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Toshito Taniguchi and Koichi Takahashi* : **Microhabitat preference and seed production of exotic species *Verbascum thapsus* (Scrophulariaceae) at a riverside in central Japan**

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Common mullein (*Verbascum thapsus* L.), native to Europe, is widely distributed in North and South America, Australia and Asia (Shimizu et al. 2001). *V. thapsus* is a monocarpic biennial plant with a deep tap root. It produces a low vegetative rosette up to 60 cm in diameter in its first year, overwinters and produces a stout flowering stem 0.3–2.0 m tall in the next growing season (Gross and Werner 1978). *V. thapsus* is recognized as an early-successional species in Europe and North America (Gross and Werner 1978 ; Gross 1980). *V. thapsus* often dominates in abandoned agricultural fields, and its density declines with the progress of succession (Gross and Werner 1978), because it requires bare ground for germination (Gross 1980). Thus, microhabitats for seedling establishment greatly affect the persistence of *V. thapsus* populations.

Early-successional species often have small seeds, which are effective for wide dispersal (Clark et al. 1998). The mean seed mass of *V. thapsus* in North America is 0.067 mg (Gross 1980), which is a very small size among herbaceous species. By contrast, germination of small seeds tends to be affected by environmental conditions, such as litter depth (Knapp and Smith 1982 ; Foster and Janson 1985). Thus, small seed size may limit the germination of *V. thapsus* at particular sites. Not only seed size but also the number of seeds per plant affect reproductive success of an individual plant. Seed production per plant mainly depends on plant size. Thus, examination of life-history traits, such as microhabitat preference for seedling establishment and allometry between seed production and plant size, is important to clarify the population dynamics of *V. thapsus*.

V. thapsus was introduced into Japan in 1868 as a garden plant species (Shimizu et al. 2005), and then spread widely in Japan (Konta et al. 2006). *V. thapsus* often grows at human-disturbed sites, such as riversides, roadsides and vacant lots, in Japan (Shimizu 2003). Of the human-disturbed sites, many *V. thapsus* individuals are often found along riversides. Concrete banks are usually made along rivers in residential areas to protect from floods. Riversides are often laid with turf for relaxation of people. Thus, riversides in residential areas are mainly man-made environments. However, no information exists about the microhabitat preference of *V. thapsus* in man-made environments. Therefore, this study aimes to describe microhabitat preference and seed production of *V. thapsus* at a riverside in central Japan, and to discuss how these traits contribute to the maintenance of *V. thapsus* populations at the riverside.

Materials and methods

This study was done at a riverside of Metoba river in Matsumoto, central Japan (36°15′N, 137°58′E, 620 m a.s.l.). Reed vegetation (*Phragmites communis* Trin.) was at the riverside (Fig. 1), and the substrate condition of the reed vegetation was wet. The riverside was well managed, and the frontage was lawn (*Zoysia japonica* Steud.). Banks were constructed next to the lawn. The bank was made of concrete blocks (30 cm × 40 cm). Paved roads for vehicles were along the bank. The roadside and blocks were hardly covered with soil, and vegetation was not developed on these substrates.

To investigate the microhabitat preference of *V. thapsus*, a plot (67 m × 22 m) was established from the riverside to the roadside just above the bank in 2007 (Fig. 1). Microhabitats within the plot were classified as concrete blocks on the bank, roadside, lawn (*Z. japonica*) and reed vegetation (*P. communis*). The area occupied by each microhabitat in the plot was measured, and *V. thapsus* at each microhabitat was counted.

The relative abundance of *V. thapsus* at each microhabitat was examined. The relative area (%) of the four microhabitats was calculated. If *V. thapsus* had randomly distributed irrespective of the four microhabitats, the relative number (%) of *V. thapsus* at the four microhabitats would be the same as the relative area of the four microhabitats. A chi-squared (χ^2) goodness-of-fit test was used for this comparison.

Thirty eight individuals were sampled in the plot in summer before seed dispersal. All seeds were taken from the plant capsules, the seeds were oven-dried at 80°C for 2 days and the seed mass per plant was weighed. Stem length was also measured. Because the stem of *V. thapsus* is a vertical erect stem, stem height was equal to the stem length. Total mass of 100 seeds selected arbitrarily was weighed to measure mean mass of a seed.

