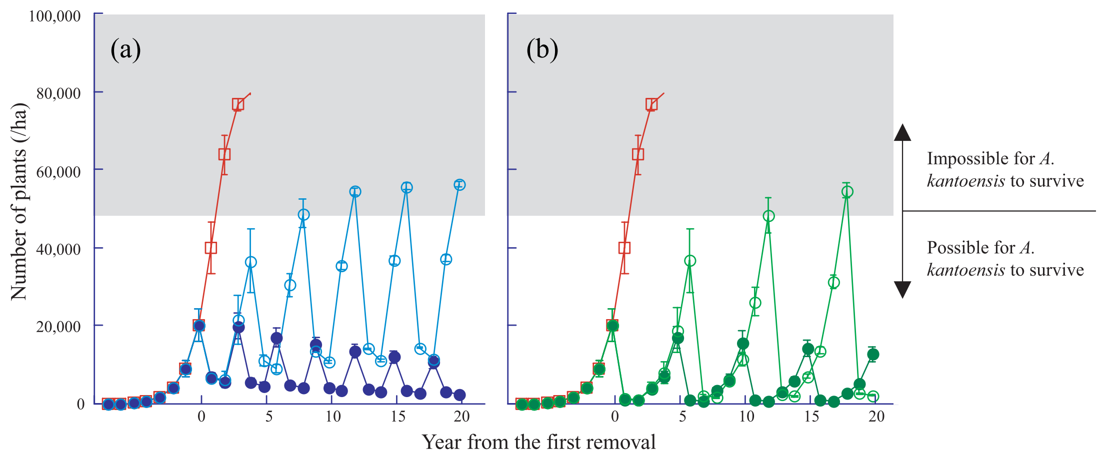


Fig. 7 Model simulation of the effects of mechanical removal of *E. curvula* from part of the floodplain dominated by the species.
Cases of mechanical removal (a) immediately after (July) and (b) before (March) the seed production of *E. curvula* are shown. (Drawn according to data from Muranaka & Washitani 2001b, 2003, and Muranaka *et al*. submitted).
(a) □: plot with no removal, ○: plot with removal at five year intervals, ●: plot with removal at six year intervals. (b) □: plot with no removal, ○: plot with removal at six year intervals, ●: plot with removal at seven year intervals.


(a)


(e)


(b)


(f)


(c)


(g)

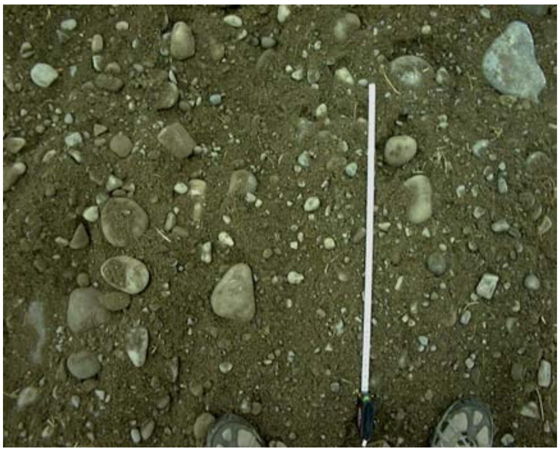

(d)

Fig. 8 Exclusion of invasive grasses and restoration of a suitable habitat for endemic river species on a floodplain of the middle reaches of the Kinu River.
E. curvula was mechanically removed from two 30 m × 30 m sites on the floodplain, and fine sand and silt were washed out by high-pressure water jet to restore the original gravelly substrate conditions. Photo taken in March 2002 along the Kinu River. (a-b): an area dominated by *E. curvula*; (c-d): after the mechanical removal of the *E. curvula*; (e-g): after washing out to resume gravelly substrate conditions.

Fig. 9 Human-aided seed dispersal along the Kinu River in April 2002, in which 10,000 seeds of *A. kantoensis* were sown at two sites (1,800 m^2).

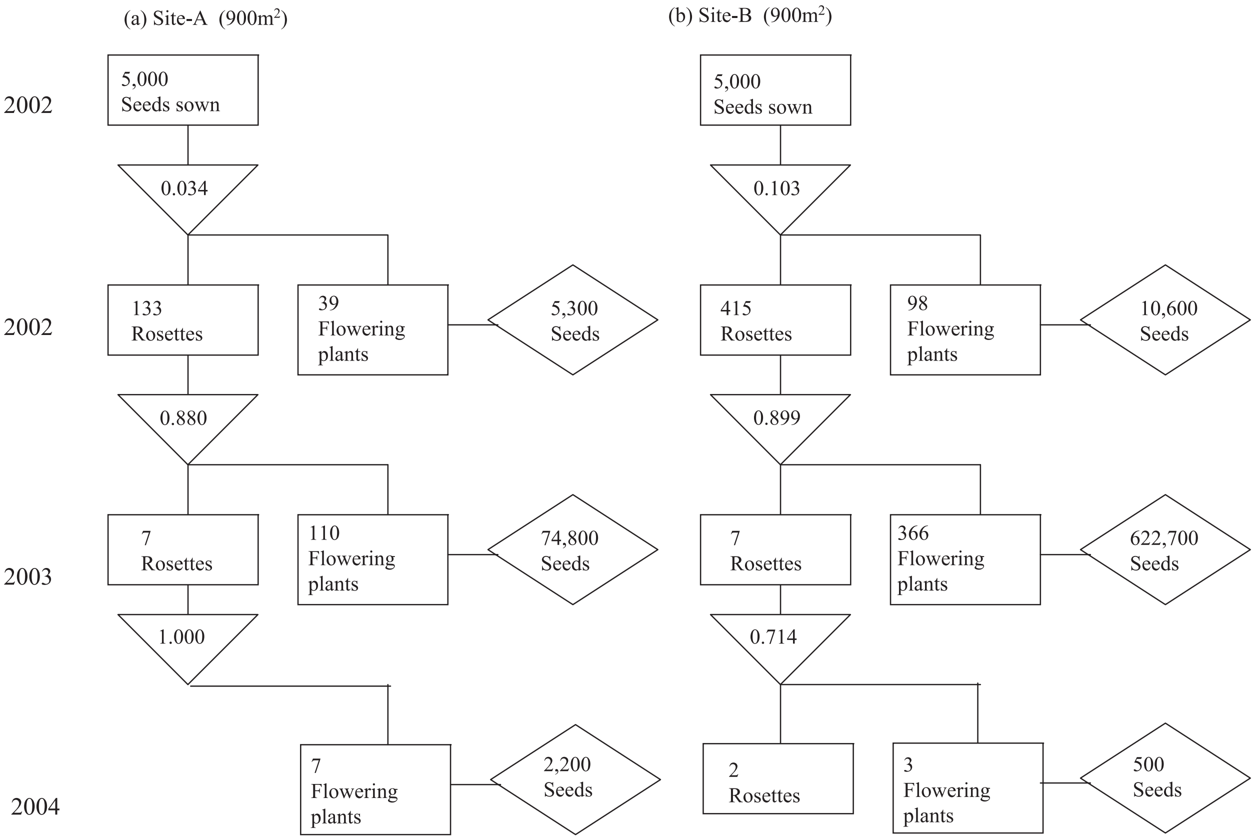


Fig. 10 Diagrammatic representation of the life table of *A. kantoensis* at each restored site (Drawn according to data from Muranaka & Washitani, submitted).

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(Received 30 September 2004, Accepted 9 December 2004)