The relationship between total seed mass and stem height was analyzed. An allometric relationship was fitted by using a standardized major axis regression (program (S)MATR, version 1) (Falster et al. 2003 ; Warton et al. 2006).

Results

We sampled *V. thapsus* individuals of stem height 35 to 200 cm. The total seed mass per plant increased with stem height (Fig. 2). The mean mass of a seed was 0.0995 mg. The number of seeds per plant was estimated as 2,726 to 275,682 seeds, an average of 69,861 seeds for *V. thapsus* examined for the allometry.

The lawn (44%) and reed vegetation (32%) occupied greater areas of the study site than blocks (19%) and roadside (5%) (Table 1). However, the distribution pattern of *V. thapsus* significantly differed from the land area pattern (χ^2 = 791.8, P < 0.001; Table 1). Ninety per cent of *V. thapsus* distributed on blocks, despite the land area percentage of the blocks was only 19% (Table 1). Most *V. thapsus* individuals rooted between blocks. *V. thapsus* also slightly

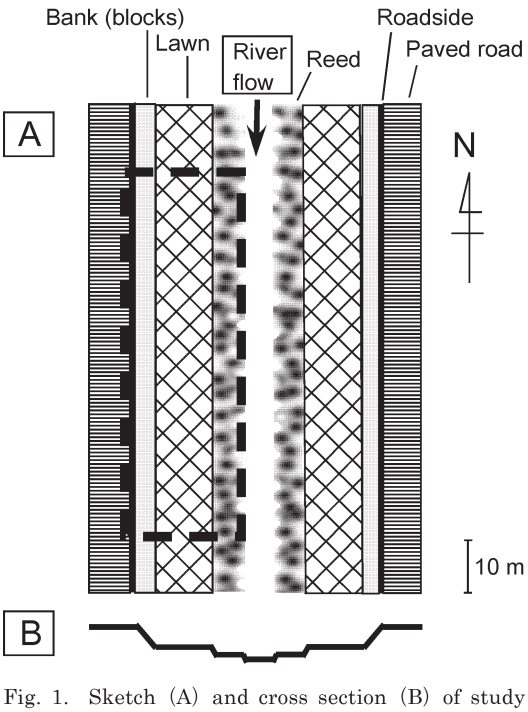

Fig. 1. Sketch (A) and cross section (B) of study site at the riverside of Metoba river. The study plot (67 m × 22 m) is shown by a broken-line rectangle.

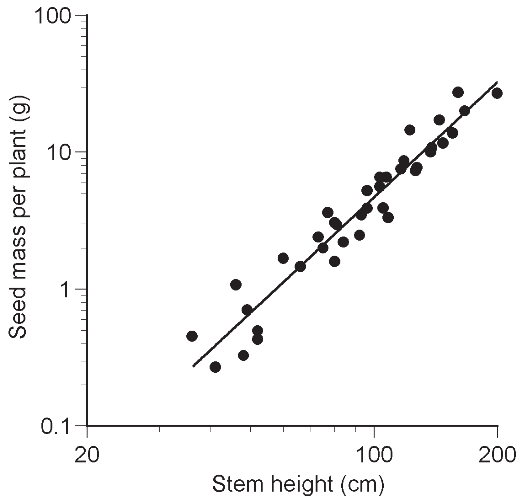

Fig. 2. Relationship between stem height (X) and total seed mass per plant (Y). The major axis regression equation is logY = 2.91logX − 11.8 (R^2 = 0.93, P < 0.001, n = 38).

Table 1. The number of *Verbascum thapsus* individuals at four types of microhabitats, and the area of each microhabitat

	Block	Lawn	Roadside	Reed	Total
Number of plants	204	1	21	0	226
(%)	(90.3)	(0.4)	(9.3)	(0)	(100)
Area (m^2)	272.7	638.4	73.2	465.5	1,449.7
(%)	(18.8)	(44.0)	(5.1)	(32.1)	(100)

concentrated at the roadside. *V. thapsus* at the roadside rooted between the asphalt of the road and the blocks on the bank. *V. thapsus* scarcely distributed on the lawn (0.4%) and among reed vegetation (0%), despite these vegetations occupying large areas (Table 1).

Discussion

The mean mass of seeds is 0.01 to 10 mg in herbaceous species of 13 families (Harper et al. 1970). Thus, a seed of *V. thapsus* is considerably small compared with other species, although *V. thapsus* produced many seeds. Many small seeds (average 180,000 seeds per plant, average seed weight 0.067 mg) of *V. thapsus* was also reported for North America (Gross and Werner 1978). Small seeds are advantageous for invasion into disturbed sites because of the wide dispersal of seeds (cf. Lake and Leishman 2004). The longevity of *V. thapsus* seeds is about 40 years (Darlington 1931 ; Toole and Brown 1946 ; Darlington and Steinbauer 1961). Thus, *V. thapsus* disperses seeds not only in space but also in time, which is advantageous for responses to disturbances because the occurrence of disturbances is unpredictable.

The spatial distribution of *V. thapsus* was mainly affected by the microhabitats at the study site. Although this study did not examine soil properties, the soil surface was rather stable at the lawn because the lawn was rooted tightly on the soil surface. We found neither seedling nor fully grown up plants of *V. thapsus* with erect stems at the lawn, suggesting that seeds of *V. thapsus* cannot germinate there. Gross (1980) reported that *V. thapsus* seedlings did not establish in small experimental-created openings (15 cm × 15 cm) in a 15-year old field, but colonized larger openings (> 0.5 m^2) created by animal digging. Small seeds cannot germinate unless mineral soil is exposed (Nakashizuka 1989). Thus, lawn vegetation where soil disturbance hardly occurs is disadvantageous for colonization of *V. thapsus* with small seeds. The reed vegetation was much wetter than the three other microhabitats (blocks, roadside and lawn). *V. thapsus* grows on stony ground in wasteland, woodland clearings and roadsides (Turker and Gurel 2005). It grows well in shallow and well-drained soils (Semenza et al. 1978). In this study, we did not find *V. thapsus* seedlings among the reed vegetation. Thus, it is suggested that the wetland of reed vegetation is not a suitable site for germination of *V. thapsus*. There was almost no soil accumulation on blocks on the bank, and most *V. thapsus* distributed in the gaps between blocks on the bank and between the blocks and asphalt of the road because the taproot of *V. thapsus* can penetrate into the soil. Furthermore, seed size of *V. thapsus* is small enough to fall into the small gaps. The large number of seeds also would increase the chance of attaining to the gaps. Thus, the distribution of *V. thapsus* with small seeds was restricted to the gaps between the blocks in this study.

This study showed that *V. thapsus* produced many small seeds and that the distribution of *V. thapsus* was restricted mainly to roadside and concrete blocks on the bank. While the small seed size and tall stem height of *V. thapsus* contribute to the spread of spatial distribution (Donnelly et al. 1998 ; Hamilton et al. 2005), safe sites for seedling establishment were limited. Therefore, an increase in stony ground due to shore-protection works would promote invasion of *V. thapsus*. Understanding the ecological traits of *V. thapsus* would help manage this exotic species.

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谷口寿仁・高橋耕一：河川敷における外来植物ビロードモウズイカの微地形の嗜好性と種子生産

ビロードモウズイカは日本に広く分布している二年生外来植物である。この研究では人為的に攪乱された場所においてビロードモウズイカがどのように個体群を維持しているかを議論するために，管理された河川敷においてビロードモウズイカの種子生産，そして空間分布について調査した。ビロードモウズイカの種子は非常に小さかったが（平均0.0995 mg），個体あたりの種子数は非常に多かった（最大で27 × 10^4個が観察された）。土地の微地形を堤

防上のブロック，芝生，ヨシ群落，そして道路際の4タイプに区分した。ブロックの相対的な面積比は19%しかなかったが，ビロードモウズイカの約90%の個体はブロックとブロックの隙間に分布していた。以上のことから，多くの種子数はビロードモウズイカの分布拡大に貢献し，ブロックによって覆われた堤防の建設のような人為的な攪乱はビロードモウズイカの分布拡大を促進することが示唆された。
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